New Zealand's Greenhouse Gas Inventory

1990–2016

Fulfilling reporting requirements under the United National Framework Convention on Climate Change and the Kyoto Protocol

New Zealand Government

Ministry for the
Environment
Manatū Mō Te Taiao

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Acknowledgements

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Abbreviations

AAU	assigned amount unit
AD	activity data
APEC	Asia-Pacific Economic Cooperation
ARR	Assessment Review Report
BERG	Biological Emissions Reference Group
BOD	biochemical oxygen demand
BRANZ	Building Research Association of New Zealand
C_2F_6	hexafluoroethane
C_3F_8	perfluoropropane
CaO	calcium oxide
$Ca(OH)_2$	calcium hydroxide
CDM	Clean Development Mechanism
CEF	carbon equivalent forest
CEF_{hc}	carbon equivalent forest (harvested and converted)
CEF_{ne}	carbon equivalent forest (newly established)
CER	certified emission reduction unit
CFC	chlorofluorocarbon
CF_4	tetrafluoromethane
CH_4	methane
CMP	Conference of the Parties serving as the Meeting of the Parties to the Kyoto Protocol
CNG	compressed natural gas
CO	carbon monoxide
COD	chemical oxygen demand
CO_2	carbon dioxide
CO_2-e	carbon dioxide equivalent
CP1	first commitment period under the Kyoto Protocol
CP2	second commitment period under the Kyoto Protocol
CRF	common reporting format
DCD	dicyandiamide
DEF	default emissions factor
DMD	dry-matter digestibility
DMI	dry-matter intake
DOC	degradable organic carbon
DPFI	Delivery of Petroleum Fuels by Industry
EF	emission factor
EPA	Environmental Protection Authority

ERT	expert review team
ERU	emission reduction unit
ETS	Emissions Trading Scheme
FAO	Food and Agriculture Organization
FAOSTAT	Database produced by the Statistics Division of the Food and Agriculture Organization the United Nations
FDM	faecal dry matter
FMRL	forest management reference level
FMRL$_{corr}$	recalculated forest management reference level
FOD	First Order Decay
FOLPI	Forestry-Oriented Linear Programming Interpreter
GDP	gross domestic product
GEI	gross energy intake
Gg	gigagram(s)
GHG	greenhouse gas(es)
GIS	geographic information system
GJ	gigajoule(s)
GPS	global positioning system
GRA	Global Research Alliance on Agricultural Greenhouse Gases
GST	goods and services tax
ha	hectare(s)
HCFC	hydrochlorofluorocarbon
HEEP	Household Energy End-use Project
HFC	hydrofluorocarbon
IE	included elsewhere
IEF	implied emission factor
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Processes and Product Use
IRENA	International Renewable Energy Agency
ITL	International Transaction Log
KGTP	Kapuni Gas Treatment Plant
KP-LULUCF	Land Use, Land-use Change and Forestry activities under the Kyoto Protocol
kt	kilotonne(s)
LCDB	Land Cover Database
ICER	long-term certified emission reduction unit
LFG	landfill gas
LIC	Livestock Improvement Corporation
LiDAR	Light Detection and Ranging
LPG	liquefied petroleum gas
LUCAS	Land Use Carbon Analysis System

LUE	land use effect
LULUCF	Land Use, Land-Use Change and Forestry
MBIE	Ministry of Business, Innovation and Employment
MCF	methane correction factor
MDI	metered dose inhaler
MDO	marine diesel oil
ME	metabolisable energy
MFAT	Ministry of Foreign Affairs and Trade
MfE	Ministry for the Environment
MgO	magnesium oxide
MOS	Monthly Oil Supply
MPI	Ministry for Primary Industries
Mt	megatonne(s)
MW	megawatt(s)
N$_2$O	nitrous oxide
NA	not applicable
NDC	National Determined Contribution
NE	not estimated
NEFD	National Exotic Forest Description
N$_{ex}$	nitrogen excretion rates
NF$_3$	nitrogen trifluoride
NIR	national inventory report
NMVOC	non-methane volatile organic compound
NO	not occurring
NOx	nitrogen oxides (other than nitrous oxide)
NSD	National Soils Database
NZAS	New Zealand Aluminium Smelters Limited
NZ ETS	New Zealand Emissions Trading Scheme
NZETR	New Zealand Emission Trading Register
NZLRI	New Zealand Land Resource Inventory
NZU	New Zealand Unit
ODS	ozone-depleting substances
OECD	Organisation for Economic Co-operation and Development
PFC	perfluorocarbon
PJ	petajoule(s)
PSP	permanent sample plot
QA	quality assurance
QC	quality control
RGG	Reporting Governance Group
RMU	removal unit

SDGs	sustainable development goals
SEF	standard electronic format
SF$_6$	sulphur hexafluoride
SO$_2$	sulphur dioxide
SOC	soil organic carbon
StatsNZ	Statistics New Zealand
TACCC	transparency, accuracy, completeness, comparability and consistency
tCER	temporary certified emission reduction unit
TJ	terajoule
TOW	total organics in wastewater
UEF	unique emissions factor
UNFCCC	United Nations Framework Convention on Climate Change

Executive summary

Key points

In 2016

- New Zealand's gross greenhouse gas emissions were 78,727 kilotonnes carbon dioxide equivalent (kt CO_2-e).

- The Agriculture and Energy sectors were the two largest contributors to gross emissions at 49 per cent and 40 per cent respectively.

- The Land Use, Land-Use Change and Forestry sector offset 29 per cent of New Zealand's gross emissions.

- The decline in the deforestation rate continued.

- Emissions from the Waste sector were below 1990 levels.

Since 1990

- New Zealand's gross emissions have increased by 20 per cent. The five emission sources that contributed the most to this increase were:

  – enteric fermentation (methane) from dairy cattle

  – road transport (carbon dioxide) from increased fuel use

  – chemical industry and food processing (carbon dioxide) from increased production due to economic growth and population increase

  – agricultural soils (nitrous oxide) mainly from increased fertiliser use

  – industrial and household refrigeration and air-conditioning systems (fluorinated gases) because greenhouse gases were used as replacements for ozone-depleting substances.

- New Zealand's net emissions increased by 54 per cent due to the influence of forestry harvesting cycles and the underlying increase in gross emissions.

Between 2015 and 2016

- Gross emissions decreased by 2.4 per cent, with all contributing sectors showing a decrease in emissions.

  – The largest decrease was in the Energy sector, which decreased 3 per cent, or 1,079 kt CO_2-e, due to a lower use of coal and gas for electricity generation and increased hydroelectric generation.

  – Emissions from the Agriculture sector decreased by 1 per cent (409 kt CO_2-e) primarily due to a decline in the sheep population.

  – Emissions from the Industrial Processes and Product Use sector decreased 9 per cent largely due to the closure of a cement plant and consolidation in the New Zealand steel industry.

  – Emissions from the Waste sector decreased 0.7 per cent due to continued improvements to landfill management practices.

- Removals from the Land Use, Land-Use Change and Forestry sector decreased by 8 per cent mainly because of an increase in the harvest rate of planted forests.

- Removals from afforestation and reforestation have also decreased slightly because more of these forests are reaching maturity and being harvested.

ES.1 Background

New Zealand's Greenhouse Gas Inventory (the inventory) is the official annual report of all anthropogenic (human-induced) emissions and removals of greenhouse gases in New Zealand. It measures New Zealand's progress against obligations under the United Nations Framework Convention on Climate Change (the Convention) and the Kyoto Protocol and is the official method of measuring New Zealand's progress towards its international emissions reduction targets.

The inventory submission consists of the common reporting format (CRF) database and this publication, the national inventory report (NIR). The NIR is a narrative that presents major emission trends and methodology for estimating emissions. It also includes sections on the inventory uncertainties, recalculations and improvements.

Inventory reporting under the Convention covers seven direct greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3).[1] The indirect greenhouse gases[2] are also included; however, only emissions and removals of the direct greenhouse gases are included in estimates of gross emissions under the Convention and accounted for under the Kyoto Protocol.

The gases are reported under five sectors: Energy; Industrial Processes and Product Use (IPPU); Agriculture; Land Use, Land-Use Change and Forestry (LULUCF); and Waste.

ES.2 National trends

Gross emissions

Gross emissions include those from the Energy, IPPU, Agriculture and Waste sectors, but do not include emissions and removals from the LULUCF sector. Reporting of gross emissions, excluding the LULUCF sector, is consistent with the reporting requirements under the Convention (UNFCCC, 2013).

1990–2016

In 1990, New Zealand's gross emissions were 65,814.8 kilotonnes carbon dioxide equivalent (kt CO_2-e). Between 1990 and 2016, gross emissions increased by 12,912.1 kt CO_2-e (19.6 per cent) to 78,726.9 kt CO_2-e in 2016 (figure 2.1.1). From 1990 to 2016, the average annual growth in gross emissions was 0.7 per cent.

The emission categories that contributed the most to this increase in gross emissions were *Enteric fermentation[3] from dairy cattle*, *Road transportation*, *Agricultural soils*, and *Manufacturing industries and construction* (especially the categories *Chemicals* and *Food processing, beverages and tobacco*).

2015–2016

Between 2015 and 2016, New Zealand's gross emissions decreased by 1,976.1 kt CO_2-e (2.4 per cent). This reflected emissions decreases across all contributing sectors. The Energy sector showed the largest decrease (1,078.6 kt CO_2-e or 3.3 percent). This is primarily due to a

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[1] Nitrogen trifluoride emissions do not occur in New Zealand and, therefore, they are not included in this report.

[2] Indirect gases include carbon monoxide (CO), sulphur dioxide (SO_2), oxides of nitrogen (NO_X) and non-methane volatile organic compounds (NMVOCs).

[3] Methane emissions produced from ruminant livestock.

decrease of emissions from lower use of thermal fuels (coal and gas) for electricity generation and increased hydroelectric generation. There was also a decrease in emissions from venting and flaring from oil and gas operations.

The decrease in Agriculture sector emissions is mainly attributed to a significant fall in the sheep population. The decline in sheep numbers between 2015 and 2016 was caused by drought conditions in the South Island, and relatively weak lamb and mutton prices. Sheep numbers in the North Island also declined due to a high incidence of facial eczema due to warmer and more humid conditions.

IPPU sector emissions decreased mainly as a result of the closure of a cement plant, consolidation in the steel industry, and a decrease in the import and use of HFCs for refrigeration and air conditioning.

Waste sector emissions decreased as a result of reductions in CH_4 emissions, largely due to ongoing improvements in municipal solid waste management and the continuation of a gradual reduction in the total waste disposed on farms.

Net emissions – reporting under the Convention

Net emissions include emissions from the Energy, IPPU, Agriculture and Waste sectors, together with emissions and removals from the LULUCF sector.

In 1990, New Zealand's net emissions were 36,275.3 kt CO_2-e. Between 1990 and 2016, net emissions increased by 19,678.0 kt CO_2-e (54.2 per cent) to 55,953.3 kt CO_2-e (figure ES 2.1).

The four categories that contributed the most to the increase in net emissions between 1990 and 2016 were *Enteric fermentation from dairy cattle*, *Land converted to forest land*, *Road transportation* and *Forest land converted to grassland*.

Figure ES 2.1   New Zealand's gross and net emissions (under the Convention) from 1990 to 2016
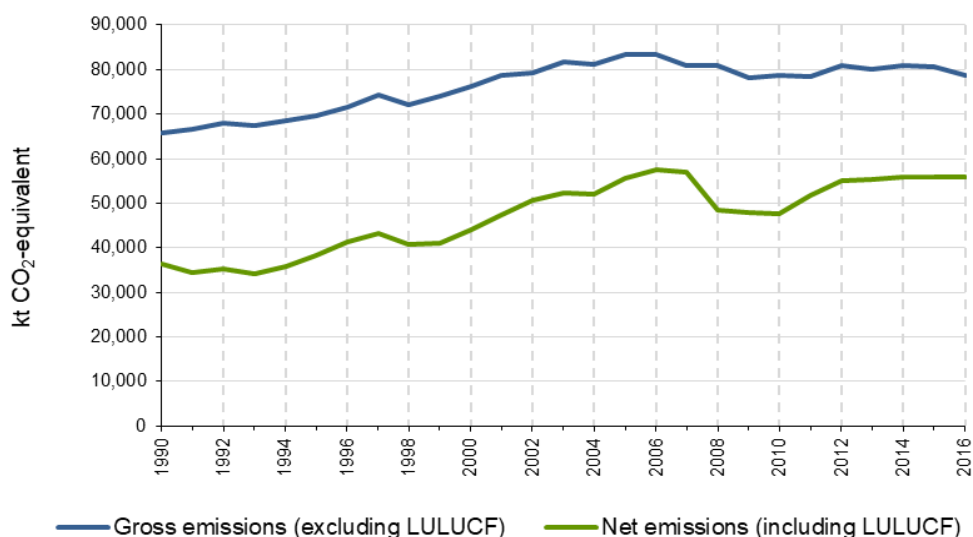
Accounting for New Zealand's 2020 target

For the period up to 2020, New Zealand has taken a target under the Convention. This target is to reduce emissions to 5 percent below 1990 levels by 2020. New Zealand will apply the Kyoto Protocol framework of rules in accounting for its 2020 target under the Convention. This means New Zealand will count net removals from Article 3.3 – *Afforestation and reforestation* and *Deforestation* and Article 3.4 – *Forest management* of the Kyoto Protocol towards its target.

New Zealand's emissions budget for the period 2013 to 2020 is 509,774,982 tonnes CO_2-e. This based on the gross emissions data for 1990 included in New Zealand's 2016 inventory submission (New Zealand's Initial Report, Ministry for the Environment, 2016).[4]

New Zealand tracks progress towards its 2020 target in the 2020 net position report. This report can be found on New Zealand's Ministry for the Environment website (www.mfe.govt.nz/climate-change/reporting-greenhouse-gas-emissions/latest-2020-net-position).

New Zealand's 2030 target under the Paris Agreement is 30 per cent below 2005 levels (as announced in New Zealand's National Determined Contribution (NDC). This is equivalent to 11 per cent below 1990 levels by 2030.

New Zealand has also gazetted a long-term target of 50 per cent below 1990 greenhouse gas emissions levels by 2050. The Government has proposed to build on this by introducing a new Zero Carbon Bill in 2018, which could set a new target for 2050 and establish an independent climate change commission.

ES.3 Greenhouse gas trends

Inventory reporting under the Convention covers seven direct greenhouse gases: CO_2, CH_4, N_2O, SF_6, PFCs, HFCs and NF_3. Because NF_3 emissions do not occur in New Zealand, no NF_3 data are included in this report. Figure ES 3.1 presents New Zealand's 2016 emissions by gas.

Table ES 3.1 provides a summary of emissions for each gas in 1990 and 2016 and the changes since 1990. This is also illustrated in figure ES 3.2.

Figure ES 3.1   New Zealand's gross emissions by gas in 2016
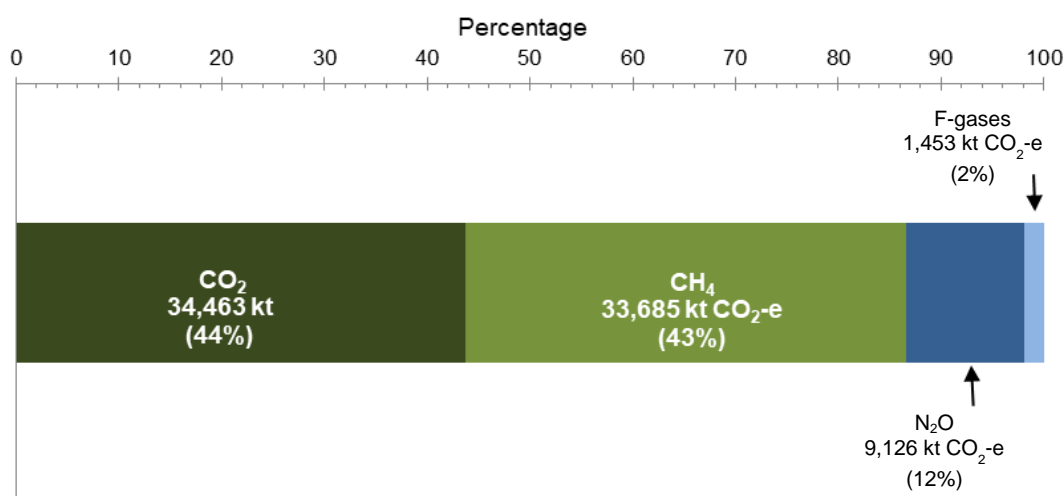
Note: The percentages may not add up to 100 per cent due to rounding.

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[4]   For more details, refer to *New Zealand's Initial Report to Facilitate the Calculation of its Emissions Budget for the Period 2013 to 2020* (www.mfe.govt.nz/sites/default/files/media/Climate%20Change/New%20Zealand%27s%20Initial%20Report%20July%202016.pdf).

Table ES 3.1   New Zealand's gross emissions by gas in 1990 and 2016

Direct greenhouse gas emissions	kt CO_2-equivalent		Change from 1990 (kt CO_2-equivalent)	Change from 1990 (%)
	1990	2016		
CO_2	25,453.6	34,462.9	9,009.4	35.4
CH_4	32,277.2	33,684.8	1,407.6	4.4
N_2O	7,154.1	9,126.2	1,972.1	27.6
HFCs	0.0	1,387.0	1,387.0	NA
PFCs	909.9	48.7	−861.3	−94.6
SF_6	20.0	17.3	−2.7	−13.4
Gross, all gases	**65,814.8**	**78,726.9**	**12,912.1**	**19.6**

Note: Gross emissions exclude net removals from the LULUCF sector. The per cent change for HFCs is not applicable (NA) because no production of HFCs occurred in 1990. Columns may not total due to rounding. Percentages presented are calculated from unrounded values.

Figure ES 3.2   New Zealand's emissions by gas in 1990 and 2016
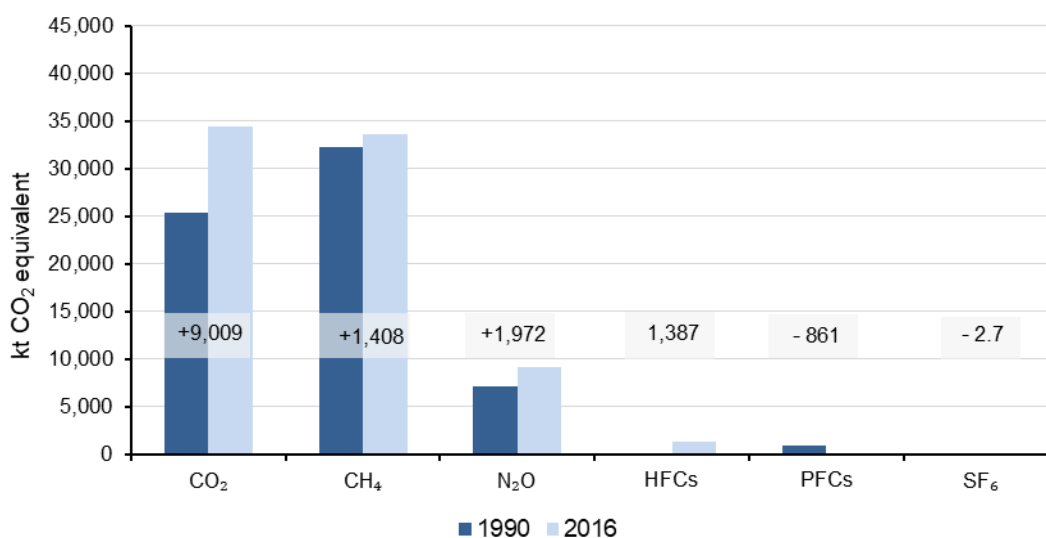
In 1990, CH_4 made up the largest proportion of gross emissions; while, in 2016, CO_2 and CH_4 contributed nearly equal proportions to the gross national emissions (see figure ES 3.2). While emissions of CH_4 have also increased over this time, the proportion of CH_4 has decreased over the time series, because CO_2 emissions have increased a greater amount. This trend largely reflects the increase in CO_2 emissions from the Energy sector, because 87.5 per cent of New Zealand's CO_2 emissions come from that sector.

In 2016, net emissions from the LULUCF sector (under the Convention) were −22,773.7 kt CO_2-e. This offset 29 per cent of New Zealand's gross emissions.

Between 1990 and 2016, net emissions from the LULUCF sector have increased by 6,765.8 kt CO_2-e (22.9 per cent) from the 1990 level of −29,539.5 kt CO_2-e. This increase reflects the age structure of the forest and is the result of increased harvesting and deforestation since 1990.

Indirect gases

Under the Convention, indirect greenhouse gases are included in inventory reporting but are not counted in emissions totals. These indirect gases are carbon monoxide (CO), sulphur dioxide (SO_2), oxides of nitrogen (NO_X) and non-methane volatile organic compounds (NMVOCs).

Table ES 3.2 summarises New Zealand's indirect greenhouse gas emissions in 1990 and 2016 as well as the change between these years.

Table ES 3.2   New Zealand's indirect greenhouse gas emissions (exluding LULUCF) in 1990 and 2016

Indirect greenhouse gas emissions	kt		Change from 1990 (kt)	Change from 1990 (%)
	1990	2016		
CO	602.8	725.1	122.2	20.3
NMVOCs	143.5	184.9	41.4	28.8
NO$_x$	101.7	158.0	56.3	55.3
SO$_2$	57.1	69.3	12.3	21.5

Note: Columns may not total due to rounding. Percentages presented are calculated from unrounded values.

ES.4 Sector trends

The Agriculture and Energy sectors dominate New Zealand's gross emissions portfolio, together producing almost 90 per cent of New Zealand's gross greenhouse gas emissions and contributing the largest amounts of CO_2, CH_4 and N_2O, compared with other inventory sectors from 1990 to 2016. The IPPU and Waste sectors contribute relatively small amounts of greenhouse gases to gross emissions, contributing between 4 per cent and 7 per cent for the entire time series. Figure ES 4.1 shows the proportion that each inventory sector contributed to New Zealand's gross emissions. It also shows the proportion of gross emissions offset by the LULUCF sector, which was a net greenhouse gas sink between 1990 and 2016.

Figure ES 4.1   Changes in New Zealand's gross emissions profile by sector from 1990 to 2016
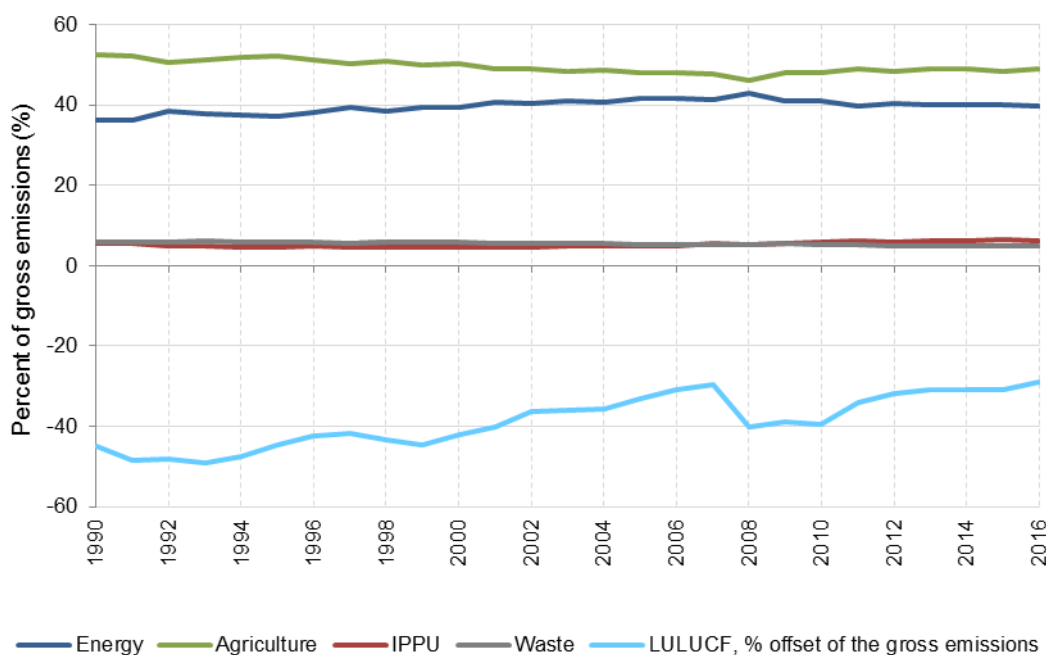
Figure ES 4.2 shows emissions by sector in 2016. Agriculture was New Zealand's largest sector (49.2 per cent of the gross emissions) in 2016. New Zealand's Energy sector contributed 39.8 per cent to the gross emissions, while the IPPU and Waste sectors contributed 6.2 per cent and 4.9 per cent to the gross emissions respectively (see figure ES 4.2).

Figure ES 4.2   New Zealand's emissions by sector in 2016

kt CO_2-equivalent
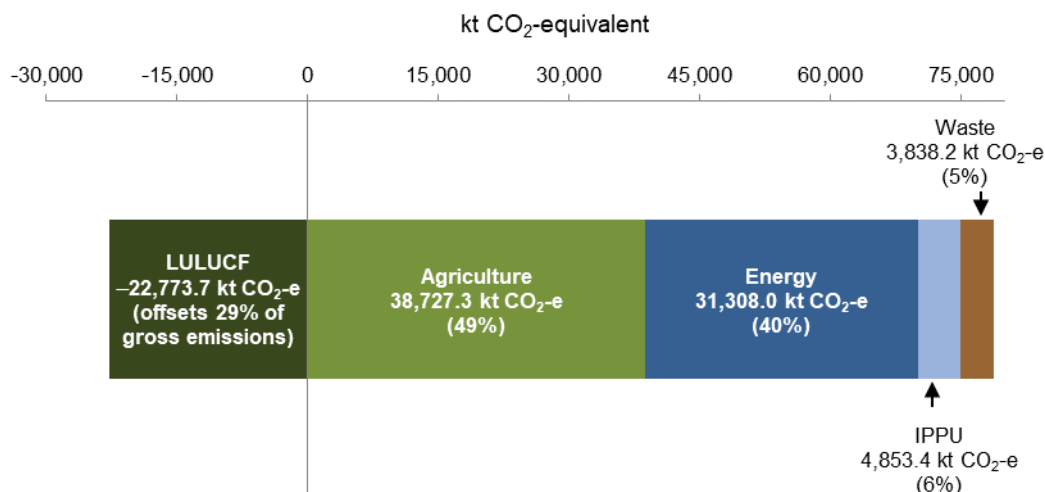
Note: The percentages may not add up to 100 per cent due to rounding. The LULUCF sector, which is not a part of gross emissions, is included here as a negative value.

Table ES 4.1 and figure ES 4.3 summarise emissions by sector in 1990 and 2016 as well as the change between those years. A more detailed description of emission trends for each sector is presented in chapter 2, section 2.2.

Table ES 4.1   New Zealand's gross emissions by sector in 1990 and 2016

Sector	kt CO_2-equivalent		Change from 1990 (kt CO_2-equivalent)	Change from 1990 (%)
	1990	2016		
Energy	23,785.2	31,308.0	7,522.8	31.6
Industrial processes and product use	3,585.1	4,853.4	1,268.3	35.4
Agriculture	34,581.9	38,727.3	4,145.5	12.0
Waste	3,862.6	3,838.2	−24.4	−0.6
Gross (excluding LULUCF)	**65,814.8**	**78,726.9**	**12,912.1**	**19.6**
LULUCF	−29,539.5	−22,773.7	6,765.8	22.9
Net (including LULUCF)	**36,275.3**	**55,953.3**	**19,678.0**	**54.2**

Note: Net emissions from the LULUCF sector are reported as a negative number because the sector removes more CO_2 from the atmosphere than it emits (see chapter 6). Columns may not total due to rounding. Percentages presented are calculated from unrounded values.
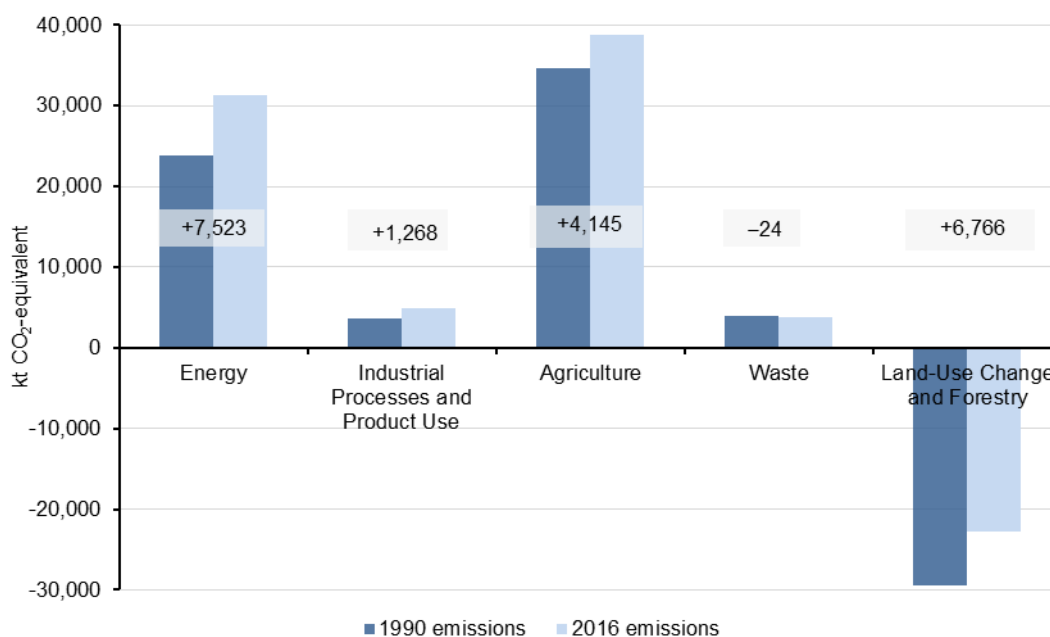
Sector-specific trends

Energy (chapter 3)

2016

In 2016, the Energy sector produced 31,308.0 kt CO_2-e, representing 39.8 per cent of New Zealand's gross emissions. The largest sources of emissions in the Energy sector were *Road transportation*, contributing 13,612.6 kt CO_2-e (43.5 per cent of the sector's emissions), and *Public electricity and heat production*, contributing 3,038.6 kt CO_2-e (9.7 per cent of the sector's emissions).

1990–2016

In 2016, emissions from the Energy sector had increased by 31.6 per cent (7,522.8 kt CO_2-e) from the 1990 level of 23,785.2 kt CO_2-e. This growth in emissions is primarily from:

- *Road transportation*, which increased by 6,137.3 kt CO_2-e (82.1 per cent)

- *Chemicals*, which increased by 1,416.1 kt CO_2-e (256.0 per cent)

- *Food processing, beverages and tobacco*, which increased by 1,126.8 kt CO_2-e (67.9 per cent).

The *Manufacture of solid fuels and other energy* and *Public electricity and heat production* both decreased appreciably below their 1990 levels, with decreases of 1,446.1 kt CO_2-e (−84.0 per cent) and 463.6 kt CO_2-e (−13.2 per cent) respectively. This decrease is primarily due to the cessation of synthetic gasoline production in 1997, combined with the falling dependence on coal and gas for public electricity generation.

Figure ES 4.1 shows the energy emissions time series from 1990 to 2016. The trend shows emissions increasing up until 2008, after which there is a general decline. The decline reflected a steady growth in energy production from renewable sources (mostly geothermal) as well as the sensitivity of the Energy sector to the effects of the recent global economic recession and

earthquakes in 2011, 2013 and 2016, and the changes in rainfall from year to year, which affect the amount of hydroelectric energy produced (see section 2.2 in chapter 2 for further details).

2015–2016

Between 2015 and 2016, emissions from the Energy sector decreased by 1,078.6 kt CO_2-e (3.3 per cent). Emissions from *Public electricity and heat production* decreased by 995.3 kt CO_2-e (24.7 per cent). This is mainly due to a 21.6 per cent decrease in coal- and gas-fired electricity generation. A higher proportion of hydroelectricity flowing to the national grid resulted in lower utilisation of coal- and gas-fired generators.

The decrease of emissions from this category was partially offset by an increase from *Road transportation*, which increased by 327.7 kt CO_2-e (2.5 per cent).

IPPU (chapter 4)

2016

In 2016, emissions in the IPPU sector contributed 4,853.4 kt CO_2-e or 6.2 per cent of New Zealand's gross emissions.

The largest source category is the *Metal industry*, where substantial CO_2 emissions come from *Iron and steel production* and *Aluminium production*. The *Mineral industry* and *Chemical industry* categories also contribute significant CO_2 emissions, and most of the non-CO_2 emissions come from *Product uses as substitutes for ozone depleting substances*.[5] Coal and natural gas are also used on a significant scale for energy in these industries, and related emissions are reported under the Energy sector.

1990–2016

IPPU sector emissions in 2016 were 1,268.3 kt CO_2-e (35.4 per cent) higher than emissions in 1990 (3,585.1 kt CO_2-e). This increase was mainly driven by increasing emissions from the *Product uses as substitutes for ODS* category due to the introduction of HFCs to replace ozone-depleting substances in refrigeration and air conditioning, and to the increased use of household and commercial air conditioning. Carbon dioxide emissions have also increased, due to increased production of metals, lime and cement, but at a slower rate. There has been a substantial reduction in emissions of PFCs, due to improved management of anode effects in *Aluminium production*, and some reduction in emissions of N_2O used for medical applications in *Other product manufacture and use*.

New Zealand is considering ratification of the Kigali Amendment to the Montreal Protocol, which will require imports of HFCs to be phased down by 85 per cent by 2036. New Zealand expects to implement the phase down through an import permitting system. In future years, compliance with the Montreal Protocol will mean that emissions will be reduced.

2015–2016

IPPU sector emissions in 2016 were 461.9 kt CO_2-e (8.7 per cent) lower than emissions in 2015. This change was mainly a result of decreases in emissions from the *Product uses as substitutes for ODS* (173.3 kt CO_2-e or 11.1 per cent), *Mineral industry* (149.5 kt CO_2-e or 17.1 per cent), *Chemical industry* (72.4 kt CO_2-e or 18.6 per cent) and *Metal industry* (66.1 kt CO_2-e or 2.8 per cent) categories. The two largest decreases were due to the closure of a cement plant and a decrease in the import and use of HFCs for refrigeration and air conditioning.

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[5] 'ODS' stands for ozone-depleting substances.

Agriculture (chapter 5)

2016

In 2016, the Agriculture sector contributed 38,727.3 kt CO_2-e (49.2 per cent of New Zealand's gross emissions) (see figure ES 4.2).

The largest source of emissions within the Agriculture sector in 2016 was CH_4 emissions from *Enteric fermentation*, a process that produces CH_4 from livestock digestive systems (71.7 per cent of the total emissions from the sector). This was followed by N_2O emissions from *Agricultural soils* (which come from adding nitrogen to soil, e.g., manure or fertiliser) (22.2 per cent of the total emissions from the sector).

1990–2016

Agriculture sector emissions in 2016 were 4,145.5 kt CO_2-e (12.0 per cent) higher than emissions in 1990 (34,581.9 kt CO_2-e). This increase is primarily due to a 1,064.7 kt CO_2-e (4.0 per cent) increase in CH_4 emissions from *Enteric fermentation* and a 1,895.8 kt CO_2-e (28.3 per cent) increase in N_2O emissions from *Agricultural soils*. The key drivers for these changes in emissions are an increase of 92.4 per cent in the size of the national dairy herd since 1990 and an approximately 600 per cent increase in the use of nitrogen-containing synthetic fertiliser. A decrease of 52.3 per cent in the sheep population and 23.1 per cent in the non-dairy cattle population partially offsets these increases.

2015–2016

Total agricultural emissions in 2016 were 409.3 kt CO_2-e (1.0 per cent) less than those in 2015. This decrease is largely due to a significant fall in the sheep population of 1,537,154 animals (5.3 per cent), resulting in a 359.6 kt CO_2-e (3.3 per cent) decrease in emissions from sheep.

The decline in sheep numbers between 2015 and 2016 was caused by drought conditions in the South Island and relatively weak lamb and mutton prices. Sheep numbers in the North Island also declined due to a high incidence of facial eczema due to warmer and more humid conditions.

There was also a small 58.1 kt CO_2-e (0.3 per cent) decrease in emissions from dairy cattle, due to a fall in milk production, and an increase in N_2O emissions from synthetic fertiliser of 52.7 kt CO_2-e (3.4 per cent).

LULUCF (chapter 6)

The following information on LULUCF summarises reporting under the Convention. Reporting for Article 3.3 and Article 3.4 LULUCF activities under the Kyoto Protocol are covered in section ES.5.

2016

The LULUCF sector under the Convention was a sink of –22,773.7 kt CO_2-e net emissions. This offset 29 per cent of New Zealand's gross emissions in 2016. The category contributing the most to both removals and emissions is *Forest land remaining forest land*. This is because most of New Zealand's forests are removing a large amount of CO_2 from the atmosphere due to growth, while also being a large source of emissions due to the current high levels of sustainable harvesting that is occurring in New Zealand's plantation forests.

For the entire period 1990–2016, the LULUCF sector represented a net sink, that is, the total removals from the sector were greater than its total emissions.

From 1990 to 2016, net emissions from LULUCF increased by 6,765.8 kt CO_2-e (22.9 per cent) from the 1990 level of –29,539.5 kt CO_2-e (see figure ES 4.4). This is the result of the cyclical nature of growth and harvest of New Zealand's plantation forests and its impact on carbon stocks, coupled with the uneven age-class distribution of these forests (see figure 6.4.4 in chapter 6). Net emissions are higher because current harvest rates are higher than they were in 1990. Emissions have also increased in the *Grassland* category since 1990 due to the higher level of deforestation occurring now compared with 1990.

The fluctuations in net removals from the LULUCF sector (figure ES 4.4) are influenced by harvesting and deforestation rates. Harvesting rates are driven by a number of factors, particularly forest stand age and log prices. Deforestation rates are driven largely by the relative profitability of forestry, compared with alternative land uses. The increase in net emissions between 2004 and 2007 was largely due to the increase in planted forest deforestation that occurred leading up to 2008, before the introduction of the New Zealand Emissions Trading Scheme (NZ ETS).[6] Emissions from deforestation were much lower in 2008. The level of harvesting increased from 2008 to 2013 before levelling off during 2014 and 2015, and increasing again in 2016.

Figure ES 4.4   New Zealand's LULUCF sector net emissions from 1990 to 2016
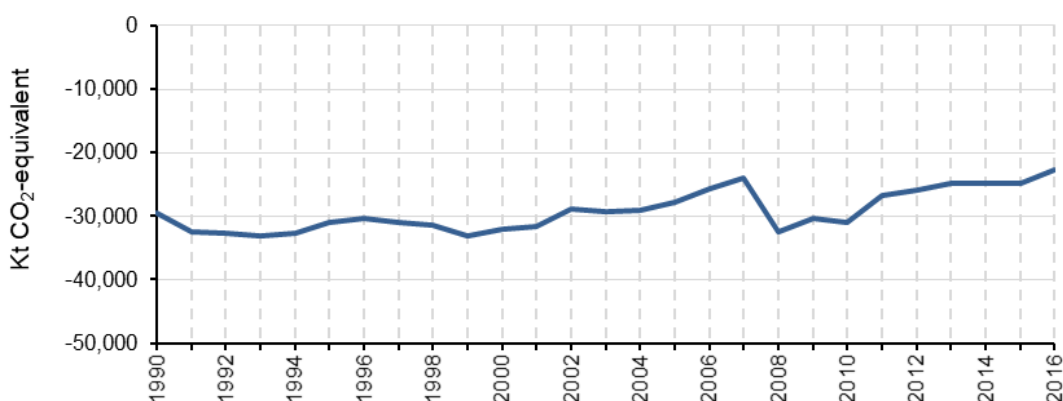
2015–2016

Between 2015 and 2016, net CO_2 emissions from the LULUCF sector increased by 2,087.4 kt CO_2-e (8.4 per cent). The largest change occurred in the *Forest land* category, with a 9.2 per cent increase in net emissions.

This was caused by an increased harvest rate and reduced deforestation rate.[7] The second largest change between 2015 and 2016 was the decrease in net emissions of 685.8 kt CO_2-e (13.3 per cent) that occurred in the *Grassland* category, due to the reduction in deforestation reported between years.

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[6]   The New Zealand Emissions Trading Scheme included the *Forestry* sector as of 1 January 2008.

[7]   This reflects the guidelines for international reporting because emissions associated with forest harvest are reported in the *Forest land* category, unless a land-use change occurs after harvest. In this case, the emissions are reported within the new land use category (e.g., emissions will be reported under the *Grassland* category).

Waste (chapter 7)

2016

In 2016, emissions from the Waste sector contributed 3,838.2 kt CO_2-e or 4.9 per cent of New Zealand's gross emissions. The largest source category is *Solid waste disposal*, which captures emissions from municipal landfills and unmanaged solid waste.

1990–2016

Total Waste sector emissions in 2016 were 24.4 kt CO_2-e (0.6 per cent) below 1990 emissions of 3,862.6 kt CO_2-e. Annual emissions increased between 1990 and 2002, peaking at about 4,500 kt CO_2-e in 2002, and have decreased since that time.

There has been ongoing growth in population and economic activity over the period, which has resulted in increasing volumes of solid waste and wastewater for the whole of the time series. This drove the increase in Waste sector emissions from 1990 to 2002. Since 2002, emissions have fallen due to ongoing improvements in the management of solid waste disposal at municipal landfills, particularly increased CH_4 recovery. As a result, total Waste sector emissions have been trending down since 2005 (see figure 2.2.11 in chapter 2).

2015–2016

Between 2015 and 2016, there was a small decrease in emissions from the Waste sector of 26.3 kt CO_2-e (0.7 per cent). This decrease is the result of reductions in CH_4 emissions in *Solid waste disposal*, largely due to ongoing improvements in municipal solid waste management and the continuation of a gradual reduction in the total waste disposed on farms.

ES.5 Activities under Article 3.3 and Article 3.4 of the Kyoto Protocol (chapter 11)

For Annex I Parties that have taken a target to reduce greenhouse gas emissions under the Kyoto Protocol, reporting of *Afforestation and reforestation* and *Deforestation* activities since 1990, and *Forest management*, is mandatory during the second commitment period of the Kyoto Protocol. This is a change from the first commitment period, when reporting on *Forest management* was voluntary for Annex I Parties. Reporting on *Cropland management*, *Grazing land management*, *Revegetation*, and *Wetland drainage and rewetting* is voluntary for 2013–20 (Kyoto Protocol, Article 3.4). New Zealand has not elected to report on any of these voluntary categories.

More information on how New Zealand accounts against its target is provided in section ES.2.

New Zealand reports on activities under Article 3.3 and Article 3.4 of the Kyoto Protocol by monitoring trends in land use. The Ministry for the Environment tracks forest land use and periodically produces land use maps. This information is supplemented by forestry statistics produced by the Ministry for Primary Industries. These data sources are used to detect the following trends in land use.

Afforestation and reforestation

The net area subject to *Afforestation and reforestation* activities between 1990 and 2016 was 655,323 hectares. This excludes the area subsequently converted to another land use, which is reported as a *Deforestation* activity. The provisional estimate of *Afforestation and reforestation* for 2016 is 4,302 hectares.

Deforestation

The area deforested between 1 January 1990 and 31 December 2016 was 191,682 hectares. The area subject to *Deforestation* in 2016 was 3,713 hectares.

Forest management

The net area reported under *Forest management* as at the end of 2016 was 9,249,653 hectares. This represents 34.4 per cent of New Zealand's total land area.

Table ES 5.1(a)   New Zealand's land use areas for Afforestation and reforestation, Deforestation and Forest management

	Hectares			
	2013	**2014**	**2015**	**2016**
Afforestation and reforestation				
Net cumulative area since 1990	644,706	648,700	651,567	655,323
Area in calendar year	4,838	4,847	3,742[P]	4,302[P]
Deforestation				
Net cumulative area since 1990	173,684	182,552	187,969	191,682
Area in calendar year	9,589	8,868	5,417[P]	3,713[P]
Forest management				
Area included	9,264,580	9,256,565	9,252,023	9,249,653
Total area included in Kyoto Protocol reporting	**10,082,970**	**10,087,817**	**10,091,559**	**10,096,658**

Note: Afforestation and reforestation refers to new forest established since 31 December 1989 but exluding areas of carbon equivalent forest. This means the areas differ from those reported in chapter 6 because the carbon equivalent forest provision means some new forest is reported under Forest management. Columns may not total due to rounding. P = provisional figure.

Emissions and removals for 2016

The emissions and removals associated with the above land-use changes are:

- net removals of 16,897.1 kt CO_2-e for *Afforestation and reforestation*
- net emissions of 2,186.2 kt CO_2-e for *Deforestation*
- net removals of 14,858.1 kt CO_2-e for *Forest Management*.

Emissions and removals for 2013 to 2016

Estimates of emissions and removals for activities under Article 3.3 and Article 3.4 of the Kyoto Protocol for the period 2013 to 2016 are included in the inventory because these are used to establish the accounting quantity. This is the value that New Zealand can use towards meeting its 2020 target (see table ES 5.1(b)). The specific rules that apply when accounting against a target are explained in chapter 11, section 11.3.4.

New Zealand's accounting quantity for the first four years of the period is 50,282.0 kt CO_2-e.

Table ES 5.1(b) New Zealand's net emissions and accounting quantity by year for Afforestation and Reforestation, Deforestation and Forest management

Activity	kt CO₂-equivalent			
	2013	**2014**	**2015**	**2016**
Afforestation and reforestation	−17,044.7	−17,239.6	−17,172.8	−16,897.1
Deforestation	6,200.8	6,276.1	3,409.1	2,186.2
Forest management	−21,697.1	−20,585.1	−18,119.7	−14,858.1
Net emissions	**−32,541.0**	**−31,548.6**	**−31,883.4**	**−29,569.0**
Accounting quantity	**−10,843.9**	**−10,963.5**	**−13,763.7**	**−14,710.9**

Note: The accounting quantity excludes net emissions from forest management because these will be accounted for against a forest management reference level at the end of the 2020 year and a cap will apply; further information on this is included in chapter 11, section 11.3.4. Removals are expressed as a negative value as per section 2.2.3 of the 2006 IPCC Guidelines (IPCC, 2006). Afforestation and reforestation refers to new forest established since 31 December 1989. Columns may not total due to rounding.

ES.6 Improvements introduced

A range of improvements have been made to the inventory since the 2017 inventory submission. Improvements are made as a result of recommendations from international expert review teams, to correct errors, and planned improvement work carried out by the agencies involved in preparing the inventory. When improvements are made, it is good practice to recalculate the whole time series from 1990 to the current inventory year to ensure a consistent time series. This means estimates of emissions in a given year may differ from emissions reported in the previous inventory submission.

The main improvements by sector are outlined below.

Energy (chapter 3)

The main improvements include:

- disaggregation of activity data for fisheries and off-road activities within the category *Agriculture/forestry/fishing*

- validation of road transport fuel statistics with vehicle kilometre data by vehicle type.

IPPU (chapter 4)

In the *Product uses as substitutes for ODS* category, activity data and emissions for refrigeration and air conditioning are disaggregated by sub-application. Emissions from refrigeration and air conditioning for all years have also been recalculated to better account for changes in the bank of refrigerant in operating equipment, refrigerant stockpiled by importers, and the timing of disposal.

Agriculture (chapter 5)

For the 2018 submission, an improvement was made to the method used to calculate the apportioning of crop residue burning areas between barley, oat and wheat crops.

The 2018 submission also corrected the following errors that were identified for the agriculture emissions calculations in 2017:

- the estimate of nitrogen retained in wool by sheep

- an equation used to estimate monthly populations of deer.

LULUCF (chapter 6)

The main differences between this submission and the previous inventory submission are the result of (in decreasing order of magnitude):

- inclusion of information on market specific activity data and emission factors for exported raw materials, which affects harvested wood products

- revision of the post-1989 planted forest yield table, which affects the estimate of carbon stocks per hectare

- emissions from peat extraction, which are reported for the first time

- continued improvements to the 1990, 2008 and 2012 land use maps. This followed a review that showed some areas of shrub cover were not becoming forest and are more accurately classified as *Grassland with woody biomass* within the inventory.

Waste (chapter 7)

The most significant improvements have been made to the *Unmanaged waste disposal sites* category with the inclusion of an additional survey of farm waste.

KP-LULUCF (chapter 11)

Improvements have been introduced to the 2018 submission resulting in recalculations for all three activities. The main differences are the result of (in order of decreasing magnitude):

- the revision of New Zealand's harvested wood products model to include the contribution of export logs based on an export markets study

- the revision of the post-1989 planted forest yield table, which is used to estimate emissions per hectare for growing, harvesting and deforestation of post-1989 forest.

Chapter 10 provides information on all recalculations made to the estimates.

Future improvements to national inventory system

Changes are planned to the national inventory system for the period 2018 to 2020 as a result of New Zealand extending its ratification of the Convention and the Paris Agreement to include Tokelau.

New Zealand ratified the Paris Agreement on 4 October 2016, specifically excluding Tokelau. On 14 November 2017, New Zealand extended its ratification of the Convention and the Paris Agreement to include Tokelau, with implications for including Tokelau in the obligatory climate change reporting managed by the Ministry for the Environment. Delivering on this obligation means that, in the future, New Zealand's greenhouse gas inventory will include greenhouse gas estimates for Tokelau (see chapter 13).

ES.7 National registry (chapters 12 and 14)

The Environmental Protection Authority is designated as the agency responsible for the implementation and operation of New Zealand's national registry under the Kyoto Protocol, the New Zealand Emission Unit Register. The registry is electronic and accessible via the internet (www.eur.govt.nz).

New Zealand replaced its registry system in August 2016. Testing and review involving United Nations Framework Convention on Climate Change (UNFCCC) secretariat staff took place during the period leading up to go-live of the new Register. No additional changes have been made to New Zealand's national registry since the 2017 submission.

In January 2008, New Zealand's national registry was issued with New Zealand's assigned amount of 309,564,733 metric tonnes CO_2-e.

The commitment period reserve for the first commitment period (CP1), of 278,608,260 metric tonnes CO_2-e is 90 per cent of the assigned amount, was fixed after the initial review in 2007.

At the beginning of the calendar year 2017, New Zealand's national registry held 308,343,858 CP1 assigned amount units, 110,744,560 CP1 emissions reduction units, 21,685,909 CP1 certified emission reduction units and 100,845,399 CP1 removal units. The number and mix of units held at the end of 2017 was the same as at the beginning of 2017 because no international transactions occurred during this period. This value includes the units retired to meet CP1 obligations. No second commitment period (CP2) units were held by New Zealand in 2017.

New Zealand's national registry did not hold any temporary certified emission reduction units or long-term certified emissions reduction units during 2017.

Executive summary: References

IPCC. 2006. Eggleston HS, Buendia L, Miwa K, Ngara T, Tanabe K (eds). *2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4. Agriculture, Forestry and Other Land Use.* IPCC National Greenhouse Gas Inventories Programme. Japan: Published for the IPCC by the Institute for Global Environmental Strategies.

Ministry for the Environment. 2016. *New Zealand's Initial Report to Facilitate the Calculation of its Emissions Budget for the Period 2013 to 2020.* Wellington: Ministry for the Environment.

UNFCCC. 2013. FCCC/CP/2013/10/Add.3. *Report of the Conference of the Parties on its nineteenth session, held in Warsaw from 11 to 23 November 2013: Addendum; Decision 24/CP.19 Revision of the UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention.*

Chapter 1: Introduction

1.1 Background

Greenhouse gases in the Earth's atmosphere trap warmth from the sun and make life as we know it possible. The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (IPCC, 2013) confirms that warming in the climate system is unequivocal, with many of the observed changes unprecedented over decades to millennia: warming of the atmosphere and the ocean, diminishing snow and ice, rising sea levels and increasing concentrations of greenhouse gases. The report also suggests that, since the beginning of the industrial revolution (about 1750 AD), the atmospheric concentrations of the greenhouse gases carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) have all increased due to human activity. Continued emissions of greenhouse gases will cause further warming and changes to all components of the climate system.

1.1.1 United Nations Framework Convention on Climate Change

The science of climate change is assessed by the IPCC. In 1990, the IPCC concluded that human-induced climate change was a threat to our future. In response, the United Nations General Assembly convened a series of meetings that culminated in the adoption of the United Nations Framework Convention on Climate Change (the Convention) at the Earth Summit in Rio de Janeiro in May 1992.

The Convention has been signed and ratified by 197 nations, including New Zealand, and took effect on 21 March 1994.

The main objective of the Convention (UNFCCC, 1992, Article 2) is to achieve:

> … stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.

All countries that ratify the Convention (the Parties) are required to address climate change, including monitoring trends in anthropogenic greenhouse gas emissions. The annual inventory of greenhouse gas emissions and removals fulfils this obligation. Parties are also obligated to protect and enhance carbon sinks and reservoirs, for example, forests, and implement measures that assist in national and/or regional climate change adaptation and mitigation. In addition, Parties listed in Annex II[8] to the Convention commit to providing technology transfer, capacity building and financial assistance to non-Annex I[9] Parties (developing country parties).

Annex I Parties also agreed to non-binding targets, aiming to return greenhouse gas emissions to 1990 levels by the year 2000. Only a few Annex I Parties made appreciable progress towards achieving this aim. The international community recognised that the existing commitments in the Convention were not enough to ensure greenhouse gas levels would be stabilised at a safe

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[8]   Annex II to the Convention (a subset of Annex I) lists the Organisation for Economic Co-operation and Development (OECD) member countries at the time the Convention was agreed.

[9]   Annex I to the Convention lists the countries included in Annex II, as defined above, together with countries defined at the time as undergoing the process of transition to a market economy, commonly known as 'economies in transition'.

level. In response, in 1995, Parties launched a new round of talks to provide stronger and more detailed commitments for Annex I Parties. After two-and-a-half years of negotiations, the Kyoto Protocol was adopted in Kyoto, Japan, on 11 December 1997. New Zealand ratified the Kyoto Protocol on 19 December 2002. The Protocol came into force on 16 February 2005.

1.1.2   Kyoto Protocol

The Kyoto Protocol shares and expands upon the Convention's objectives, principles and institutions. Only Parties to the Convention that have also become Parties to the Protocol (by ratifying, accepting, approving or acceding to it) are bound by the Protocol's commitments. The original objective of the Kyoto Protocol was to reduce the aggregate emissions of six greenhouse gases from Annex I Parties (as listed in Annex B to the Kyoto Protocol, together with targets for the first commitment period (CP1)) by at least 5 per cent below 1990 levels in the CP1 (2008–12). New Zealand's target in the CP1 was to return emissions to 1990 levels[10] on average over the commitment period or otherwise take responsibility for the excess.

The eighth session of the Conference of the Parties, serving as the meeting of the Parties to the Kyoto Protocol (Doha, Qatar, November to December 2012), agreed to amendments to the Kyoto Protocol for the period 2013–20, including an amended Annex B.

New Zealand has taken a target under the Convention during the 2013–20 period and does not have a commitment listed in the amended Annex B of the Kyoto Protocol. However, New Zealand remains a Party to the Kyoto Protocol and applies the Kyoto Protocol framework of rules to the 2013–20 period.

When reporting emissions and removals from the Land Use, Land-Use Change and Forestry (LULUCF) sector, New Zealand continues to use a land-based approach, as required by the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006a). For the period 2013–20, New Zealand will also complete activity-based reporting under Article 3.3 of the Kyoto Protocol for the categories *Afforestation*, *Reforestation* and *Deforestation*, and under Article 3.4 for *Forest management*.

1.1.3   The inventory

The Convention covers emissions and removals of all anthropogenic greenhouse gases not controlled by the Montreal Protocol. *New Zealand's Greenhouse Gas Inventory* (the inventory) is the official annual report of these emissions and removals in New Zealand.

The methodologies, content and format of the inventory are prescribed by the IPCC (IPCC, 2006b) and reporting guidelines agreed by the Conference of the Parties to the Convention and Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol (CMP). The most recent reporting guidelines are FCCC/CP/2013/10/Add.3 (UNFCCC, 2013b). As per the Convention reporting guidelines, New Zealand followed the 2006 IPCC Guidelines in the preparation of the 2018 inventory submission.

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[10]   New Zealand's target under the Kyoto Protocol was a responsibility target. A responsibility target means that New Zealand can meet its target through a mixture of domestic emission reductions, the storage of carbon in forests and the purchase of emission reductions in other countries through the emissions trading mechanisms established under the Kyoto Protocol. The target was based on total gross emissions from the following sectors: Energy, Industrial Processes, Solvent and Other Product Use (from 2015, Industrial Processes and Solvent and Other Product Use are reported jointly under the Industrial Processes and Product Use sector), Agriculture and Waste.

A complete inventory submission contains two components: the national inventory report (NIR) and the common reporting format (CRF) tables. Inventories are subject to an annual technical review process administered by the United Nations Framework Convention on Climate Change (UNFCCC) secretariat. The results of these reviews are available online (www.unfccc.int).

The inventory reports on emissions and removals of the gases CO_2, CH_4, N_2O, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3).[11] The indirect greenhouse gases,[12] carbon monoxide (CO), sulphur dioxide (SO_2), oxides of nitrogen (NO_X) and non-methane volatile organic compounds (NMVOCs), are also included. Only emissions and removals of the direct greenhouse gases (CO_2, CH_4, N_2O, HFCs, PFCs, SF_6 and NF_3) are reported in gross and net emissions under the Convention and are accounted for under the Kyoto Protocol. The gases are reported under five sectors: Energy, Industrial Processes and Product Use (IPPU), Agriculture, LULUCF and Waste.

Reporting on afforestation, reforestation and deforestation activities since 1990 (Article 3.3 activities under the Kyoto Protocol) and forest management (under Article 3.4 of the Kyoto Protocol) are mandatory during the 2013–20 period of the Kyoto Protocol. Afforestation, reforestation, deforestation and forest management activities are defined below. The definitions are consistent with Decision 16/CMP.1 (UNFCCC, 2005a).

1.1.4 Supplementary information required

Following guidelines adopted by the CMP for reporting under Article 7.1 of the Kyoto Protocol, New Zealand includes supplementary information in its annual inventory submission.

The supplementary information covers:

- information on emissions and removals for each activity under Article 3.3, forest management under Article 3.4, and for any elected activities under Article 3.4 (chapter 11)

- holdings and transactions of units transferred and acquired under Kyoto Protocol mechanisms (chapter 12)

- significant changes to a Party's national system for estimating emissions and removals (chapter 13) and to the Kyoto Protocol unit registry (chapter 14)

- information related to the implementation of Article 3.14 on the minimisation of adverse impacts on non-Annex I Parties (chapter 15).

1.2 Description of the national inventory arrangements

1.2.1 Institutional, legal and procedural arrangements

In 2002 New Zealand passed into legislation the Climate Change Response Act 2002. This enables New Zealand to meet its international obligations under the Convention and Kyoto Protocol. A Prime Ministerial directive for the administration of the 2002 Act names the Ministry for the Environment (MfE) as New Zealand's 'inventory agency'. Part 3, section 32, of the Act specifies the following functions and requirements.

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[11] Nitrogen trifluoride emissions do not occur in New Zealand and, therefore, are not included in this report.

[12] Indirect greenhouse gases are the gases that have indirect radiative effects in the atmosphere. This may happen either through conversion of an indirect gas to a direct greenhouse gas in the atmosphere (like CO is converted to CO_2) or when chemical reactions in the atmosphere involving these gases change the concentrations of direct greenhouse gases.

1. The primary functions of the inventory agency are to:

   – estimate annually New Zealand's anthropogenic emissions by sources and removals by sinks, of greenhouse gases

   – prepare the following reports for the purpose of discharging New Zealand's obligations:

      i. New Zealand's annual inventory report under Article 7.1 of the Kyoto Protocol, including (but not limited to) the quantities of long-term certified emission reduction units and temporary certified emission reduction units that have expired or have been replaced, retired, or cancelled

      ii. New Zealand's national communication (or periodic report) under Article 7.2 of the Kyoto Protocol and Article 12 of the Convention

      iii. New Zealand's report for the calculation of its initial assigned amount under Article 7.4 of the Kyoto Protocol, including its method of calculation.

2. In carrying out its functions, the inventory agency must:

   – identify source categories

   – collect data by means of:

      i. voluntary collection

      ii. collection from government agencies and other agencies that hold relevant information

      iii. collection in accordance with regulations made under Part 3 of the Act (if any)

   – estimate the emissions and removals for each source category

   – undertake assessments on uncertainties

   – undertake procedures to verify the data

   – retain information and documents to show how the estimates were determined.

Compliance provisions in section 36 of the Act provide for the authorisation of inspectors to collect information needed to estimate emissions or removals of greenhouse gases.

1.2.2   Inventory planning, preparation and management

New Zealand is required under Article 5.1 of the Kyoto Protocol to have a national system for its inventory. New Zealand provided a full description of the national system in its initial report under the Kyoto Protocol (Ministry for the Environment, 2006). Changes to the national inventory system are documented in section 1.2.4 and chapter 13 of this submission.

New Zealand has developed national inventory system guidelines that document the tasks required to officially submit the inventory. These guidelines cover multiple aspects of the production of the inventory: planning, inventory process, quality assurance and quality control (QA/QC) processes, communication and error management. This is a living document that is updated during each inventory year.

Inventory management

New Zealand uses a hybrid (centralised/distributed) approach to management for the inventory programme. Management and coordination of the inventory programme, as well as compilation, publication and submission of the inventory, are carried out by the inventory agency (MfE) in a centralised manner. Sector-specific work, which includes obtaining and processing activity data,

estimating emissions, preparing sectoral common reporting format tables and writing sectoral inventory chapters, is carried out by designated agencies across New Zealand's Natural Resource sector.

Inventory governance within each sector, as well as sectoral quality control, is managed by the agencies responsible for the sectors. The Reporting Governance Group (RGG) provides cross-agency governance over the climate change reporting, modelling and projections of greenhouse gas emissions and removals. The RGG is chaired by MfE, and its membership includes representation from the Environmental Protection Authority (EPA), the Ministry for Primary Industries (MPI) and the Ministry of Business, Innovation and Employment (MBIE). The main roles and expectations of the RGG include:

- guiding, conferring and approving inventory and emissions projection improvements and assumptions (on the basis of advice from technical experts), planning and priorities, key messages, management of stakeholders and risks

- focusing on delivery of reporting commitments to meet national and international requirements

- providing reporting leadership and guidance to analysts, modellers and technical specialists

- sharing information, providing feedback and resolving any differences between departments that impact on the delivery of the work programme

- monitoring and reporting to the Climate Change Directors Group (a cross-agency group that oversees New Zealand's international and domestic climate change policy) on the 'big picture' of the reporting work programme, direction, progress in delivery and capability to deliver.

MfE is New Zealand's single national entity for the inventory. It is responsible for the overall coordination, compilation and submission of the inventory to the UNFCCC secretariat. The National Inventory Compiler is based at MfE. Arrangements with other government agencies have evolved as resources and capacity have allowed, and as a greater understanding of the reporting requirements has been attained.

As well as its overall inventory coordination role, MfE also compiles emission estimates for the IPPU sector (non-CO_2 gases through industry surveys and CO_2 data provided by MBIE), Waste sector, emissions and removals for the LULUCF sector and Article 3.3 and Article 3.4 activities under the Kyoto Protocol.

MfE conducts field measurement programmes within the LULUCF sector. It undertakes land use mapping from satellite imagery to report on emissions for the LULUCF sector and Article 3.3 and Article 3.4 activities under the Kyoto Protocol. This is supplemented with data on harvested wood products production and non-CO_2 emissions collected through surveys of the sector.

MBIE estimates all emissions from the Energy sector and CO_2 emissions from the IPPU sector.

MPI estimates emissions from the Agriculture sector. The estimates are underpinned by research and modelling undertaken at New Zealand's Crown research institutes, universities and private research companies and survey data collected by the national statistics agency Statistics New Zealand.

Statistics New Zealand also provides population census data for producing the Waste and IPPU sectors' emissions estimates.

The Ministry of Foreign Affairs and Trade provides information on the minimisation of adverse effects in chapter 15 of the inventory.

The Climate Change Response Act 2002 establishes the requirement for a registry and a registrar. The EPA is designated as the agency responsible for the implementation and operation of New Zealand's national registry under the Kyoto Protocol, the New Zealand Emission Unit Register. The registry is electronic and accessible via the internet (www.eur.govt.nz). Information on the annual holdings and transactions of transferred and acquired units under the Kyoto Protocol is provided in the standard electronic format tables accompanying this submission. Refer to chapter 12 for further information.

Figure 1.2.1 shows the specific responsibilities of different agencies involved in the inventory production as well as their contribution to the inventory submission.

Figure 1.2.1   New Zealand's inventory system at a glance: how different agencies are involved
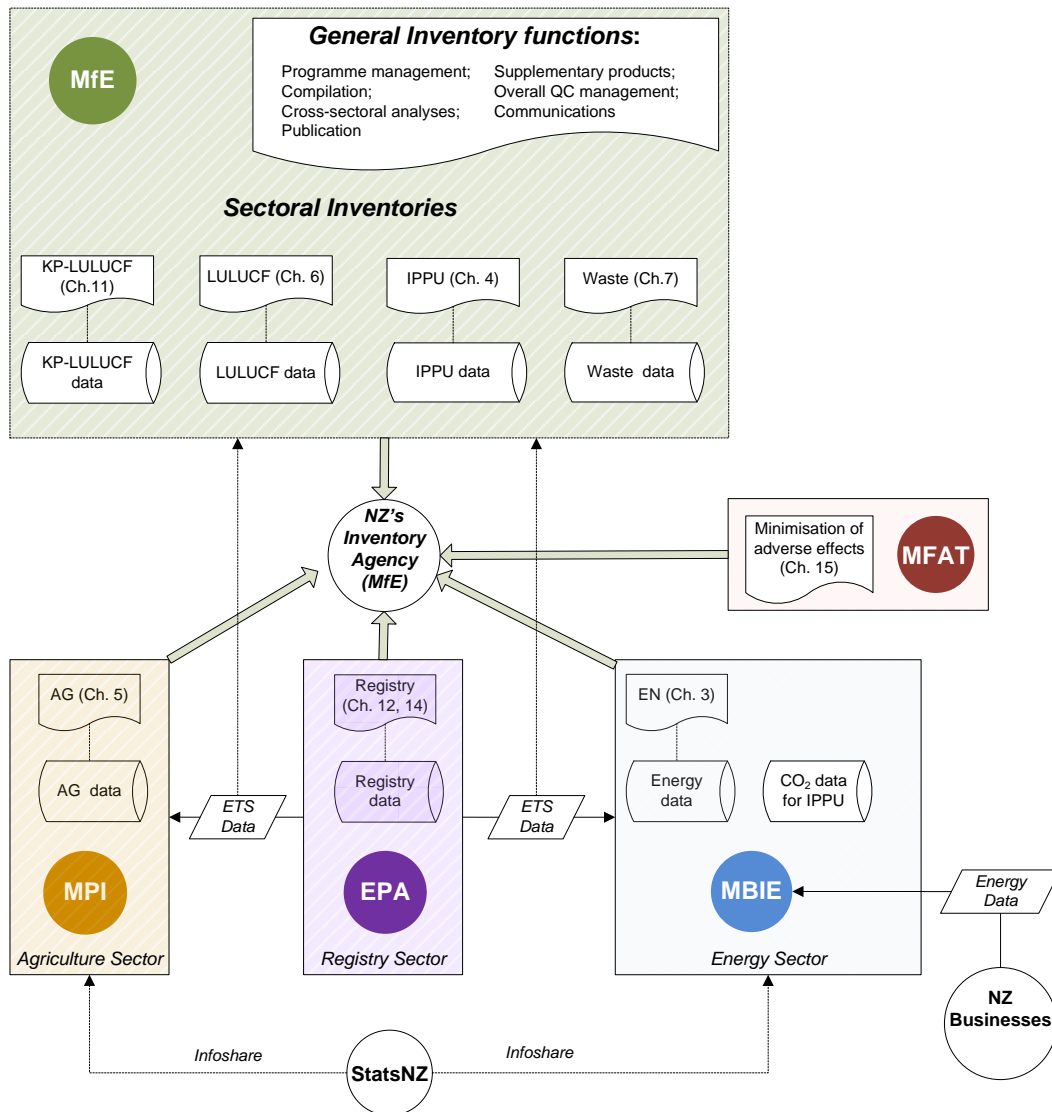
Note: AG = Agriculture; EN = Energy; EPA = Environmental Protection Authority; ETS = Emissions Trading Scheme; IPPU = Industrial Processes and Product Use; KP-LULUCF = Kyoto Protocol Land Use, Land-use Change and Forestry; LULUCF = Land Use, Land-use Change and Forestry; MBIE = Ministry of Business, Innovation and Employment; MFAT = Ministry of Foreign Affairs and Trade; MfE = Ministry for the Environment; MPI = Ministry for Primary Industries; QC = quality control; StatsNZ = Statistics New Zealand.

Inventory planning and preparation

A summary of the inventory planning and preparation process is presented in figure 1.2.2.

Figure 1.2.2   **Summary of New Zealand's inventory planning and preparation**
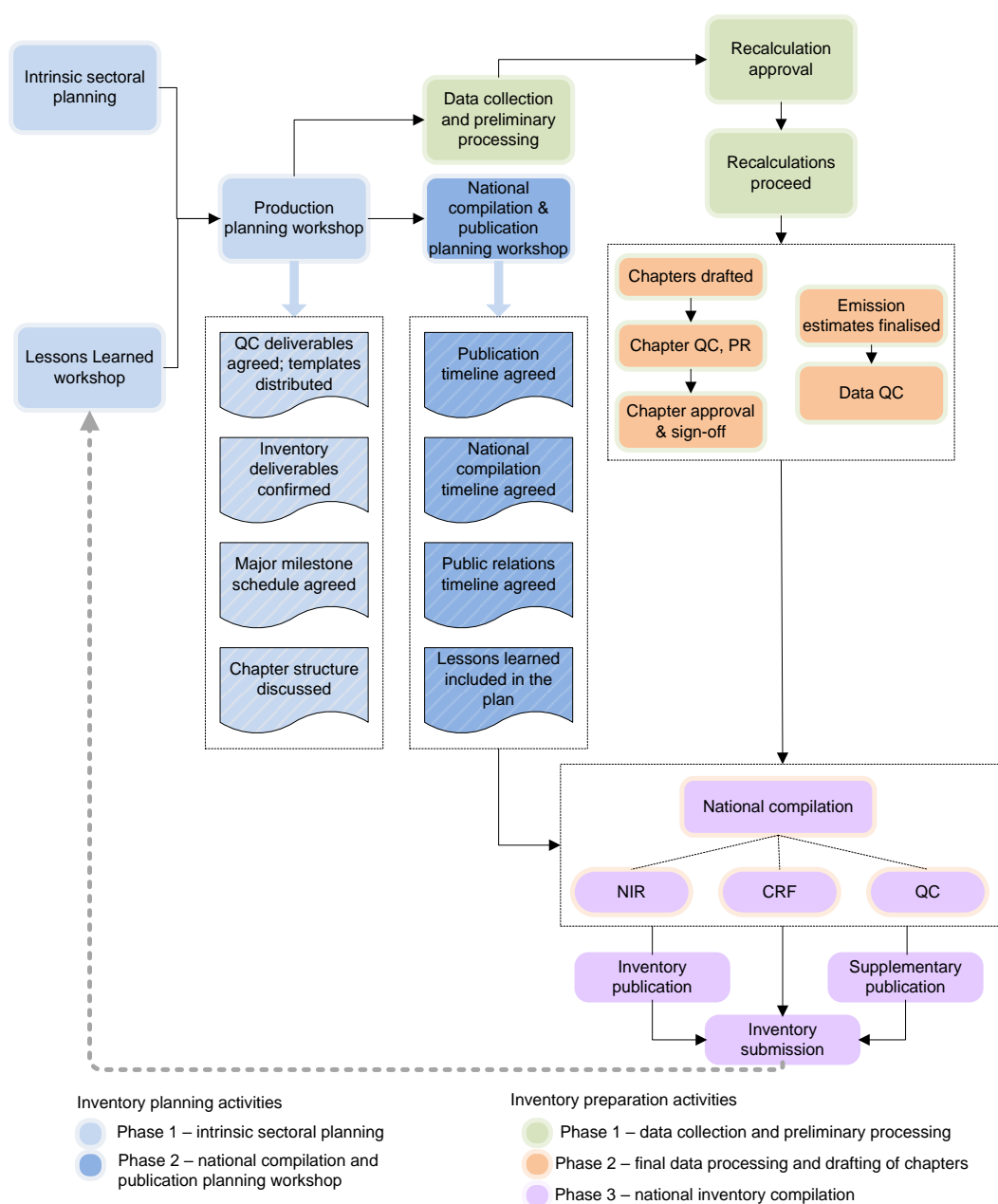
Note: CRF = common reporting format; NIR = National Inventory Report; PR = peer review; QC = quality control.

Inventory planning

Inventory planning is a two-phase process. The first phase, intrinsic sectoral planning, involves planning for the inventory compilation at the sector level. This includes planning for technical projects, actions and procedures that are specific to each sector. The second phase, national compilation and publication planning, involves planning for the cross-sectoral compilation.

Once the intrinsic sectoral planning is complete, the plans are coordinated between the agencies and adjustments are made as necessary. This usually happens through a lessons learned

workshop and a production planning workshop. The lessons learned workshop is dedicated to analysis of what worked well and what did not in the previous inventory cycle. During the production planning workshop, the following are discussed and agreed:

- inventory deliverables
- QC deliverables
- schedule of major milestones
- changes to chapter structure
- approach for solving problems during inventory preparation.

The second phase of the inventory planning, the national compilation and publication planning workshop, is dedicated to cross-sectoral compilation. The workshop occurs towards the end of each calendar year. During this workshop, different aspects of the compilation process are discussed and a detailed plan for the cross-sectoral compilation and publication is agreed. Participants in the workshop include MfE's publication and public liaison teams as well as the inter-agency inventory production team. During the national compilation and publication planning workshop, the following are discussed and agreed:

- national compilation timeline
- publication timeline
- public relations timeline.

Lessons learned are also considered in constructing the plan.

Inventory preparation

The inventory preparation cycle has three phases: data collection and preliminary processing, final data processing and chapter preparation, and the national inventory compilation.

The first phase, data collection and preliminary processing (June–October), includes data cleansing, data checks and preliminary formatting of data for further use. This phase may also include analysis of potential improvements and related recalculations involved in the inventory.

The second phase of the inventory preparation (October–January) includes final data processing and drafting of chapters. During this phase, emissions estimates are finalised, final data quality control and verification is performed, data are loaded into the CRF reporter and sectoral chapters are updated, reviewed and approved.

The final phase of the inventory preparation (February–April) includes cross-sectoral analyses, national inventory compilation and publication, as well as producing supplementary materials for the Minister for Climate Change and the general public.

During the inventory planning and preparation cycle, the National Inventory Compiler has regular meetings with sector leads and experts to ensure that all issues are addressed and the production process goes as planned. The inventory QC Manager also has regular meetings with sector leads to monitor QC processes and procedures that are in place to ensure the quality of the final product meets the Convention standards and the QC deliverables are produced according to the agreed plan. Both the National Inventory Compiler and the QC Manager provide technical support and advice to the sector leads when required.

1.2.3 Quality assurance and quality control and verification plan

Quality assurance and quality control are integral parts of preparing New Zealand's inventory. MfE developed a QA/QC plan in 2004, as required by the reporting guidelines under the Convention (UNFCCC, 2006, 2013b) to formalise, document and archive the QA/QC procedures. Details of the QA/QC activities performed during the compilation of the 2018 submission are discussed in the relevant sections below. Examples of QC checks are provided in the MS Excel spreadsheets accompanying this submission.

Quality control

The focus of New Zealand's QC plan is to meet the transparency, accuracy, completeness, consistency, comparability (TACCC) principles while ensuring efficient use of resources, and to mitigate QC-related risks in the inventory planning and preparation process.

The main elements of the QA/QC plan include:

- revising the QC deliverables to ensure they are fit for purpose, well-supported with relevant templates, and adapted to the changes in the inventory software tools

- reinforcing the error-checking process by providing dedicated personnel and support to the sector leads

- automating inventory tools to minimise the number of errors during data transfers

- adjusting QC tools to accommodate any changes in the CRF Reporter software that happened since the previous submission

- ensuring the structure of chapters in the inventory demonstrate transparency of the methods and incorporate suggestions from previous inventory reviews.

Completion of the IPCC 2006 Tier 1 QC check sheets for each sector is the responsibility of the sector leads. The Tier 1 checks are based on the procedures suggested in the 2006 IPCC Guidelines (IPCC, 2006b). Sectoral QC processes and procedures have been revised and thoroughly documented in the updated version of New Zealand's national inventory system guidelines. Wherever possible, manual checking has been replaced by automated checks.

All sector level data were entered into the web-based common reporting format database by sector compilers by 15 February 2018.

The sectoral contributions to the inventory and Tier 1 QC checks were signed off by the responsible agency before final approval of the inventory and submission to the UNFCCC.

MfE used the QC checking procedures included in the CRF Reporter to ensure the data submitted to the UNFCCC secretariat are complete. In addition, data in the common reporting format tables were also checked for anomalies, errors and omissions.

The Energy and Agriculture activity data provided by Statistics New Zealand are official national statistics and, as such, are subject to their own rigorous QA/QC procedures. Human and animal population statistics provided by Statistics New Zealand were also used for estimating emissions from the Waste sector.

Annex 6 contains details of the QA/QC processes applied during preparation of the inventory.

Quality assurance

New Zealand's QA system includes prioritisation of improvements, processes around accepting improvements into the inventory, in-depth review of sector inventories or their components every 5 to 10 years, and improving the expertise of key contributors to the inventory. The

government audit agency (Audit New Zealand) makes annual audits of the inventory performance. New Zealand also considers the international inventory reviews performed by the expert review teams at the UNFCCC as an important element of quality assurance. Regular meetings to discuss progress of QA/QC activities and relevant issues with each sector lead are in place. The main aspects of quality assurance are explained in detail below.

All sector leads are encouraged to schedule QA audits of their systems at least every five years. The Agriculture sector commenced a major QA review of its calculation models with an external party in 2012 (additional details can be found in chapter 5, sections 5.1.4 and 5.1.5 of the 2015 inventory submission). In 2013–14, a comprehensive QA review of estimates from non-municipal landfills in the Waste sector was undertaken. In 2014–15, external contractors completed a review of estimation methods for the *Industrial wastewater* category in the Waste sector (Cardno, unpublished). In 2016–17, an expert study of non-energy fuel use in the IPPU sector was undertaken. The results of the review were used during compilation of the IPPU sector in the 2018 submission.

Prioritisation of improvements

Priorities for the development of the inventory are guided by:

- the analysis of key categories (level and trend)
- the degree of improvement to be achieved for existing emission and removal estimates
- the availability of resources required to implement the change
- recommendations from previous international reviews of the inventory.

Uncertainties are also considered in prioritising improvements. For example, if a change in a methodological approach may lead to a significant increase of uncertainty of the estimates, then the proposed change may be rejected on the basis of an undesired increase in uncertainty. Otherwise, if the proposed improvement is not expected to affect the uncertainty significantly or will result in uncertainty reduction, then the change is likely to be accepted. The inventory improvement and QA and QC plans are updated annually to reflect current and future development of the inventory.

Acceptance of improvements and recalculations

All improvements in the inventory undergo peer review by an independent expert or a group of experts. The change will be included in the inventory only if the peer reviewer concludes that the change is consistent with IPCC good practice.

Given the importance of the Agriculture sector to New Zealand's emissions profile, New Zealand established the independent Agriculture Inventory Advisory Panel to assess whether proposed improvements and recalculations in the sector are scientifically robust enough to be included in the inventory. Reports and/or papers on proposed changes must be peer reviewed before they are presented to this panel of experts. The Panel then advises MPI of its recommendations. Refer to chapter 5, section 5.1.5, for further details.

All recalculations and improvements to the inventory require the approval of the Reporting Governance Group. The recalculations need to be sufficiently explained in terms of improving one or more of the IPCC good practice principles. If, due to recalculations, emissions from the recalculated category exceed 500 kilotonnes carbon dioxide equivalent (kt CO_2-e), the results and reasons for the recalculations are recorded in the Recalculation form. The recalculations and explanations are recorded for documentation and archiving purposes.

Verification activities

Where relevant, further verification activities carried out for a sector are discussed in the sector-specific sections of this report. Section 1.9.2 provides information about the verification method that has become available for the inventory by using data from the New Zealand Emissions Trading Scheme (NZ ETS).

In the Energy sector, the reference approach is used for verification of the emission estimates for CO_2 obtained from the sectoral approach.

Treatment of confidentiality issues

When specific emission and activity data in the inventory can lead to identification of individuals and/or individual businesses and, therefore, affect their wellbeing, commercial interest in trade and/or negotiations, those data are considered to be confidential. The 2006 IPCC Guidelines recommend that confidential data be aggregated so as to draw out the information that is important to the user, without disclosing confidential data (IPCC, 2006b). For New Zealand, confidentiality issues largely apply to sources of emissions in the Energy and IPPU sectors, where an entire industry or source category is often represented by just one or two companies. Therefore, a practice of presenting information as an 'industry average' is often not applicable in New Zealand because this would lead to breaching business confidentiality. Confidential information is held by the agencies leading production of the inventory sector estimates (MPI, MBIE, EPA and MfE), and each agency has security procedures (e.g., password-restricted access to files on computers) to ensure the data are kept confidential.

To protect confidentiality of businesses that contribute data to the inventory (as appropriate), two approaches are used.

1. Where emissions can be reported without compromising confidentiality, the corresponding activity data are not reported and are marked as confidential in the common reporting format tables.

2. Where reporting emissions data would risk breaching confidentiality, the emissions data are aggregated with other emissions from a different source category. The notation key 'IE' (included elsewhere) is used.

In the IPPU sector, activity data for the categories *Iron and steel production*, *Cement production* and *Glass production* are marked as confidential. Emissions for *Glass production* are reported under the *Other uses of carbonates* category.

1.2.4 Changes in national inventory arrangements since the previous annual greenhouse gas inventory submission

No changes have been made in the legal or institutional arrangements in the national inventory system since the last (2017) submission of the inventory. However, changes are planned to the national inventory system for 2018–20 as a result of New Zealand extending its ratification of the Paris Agreement to include Tokelau.

New Zealand ratified the Paris Agreement on 4 October 2016, specifically excluding Tokelau. On 14 November 2017, New Zealand extended its ratification of the Convention and of the Paris Agreement to include Tokelau, with implications for including Tokelau in the obligatory climate change reporting managed by MfE. Delivering on this obligation, inter alia, means that New Zealand's greenhouse gas inventory would include the greenhouse gas estimates from Tokelau (see chapter 13 for details).

1.3 Inventory preparation: data collection, processing and storage

Inventory planning and preparation is described above in section 1.2.

The National Inventory Compiler coordinates the calculation of level and trend uncertainties, key category assessment, and finalises the inventory. The inventory is then approved for publication by the Climate Change Director (MfE) before submission to the UNFCCC secretariat.

The inventory and all required data for the submission are stored at MfE in a restricted file system. The inventory is published on the MfE and UNFCCC websites.

Data archiving, security and recovery

To provide data security and recovery of files for the inventory in the event of a disaster, a distributive strategy for storage is in place. This includes storing the inventory files using different types of storage devices (local and networked storage devices) in different geographical locations. The changes to all files are backed up on a daily basis, and the entire system is backed up on a weekly basis.

New Zealand's archiving system reflects the distributed system. Specifically:

- all files for the inventory are stored in MfE's secure file management system and backed up on several different devices. This covers all data files and supplementary materials as part of the submission for the inventory, CRF tables, database back-up files from the CRF Reporter, sectoral chapters, the compiled inventory, confirmations of sign-off, communication between New Zealand's inventory team and the expert review team, national inventory system, process maps, project planning and documentation, and other related documents for the inventory

- each sectoral agency keeps its data in secure file systems, including communication with contractors, activity data, emission factors, preliminary calculations and specific software applications containing sectoral data models

- each of the agencies involved in the preparation of the inventory has security procedures in case of natural disasters, fire, flood or other accidents, which are kept at a high standard.

1.4 Methodologies and data sources used

The guiding documents in the inventory's preparation are the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006b), the *2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol* (IPCC, 2014), the revised *UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention* (UNFCCC, 2013b), the Kyoto Protocol (UNFCCC, 2012, 2013c), decisions 3/CMP.11 and 4/CMP.11 that cover a range of reporting and review issues (UNFCCC, 2016a, 2016b), and the guidelines on reporting and review (UNFCCC, 2005a–k). The concepts contained in the good practice guidance are implemented in stages, according to sector priorities and national circumstances.

The 2006 IPCC Guidelines provide a number of possible methodologies for calculating emissions or removals from a given category (IPCC, 2006b). In most cases, these possibilities represent calculations of the same form where the differences are in the level of detail at which the calculations are carried out. The methodologies are provided in a structure of three tiers that describe and connect the various levels of detail at which estimates can be made. The choice of method depends on factors such as the importance of the source category and availability of data. The tiered structure ensures that estimates calculated at a highly detailed level can be

aggregated up to a common minimum level of detail for comparison with all other reporting countries. The methods for estimating emissions and/or removals are distinguished between the tiers as follows:

- Tier 1 methods apply IPCC default emission factors and use IPCC default methods

- Tier 2 methods apply country-specific emission factors and use IPCC default methods

- Tier 3 methods apply country-specific emission factors and use country-specific methods.

Methodology for each sector in the inventory is described briefly here. Refer to each sector chapter for more detail.

Energy

Greenhouse gas emissions from the Energy sector are calculated using a detailed sectoral approach. This bottom-up approach is energy demand based; it involves processing energy data collected on a regular basis through various surveys. For verification, New Zealand has also applied the IPCC reference approach to estimate CO_2 emissions from fuel combustion for the time series 1990–2016 (see annex 4).

The activity data used for the sectoral approach are referred to as 'observed' energy-use figures. These are based on surveys and questionnaires administered by MBIE. The differences between 'calculated' and 'observed' figures are reported as statistical differences in the energy balance tables released along with *Energy in New Zealand 2016* (MBIE, 2017). Due to the time interval between the publication of *Energy in New Zealand* and the preparation of this submission, some data revisions may have occurred. See chapter 3 for further details on methodologies applied in the Energy sector and a description of the sources for activity data for the inventory.

IPPU

Activity data in the IPPU sector have been derived from a variety of sources. In the *Mineral industry* category, the primary data source is emissions data reported under the NZ ETS. For the *Chemical industry* and *Metal industry* categories, data (including activity data) are provided to MBIE in response to an annual survey.

For some large-scale activities in the *Mineral industry*, *Chemical industry* and *Metal industry* categories, which are carried out by only one or two companies in New Zealand, activity data are reported as confidential in the CRF tables.

Emissions data for glass production (2.A.3) are reported in 2.A.4 to aggregate the data with other sources and preserve confidentiality. Also, data on emissions from hydrogen making at the Marsden Point oil refinery are reported in the *Chemical industry* source category. This allows data from New Zealand's only industrial hydrogen-making process, which is smaller in scale than refining, to be aggregated and kept confidential.

For the *Product uses as substitutes for ODS*[13] category, updated activity data have been obtained by a detailed annual survey covering the electrical, refrigeration and other industry participants (CRL Energy, unpublished(b)) as well as importers of HFCs and other substances in this category.

New Zealand uses a combination of Tier 1 and Tier 2 methodologies for the IPPU sector. Tier 2 methods are used for all key categories.

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[13] 'ODS' stands for ozone-depleting substances.

For small amounts of indirect greenhouse gas emissions reported in the *Chemical industry* category and the *Other product manufacture and use* category, data were obtained by a detailed industry survey and analysis (CRL Energy, unpublished(a)). Emissions and activity data have been extrapolated for the years since 2006.

Country-specific emission factors have been used where available, including for emissions of indirect greenhouse gases.

Agriculture

New Zealand has developed a Tier 2 methodology with country-specific emission factors, which uses detailed data on livestock population and productivity to calculate livestock energy requirements for the major livestock categories. Animal population census data are collected by Statistics New Zealand every five years (the Agricultural Production census) and survey statistics annually between censuses (the Agricultural Production survey). Productivity data are available from the Livestock Improvement Corporation (dairy statistics) and non-governmental industry organisations such as Beef + Lamb New Zealand Ltd and Deer Industry New Zealand. Statistics on animal carcass weights are collected by MPI. Livestock population data are obtained from Statistics New Zealand through the Agricultural Production census and surveys. Slaughter statistics are collected by MPI and used as a proxy to establish changes in animal liveweight over time.

Other livestock species (*Swine*, *Goats*, *Horses*, *Llamas and Alpacas*, *Mules and Asses*, and *Poultry* – referred to as 'minor' livestock categories) account for only 0.5 per cent of New Zealand's agriculture emissions. Emissions from these minor livestock species are generally estimated using Tier 1 methods, but where information is available, New Zealand has used country-specific emission methods and factors. There is no farming of rabbits or other fur-breeding animals in New Zealand.

For estimating emissions from *Agricultural soils*, New Zealand uses methodologies based on the IPCC Guidelines (IPCC, 2006a), as well as the outputs of the Tier 2 livestock population characterisation and modelling of the livestock nutrition and energy requirements. New Zealand uses a combination of default and country-specific emission factors and parameters to calculate N_2O emissions from *Agricultural soils*. Details on these emission factors and parameters are listed in chapter 5 (tables 5.5.2 and 5.5.3) and annex 3 (tables A3.1.5 and A3.1.6). Table 5.5.4 in chapter 5 contains the parameters used to estimate emissions from the use of mitigation technologies.

Activity data on the *Liming* category are obtained from Statistics New Zealand, and data on synthetic fertiliser containing nitrogen are provided by the Fertiliser Association of New Zealand. A Tier 2 (model) approach is used to calculate emissions from burning of agricultural residues. There is no rice cultivation in New Zealand or CO_2 emissions from other carbon-containing fertilisers.

LULUCF and KP-LULUCF

New Zealand uses a combination of Tier 1, Tier 2 and Tier 3 methodologies for estimating emissions and removals for the LULUCF sector under the Convention and Article 3.3 and Article 3.4 activities under the Kyoto Protocol. Tier 2 or Tier 3 approaches have been used to estimate biomass carbon in the pools with the most living biomass at steady state: *Pre-1990 natural forest*, *Pre-1990 planted forest*, *Post-1989 forest*, *Perennial cropland* and *Grassland with woody biomass*. For all other land use categories, a Tier 1 approach is used for estimating biomass carbon. A Tier 2 modelling approach has also been used to estimate carbon changes in the mineral soil component of the soil organic matter pool, while Tier 1 is used for organic soils.

New Zealand has established a data collection and modelling programme for the LULUCF sector called the Land Use and Carbon Analysis System (LUCAS). The LUCAS programme includes the:

- use of field plot measurements for natural and planted forests

- use of allometric models to estimate carbon stock and carbon stock change in natural and planted forests respectively (Holdaway et al., unpublished; Beets et al., unpublished; Paul et al., unpublished; Paul and Kimberley, unpublished)

- wall-to-wall land use mapping for 1990, 2008 and 2012 using satellite and aircraft remotely sensed imagery, with additional information on post-1989 forest afforestation and deforestation of planted forest used for estimating change

- development of databases and applications to store and process all data associated with LULUCF activities.

Waste

Activity data have come from a variety of sources. Municipal solid waste disposal data, from mandatory reporting under the Waste Minimisation Act 2008 and from the NZ ETS, were used for the years for which it was available (2010 onwards). Activity data for all other sources were based on specific surveys. Interpolation based on gross domestic product or population is used for other years.

New Zealand uses Tier 2 methodologies for estimating emissions from the *Solid waste disposal* source category, which is a key category, and for some wastewater emissions. Tier 1 methods are used to estimate other emissions in the Waste sector.

Country-specific emission factors have been used where available, including parameters for municipal waste and for treatment of some types of industrial wastewater.

1.5 Key categories

1.5.1 Reporting under the Convention

The 2006 IPCC Guidelines (IPCC, 2006b, Vol. 1, section 4.1.1, p. 4.5) identify a key category as:

> …one that is prioritised within the National Inventory System because its estimate has a significant influence on a country's total Inventory of direct greenhouse gases in terms of the absolute level of emissions, the trend in emissions, or both.

Key categories identified within the inventory are used to prioritise inventory improvements.

Because some categories in the inventory apply default uncertainty values for emission estimates and developing country-specific uncertainty values is resource prohibitive, the key categories in the inventory have been assessed using the Approach 1 level (L1) and Approach 1 trend (T1) methodologies from the 2006 IPCC Guidelines (IPCC, 2006b). The key category analysis identifies key categories of emissions and removals as those that sum to 95 per cent of the gross or net level of emissions and those that are within the top 95 per cent of the categories that contribute to the change between 1990 and 2016, or the trend of emissions. The key categories identified in the 2016 year are summarised in table 1.5.1. In accordance with the 2006 IPCC Guidelines, the key category analysis is performed once for the inventory including the LULUCF sector and then repeated for the inventory excluding the LULUCF sector. Non-LULUCF categories that are identified as key in the first analysis are still counted even when they are not identified as a key category when the LULUCF sector is included.

The key category analysis performed for the inventory differs from that produced in the CRF tables, because the level of aggregation of categories is adjusted to better reflect New Zealand's emissions profile. Specifically, a large proportion of emissions from the Energy and Agriculture sectors are disaggregated further than the key category analysis generated in the CRF tables, to allow for a more evenly proportioned analysis of categories.

Table 1.5.2(a) identifies that the major contributions to the level analysis of net emissions for 2016 are:

- CH_4 emissions from *Dairy cattle – enteric fermentation* (12.2 per cent)

- CO_2 emissions from *Road transportation – liquid fuels* (12.1 per cent)

- CO_2 removals from *Land converted to forest land* (11.8 per cent)

- CO_2 removals from *Forest land remaining forest land* (7.9 per cent).

As detailed in table 1.5.3(a), the key categories that were identified as having the largest relative influence on the trend, when compared with the average change in net emissions from 1990 to 2016, are:

- CO_2 removals from *Land converted to forest land* (16.7 per cent as a decrease)

- CH_4 emissions from *Sheep – enteric fermentation* (14.0 per cent as a decrease*)*

- CH_4 emissions from *Dairy cattle – enteric fermentation* (12.2 per cent as an increase)

- CO_2 emissions from *Road transportation – liquid fuels* (9.5 per cent as an increase).

Table 1.5.1 **Summary of New Zealand's key categories for the 2016 level assessment and the trend assessment for 1990 to 2016 (including and excluding LULUCF activities)**

Quantitative method used: IPCC Tier 1			
CRF category code	IPCC category	Gas	Criteria for identification[14]
Energy			
1.A.1.a	Energy Industries – Public Electricity and Heat Production Gaseous Fuels	CO_2	L1, T1
1.A.1.a	Energy Industries – Public Electricity and Heat Production Solid Fuels	CO_2	L1, T1
1.A.1.b	Energy Industries – Petroleum Refining Liquid Fuels	CO_2	L1, T1
1.A.1.b	Energy Industries – Petroleum Refining Gaseous Fuels	CO_2	T1
1.A.1.c	Energy Industries – Manufacture of Solid Fuels and Other Energy Industries Gaseous fuels	CO_2	L1, T1
1.A.2.c	Manufacturing Industries and Construction – Chemicals Gaseous Fuels	CO_2	L1, T1
1.A.2.d	Manufacturing Industries and Construction – Pulp, Paper and Print Gaseous Fuels	CO_2	L1
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Solid Fuels	CO_2	L1, T1
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Gaseous Fuels	CO_2	L1, T1
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Liquid Fuels	CO_2	L1, T1
1.A.2.f	Manufacturing Industries and Construction – Non-metallic Minerals Solid Fuels	CO_2	L1, T1
1.A.2.g.iii	Other (please specify) – Mining (excluding fuels) and Quarrying Liquid Fuels	CO_2	L1, T1

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[14] According to the 2006 IPCC Guidelines (IPCC, 2006b), L1 indicates a level assessment for a Tier 1 key category, and T1 indicates a trend assessment for a Tier 1 key category.

Quantitative method used: IPCC Tier 1			
CRF category code	**IPCC category**	**Gas**	**Criteria for identification[14]**
1.A.2.g.viii	Other (please specify) – Other (please specify) Liquid Fuels	CO_2	L1, T1
1.A.2.g.viii	Other (please specify) – Other (please specify) Solid Fuels	CO_2	T1
1.A.3.a	Domestic Aviation – Jet Kerosene	CO_2	L1, T1
1.A.3.b	Transport – Road Transportation Liquid Fuels	CO_2	L1, T1
1.A.3.b	Transport – Road Transportation Gaseous Fuels	CO_2	T1
1.A.3.d	Domestic Navigation – Residual Fuel Oil	CO_2	L1
1.A.4.a	Other Sectors – Commercial/Institutional Liquid Fuels	CO_2	L1, T1
1.A.4.a	Other Sectors – Commercial/Institutional Gaseous Fuels	CO_2	L1, T1
1.A.4.b	Other Sectors – Residential Gaseous Fuels	CO_2	L1, T1
1.A.4.b	Other Sectors – Residential Liquid Fuels	CO_2	L1
1.A.4.b	Other Sectors – Residential Solid Fuels	CO_2	T1
1.A.4.c	Other Sectors – Agriculture/Forestry/Fishing Liquid Fuels	CO_2	L1
1.B.1.a.1	Coal Mining and Handling – Underground Mines	CH_4	T1
1.B.2.b.5	Natural Gas – Distribution	CH_4	L1, T1
1.B.2.c.1.ii	Venting – Gas	CO_2	L1, T1
1.B.2.c.2.iii	Flaring – Combined	CO_2	L1, T1
1.B.2.d	Other (please specify) – Geothermal	CO_2	L1, T1
1.B.2.d	Other (please specify) – Geothermal	CH_4	T1
IPPU			
2.A.1	Mineral Industry – Cement Production	CO_2	L1
2.B.8	Chemical Industry – Petrochemical and Carbon Black Production	CH_4	T1
2.C.1	Metal Industry – Iron and Steel Production	CO_2	L1, T1
2.C.3	Metal Industry – Aluminium Production	CO_2	L1
2.C.3	Metal Industry – Aluminium Production	PFCs	T1
2.F.1	Product Uses as Substitutes for ODS – Refrigeration and Air Conditioning	HFCs	L1, T1
2.F.4	Product Uses as Substitutes for ODS – Aerosols	HFCs	T1
Agriculture			
3.A.1	Option A – Dairy Cattle	CH_4	L1, T1
3.A.1	Option A – Non-Dairy Cattle	CH_4	L1, T1
3.A.2	Other (please specify) – Sheep	CH_4	L1, T1
3.A.4	Other Livestock – Deer	CH_4	L1
3.A.4	Other Livestock – Goats	CH_4	T1
3.B.1.1	Option A – Dairy Cattle	CH_4	L1, T1
3.D.1.1	Direct N_2O Emissions From Managed Soils – Inorganic N Fertilisers	N_2O	L1, T1
3.D.1.3	Direct N_2O Emissions From Managed Soils – Urine and Dung Deposited by Grazing Animals	N_2O	L1, T1
3.D.1.4	Direct N_2O Emissions From Managed Soils – Crop Residues	N_2O	L1
3.D.2.1	Indirect N_2O Emissions From Managed Soils – Atmospheric Deposition	N_2O	L1
3.D.2.2	Indirect N_2O Emissions From Managed Soils – Nitrogen Leaching and Run-off	N_2O	L1
3.G	Agriculture – Liming	CO_2	L1
3.H	Agriculture – Urea Application	CO_2	L1, T1

Quantitative method used: IPCC Tier 1			
CRF category code	**IPCC category**	**Gas**	**Criteria for identification[14]**
LULUCF			
4.A.1	Forest Land – Forest Land Remaining Forest Land	CO_2	L1, T1
4.A.2	Forest Land – Land Converted to Forest Land	CO_2	L1, T1
4.B.1	Cropland – Cropland Remaining Cropland	CO_2	L1
4.C.1	Grassland – Grassland Remaining Grassland	CO_2	L1, T1
4.C.2	Grassland – Land Converted to Grassland	CO_2	L1, T1
4.G	Land Use, Land-Use Change and Forestry – Harvested Wood Products	CO_2	L1, T1
Waste			
5.A	Waste – Solid Waste Disposal	CH_4	L1, T1
5.D	Waste – Wastewater Treatment and Discharge	CH_4	L1

Note: L1 means a key category is identified under the level analysis – approach 1 and T1 is trend analysis – approach 1.

Table 1.5.2 (a & b) 2016 level assessment for New Zealand's key category analysis including LULUCF (a) and excluding LULUCF (b)

(a) IPCC Tier 1 category level assessment – including LULUCF (net emissions): 2016					
CRF category code	**IPCC category**	**Gas**	**2016 estimate (kt CO_2-e)**	**Level assessment (%)**	**Cumulative total (%)**
3.A.1	Option A – Dairy Cattle	CH_4	13,623.6	12.2	12.2
1.A.3.b	Transport – Road Transportation Liquid Fuels	CO_2	13,470.5	12.1	24.3
4.A.2	Forest Land – Land Converted to Forest Land	CO_2	−13,149.7	11.8	36.0
4.A.1	Forest Land – Forest Land Remaining Forest Land	CO_2	−8,787.5	7.9	43.9
3.A.2	Other (please specify) – Sheep	CH_4	8,412.6	7.5	51.4
4.G	Land Use, Land-Use Change and Forestry – Harvested Wood Products	CO_2	−5,946.4	5.3	56.7
3.D.1.3	Direct N_2O Emissions From Managed Soils – Urine and Dung Deposited by Grazing Animals	N_2O	5,503.3	4.9	61.7
3.A.1	Option A – Non-Dairy Cattle	CH_4	5,228.7	4.7	66.3
5.A	Waste – Solid Waste Disposal	CH_4	3,439.0	3.1	69.4
4.C.2	Grassland – Land Converted to Grassland	CO_2	3,070.8	2.7	72.2
1.A.1.a	Energy Industries – Public Electricity and Heat Production Gaseous Fuels	CO_2	2,586.9	2.3	74.5
1.A.2.c	Manufacturing Industries and Construction – Chemicals Gaseous Fuels	CO_2	1,939.5	1.7	76.2
2.C.1	Metal Industry – Iron and Steel Production	CO_2	1,712.1	1.5	77.8
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Solid Fuels	CO_2	1,496.5	1.3	79.1
3.D.1.1	Direct N_2O Emissions From Managed Soils – Inorganic N Fertilisers	N_2O	1,332.2	1.2	80.3
1.A.4.c	Other Sectors – Agriculture/Forestry/ Fishing Liquid Fuels	CO_2	1,321.7	1.2	81.5
4.C.1	Grassland – Grassland Remaining Grassland	CO_2	1,306.4	1.2	82.6
2.F.1	Product Uses as Substitutes for ODS – Refrigeration and Air Conditioning	HFCs	1,282.5	1.1	83.8
3.B.1.1	Option A – Dairy Cattle	CH_4	930.4	0.8	84.6

(a) IPCC Tier 1 category level assessment – including LULUCF (net emissions): 2016					
CRF category code	**IPCC category**	**Gas**	**2016 estimate (kt CO$_2$-e)**	**Level assessment (%)**	**Cumulative total (%)**
3.D.2.1	Indirect N$_2$O Emissions From Managed Soils – Atmospheric Deposition	N$_2$O	910.1	0.8	85.4
1.A.3.a	Domestic Aviation – Jet Kerosene	CO$_2$	893.7	0.8	86.2
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Gaseous Fuels	CO$_2$	864.3	0.8	87.0
1.A.1.b	Energy Industries – Petroleum Refining Liquid Fuels	CO$_2$	690.2	0.6	87.6
1.B.2.d	Other (please specify) – Geothermal	CO$_2$	659.1	0.6	88.2
3.H	Agriculture – Urea Application	CO$_2$	574.4	0.5	88.7
2.C.3	Metal Industry – Aluminium Production	CO$_2$	539.4	0.5	89.2
3.G	Agriculture – Liming	CO$_2$	514.4	0.5	89.7
1.A.2.g.iii	Other (please specify) – Mining (excluding fuels) and Quarrying Liquid Fuels	CO$_2$	510.5	0.5	90.1
3.D.2.2	Indirect N$_2$O Emissions From Managed Soils – Nitrogen Leaching and Run-off	N$_2$O	501.6	0.4	90.6
2.A.1	Mineral Industry – Cement Production	CO$_2$	486.4	0.4	91.0
3.A.4	Other Livestock – Deer	CH$_4$	465.0	0.4	91.4
1.A.4.a	Other Sectors – Commercial/ Institutional Liquid Fuels	CO$_2$	458.5	0.4	91.8
1.A.1.a	Energy Industries – Public Electricity and Heat Production Solid Fuels	CO$_2$	445.7	0.4	92.2
1.A.4.a	Other Sectors – Commercial/ Institutional Gaseous Fuels	CO$_2$	439.6	0.4	92.6
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Liquid Fuels	CO$_2$	411.2	0.4	93.0
1.A.2.d	Manufacturing Industries and Construction – Pulp, Paper and Print Gaseous Fuels	CO$_2$	359.2	0.3	93.3
1.A.4.b	Other Sectors – Residential Gaseous Fuels	CO$_2$	343.2	0.3	93.6
4.B.1	Cropland – Cropland Remaining Cropland	CO$_2$	340.5	0.3	93.9
1.A.3.d	Domestic Navigation – Residual Fuel Oil	CO$_2$	300.7	0.3	94.2
1.B.2.c.2.iii	Flaring – Combined	CO$_2$	294.5	0.3	94.5
1.A.2.f	Manufacturing Industries and Construction – Non-metallic Minerals Solid Fuels	CO$_2$	275.3	0.2	94.7
1.A.1.c	Energy Industries – Manufacture of Solid Fuels and Other Energy Industries Gaseous Fuels	CO$_2$	273.3	0.2	95.0
1.B.2.c.1.ii	Venting – Gas	CO$_2$	268.2	0.2	95.2

(b) IPCC Tier 1 category level assessment – excluding LULUCF (gross emissions): 2016					
CRF category code	**IPCC category**	**Gas**	**2016 estimate (kt CO$_2$-e)**	**Level assessment (%)**	**Cumulative total (%)**
3.A.1	Option A – Dairy Cattle	CH$_4$	13,623.6	17.3	17.3
1.A.3.b	Transport – Road Transportation Liquid Fuels	CO$_2$	13,470.5	17.1	34.4
3.A.2	Other (please specify) – Sheep	CH$_4$	8,412.6	10.7	45.1
3.D.1.3	Direct N$_2$O Emissions From Managed Soils – Urine and Dung Deposited by Grazing Animals	N$_2$O	5,503.3	7.0	52.1
3.A.1	Option A – Non-Dairy Cattle	CH$_4$	5,228.7	6.6	58.7
5.A	Waste – Solid Waste Disposal	CH$_4$	3,439.0	4.4	63.1

(b) IPCC Tier 1 category level assessment – excluding LULUCF (gross emissions): 2016					
CRF category code	**IPCC category**	**Gas**	**2016 estimate (kt CO$_2$-e)**	**Level assessment (%)**	**Cumulative total (%)**
1.A.1.a	Energy Industries – Public Electricity and Heat Production Gaseous Fuels	CO$_2$	2,586.9	3.3	66.4
1.A.2.c	Manufacturing Industries and Construction – Chemicals Gaseous Fuels	CO$_2$	1,939.5	2.5	68.9
2.C.1	Metal Industry – Iron and Steel Production	CO$_2$	1,712.1	2.2	71.0
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Solid Fuels	CO$_2$	1,496.5	1.9	72.9
3.D.1.1	Direct N$_2$O Emissions From Managed Soils – Inorganic N Fertilisers	N$_2$O	1,332.2	1.7	74.6
1.A.4.c	Other Sectors – Agriculture/Forestry/ Fishing Liquid Fuels	CO$_2$	1,321.7	1.7	76.3
2.F.1	Product Uses as Substitutes for ODS – Refrigeration and Air Conditioning	HFCs	1,282.5	1.6	77.9
3.B.1.1	Option A – Dairy Cattle	CH$_4$	930.4	1.2	79.1
3.D.2.1	Indirect N$_2$O Emissions From Managed Soils – Atmospheric Deposition	N$_2$O	910.1	1.2	80.3
1.A.3.a	Domestic Aviation – Jet Kerosene	CO$_2$	893.7	1.1	81.4
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Gaseous Fuels	CO$_2$	864.3	1.1	82.5
1.A.1.b	Energy Industries – Petroleum Refining Liquid Fuels	CO$_2$	690.2	0.9	83.4
1.B.2.d	Other (please specify) – Geothermal	CO$_2$	659.1	0.8	84.2
3.H	Agriculture – Urea Application	CO$_2$	574.4	0.7	84.9
2.C.3	Metal Industry – Aluminium Production	CO$_2$	539.4	0.7	85.6
3.G	Agriculture – Liming	CO$_2$	514.4	0.7	86.3
1.A.2.g.iii	Other (please specify) – Mining (excluding fuels) and Quarrying Liquid Fuels	CO$_2$	510.5	0.6	86.9
3.D.2.2	Indirect N$_2$O Emissions From Managed Soils – Nitrogen Leaching and Run-off	N$_2$O	501.6	0.6	87.6
2.A.1	Mineral Industry – Cement Production	CO$_2$	486.4	0.6	88.2
3.A.4	Other livestock – Deer	CH$_4$	465.0	0.6	88.8
1.A.4.a	Other Sectors – Commercial/ Institutional Liquid Fuels	CO$_2$	458.5	0.6	89.4
1.A.1.a	Energy Industries – Public Electricity and Heat Production Solid Fuels	CO$_2$	445.7	0.6	89.9
1.A.4.a	Other Sectors – Commercial/ Institutional Gaseous Fuels	CO$_2$	439.6	0.6	90.5
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Liquid Fuels	CO$_2$	411.2	0.5	91.0
1.A.2.d	Manufacturing Industries and Construction – Pulp, Paper and Print Gaseous Fuels	CO$_2$	359.2	0.5	91.5
1.A.4.b	Other Sectors – Residential Gaseous Fuels	CO$_2$	343.2	0.4	91.9
1.A.3.d	Domestic Navigation – Residual Fuel Oil	CO$_2$	300.7	0.4	92.3
1.B.2.c.2.iii	Flaring – Combined	CO$_2$	294.5	0.4	92.7
1.A.2.f	Manufacturing Industries and Construction – Non-metallic Minerals Solid Fuels	CO$_2$	275.3	0.3	93.0
1.A.1.c	Energy Industries – Manufacture of Solid Fuels and Other Energy Industries Gaseous Fuels	CO$_2$	273.3	0.3	93.3
1.B.2.c.1.ii	Venting – Gas	CO$_2$	268.2	0.3	93.7
5.D	Waste – Wastewater Treatment and Discharge	CH$_4$	266.0	0.3	94.0

	(b) IPCC Tier 1 category level assessment – excluding LULUCF (gross emissions): 2016				
CRF category code	IPCC category	Gas	2016 estimate (kt CO$_2$-e)	Level assessment (%)	Cumulative total (%)
3.D.1.4	Direct N$_2$O Emissions From Managed Soils – Crop Residues	N$_2$O	252.6	0.3	94.3
1.A.4.b	Other Sectors – Residential Liquid Fuels	CO$_2$	206.4	0.3	94.6
1.A.2.g.viii	Other (please specify) – Other (please specify) Liquid Fuels	CO$_2$	200.4	0.3	94.9
1.B.2.b.5	Natural Gas – Distribution	CH$_4$	200.1	0.3	95.1

Table 1.5.3 (a & b) 1990–2016 trend assessment for New Zealand's key category analysis including LULUCF (a) and excluding LULUCF (b)

	(a) IPCC Tier 1 category trend assessment – including LULUCF (net emissions)						
CRF category code	IPCC category	Gas	1990 estimate (kt CO$_2$-e)	2016 estimate (kt CO$_2$-e)	Trend assessment	Absolute contribution to trend (%)	Absolute cumulative total (%)
4.A.2	Forest Land – Land Converted to Forest Land	CO$_2$	−19,911.5	−13,149.7	0.074	16.7	16.7
3.A.2	Other (please specify) – Sheep	CH$_4$	14,361.3	8,412.6	0.062	14.0	30.7
3.A.1	Option A – Dairy Cattle	CH$_4$	5,951.6	13,623.6	0.054	12.2	42.9
1.A.3.b	Transport – Road Transportation Liquid Fuels	CO$_2$	7,164.6	13,470.5	0.042	9.5	52.4
4.G	Land Use, Land-Use Change and Forestry – Harvested Wood Products	CO$_2$	−2,072.9	−5,946.4	0.028	6.4	58.8
4.C.2	Grassland – Land Converted to Grassland	CO$_2$	232.1	3,070.8	0.022	5.0	63.8
1.A.1.c	Energy Industries – Manufacture of Solid Fuels and Other Energy Industries Gaseous Fuels	CO$_2$	1,720.1	273.3	0.013	3.0	66.8
4.A.1	Forest Land – Forest Land Remaining Forest Land	CO$_2$	−9,143.7	−8,787.5	0.012	2.8	69.6
1.A.2.c	Manufacturing Industries and Construction – Chemicals Gaseous Fuels	CO$_2$	528.7	1,939.5	0.011	2.4	72.0
2.F.1	Product Uses as Substitutes for ODS – Refrigeration and Air Conditioning	HFCs	0.0	1,282.5	0.010	2.3	74.3
3.A.1	Option A – Non-Dairy Cattle	CH$_4$	5,737.5	5,228.7	0.010	2.3	76.5
3.D.1.1	Direct N$_2$O Emissions From Managed Soils – Inorganic N Fertilisers	N$_2$O	230.3	1,332.2	0.008	1.9	78.4
2.C.3	Metal Industry – Aluminium Production	PFCs	909.9	48.7	0.008	1.7	80.2
1.A.1.a	Energy Industries – Public Electricity and Heat Production Gaseous Fuels	CO$_2$	3,011.8	2,586.9	0.007	1.5	81.6
1.A.2.g.viii	Other (please specify) – Other (please specify) Solid Fuels	CO$_2$	731.1	92.0	0.006	1.3	83.0
4.C.1	Grassland – Grassland Remaining Grassland	CO$_2$	521.3	1,306.4	0.006	1.3	84.2
5.A	Waste – Solid Waste Disposal	CH$_4$	3,510.9	3,439.0	0.004	1.0	85.2
3.H	Agriculture – Urea Application	CO$_2$	39.2	574.4	0.004	0.9	86.1

(a) IPCC Tier 1 category trend assessment – including LULUCF (net emissions)							
CRF category code	IPCC category	Gas	1990 estimate (kt CO₂-e)	2016 estimate (kt CO₂-e)	Trend assessment	Absolute contribution to trend (%)	Absolute cumulative total (%)
3.B.1.1	Option A – Dairy Cattle	CH₄	390.1	930.4	0.004	0.9	87.0
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Solid Fuels	CO₂	938.6	1,496.5	0.003	0.8	87.8
1.B.2.d	Other (please specify) – Geothermal	CO₂	228.6	659.1	0.003	0.7	88.5
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Gaseous Fuels	CO₂	445.5	864.3	0.003	0.6	89.1
1.A.4.b	Other Sectors – Residential Solid Fuels	CO₂	344.9	31.8	0.003	0.6	89.8
3.D.1.3	Direct N₂O Emissions From Managed Soils – Urine and Dung Deposited by Grazing Animals	N₂O	5,131.8	5,503.3	0.002	0.6	90.3
2.C.1	Metal Industry – Iron and Steel Production	CO₂	1,306.7	1,712.1	0.002	0.4	90.7
1.B.1.a.1	Coal Mining and Handling – Underground Mines	CH₄	289.6	113.5	0.002	0.4	91.1
3.A.4	Other Livestock – Goats	CH₄	196.6	22.7	0.002	0.4	91.5
1.A.1.b	Energy Industries – Petroleum Refining Liquid Fuels	CO₂	778.9	690.2	0.002	0.3	91.8
1.A.4.a	Other Sectors – Commercial/Institutional Gaseous Fuels	CO₂	236.1	439.6	0.001	0.3	92.1
1.B.2.c.2.iii	Flaring – Combined	CO₂	114.4	294.5	0.001	0.3	92.4
1.A.3.b	Transport – Road Transportation Gaseous Fuels	CO₂	140.8	0.9	0.001	0.3	92.7
1.A.2.f	Manufacturing Industries and Construction – Non-metallic Minerals Solid Fuels	CO₂	382.9	275.3	0.001	0.3	93.0
1.A.1.b	Energy Industries – Petroleum Refining Gaseous Fuels	CO₂	0.0	157.1	0.001	0.3	93.2
1.B.2.c.1.ii	Venting – Gas	CO₂	109.3	268.2	0.001	0.3	93.5
1.A.2.g.viii	Other (please specify) – Other (please specify) Liquid Fuels	CO₂	51.7	200.4	0.001	0.3	93.7
1.A.2.g.iii	Other (please specify) – Mining (excluding fuels) and Quarrying Liquid Fuels	CO₂	331.5	510.5	0.001	0.2	94.0
1.A.4.b	Other Sectors – Residential Gaseous Fuels	CO₂	185.6	343.2	0.001	0.2	94.2
1.A.3.a	Domestic Aviation – Jet Kerosene	CO₂	892.6	893.7	0.001	0.2	94.4
1.B.2.b.5	Natural Gas – Distribution	CH₄	277.5	200.1	0.001	0.2	94.6
1.B.2.d	Other (please specify) – Geothermal	CH₄	54.8	172.8	0.001	0.2	94.8
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Liquid Fuels	CO₂	265.9	411.2	0.001	0.2	95.0

CRF category code	IPCC category	Gas	1990 estimate (kt CO$_2$-e)	2016 estimate (kt CO$_2$-e)	Trend assessment	Absolute contribution to trend (%)	Absolute cumulative total (%)
3.A.2	Other (please specify) – Sheep	CH$_4$	14,361.3	8,412.6	0.093	22.5	22.5
3.A.1	Option A – Dairy Cattle	CH$_4$	5,951.6	13,623.6	0.069	16.7	39.1
1.A.3.b	Transport – Road Transportation Liquid Fuels	CO$_2$	7,164.6	13,470.5	0.052	12.6	51.7
1.A.1.c	Energy Industries – Manufacture of Solid Fuels and Other Energy Industries Gaseous Fuels	CO$_2$	1,720.1	273.3	0.019	4.6	56.3
3.A.1	Option A – Non-Dairy Cattle	CH$_4$	5,737.5	5,228.7	0.017	4.2	60.5
1.A.2.c	Manufacturing Industries and Construction – Chemicals Gaseous Fuels	CO$_2$	528.7	1,939.5	0.014	3.4	63.8
2.F.1	Product Uses as Substitutes for ODS – Refrigeration and Air Conditioning	HFCs	0.0	1,282.5	0.014	3.3	67.1
3.D.1.1	Direct N$_2$O Emissions From Managed Soils – Inorganic N Fertilisers	N$_2$O	230.3	1,332.2	0.011	2.7	69.8
2.C.3	Metal Industry – Aluminium Production	PFCs	909.9	48.7	0.011	2.7	72.5
1.A.1.a	Energy Industries – Public Electricity and Heat Production Gaseous Fuels	CO$_2$	3,011.8	2,586.9	0.011	2.6	75.1
1.A.2.g.viii	Other (please specify) – Other (please specify) Solid Fuels	CO$_2$	731.1	92.0	0.008	2.0	77.1
5.A	Waste – Solid Waste Disposal	CH$_4$	3,510.9	3,439.0	0.008	2.0	79.0
3.D.1.3	Direct N$_2$O Emissions From Managed Soils – Urine and Dung Deposited by Grazing Animals	N$_2$O	5,131.8	5,503.3	0.007	1.6	80.7
3.H	Agriculture – Urea Application	CO$_2$	39.2	574.4	0.006	1.4	82.0
3.B.1.1	Option A – Dairy Cattle	CH$_4$	390.1	930.4	0.005	1.2	83.2
1.B.2.d	Other (please specify) – Geothermal	CO$_2$	228.6	659.1	0.004	1.0	84.2
1.A.4.b	Other Sectors – Residential Solid Fuels	CO$_2$	344.9	31.8	0.004	1.0	85.2
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Solid Fuels	CO$_2$	938.6	1,496.5	0.004	1.0	86.1
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Gaseous Fuels	CO$_2$	445.5	864.3	0.004	0.8	87.0
1.A.1.b	Energy Industries – Petroleum Refining Liquid Fuels	CO$_2$	778.9	690.2	0.003	0.6	87.6
1.B.1.a.1	Coal Mining and Handling – Underground Mines	CH$_4$	289.6	113.5	0.002	0.6	88.2
3.A.4	Other Livestock – Goats	CH$_4$	196.6	22.7	0.002	0.5	88.7

(b) IPCC Tier 1 category trend assessment – excluding LULUCF (gross emissions)

(b) IPCC Tier 1 category trend assessment – excluding LULUCF (gross emissions)							
CRF category code	IPCC category	Gas	1990 estimate (kt CO_2-e)	2016 estimate (kt CO_2-e)	Trend assessment	Absolute contribution to trend (%)	Absolute cumulative total (%)
1.A.2.f	Manufacturing Industries and Construction – Non-metallic Minerals Solid Fuels	CO_2	382.9	275.3	0.002	0.5	89.2
1.A.3.a	Domestic Aviation – Jet Kerosene	CO_2	892.6	893.7	0.002	0.4	89.7
1.A.3.b	Transport – Road Transportation Gaseous Fuels	CO_2	140.8	0.9	0.002	0.4	90.1
1.B.2.c.2.iii	Flaring – Combined	CO_2	114.4	294.5	0.002	0.4	90.5
1.A.4.a	Other Sectors – Commercial/Institutional Gaseous Fuels	CO_2	236.1	439.6	0.002	0.4	90.9
1.A.1.b	Energy Industries – Petroleum Refining Gaseous Fuels	CO_2	0.0	157.1	0.002	0.4	91.3
2.C.1	Metal Industry – Iron and Steel Production	CO_2	1,306.7	1,712.1	0.002	0.4	91.7
1.A.4.a	Other Sectors – Commercial/Institutional Liquid Fuels	CO_2	500.6	458.5	0.001	0.4	92.0
1.A.2.g.viii	Other (please specify) – Other (please specify) Liquid Fuels	CO_2	51.7	200.4	0.001	0.4	92.4
1.B.2.c.1.ii	Venting – Gas	CO_2	109.3	268.2	0.001	0.4	92.8
1.B.2.b.5	Natural Gas – Distribution	CH_4	277.5	200.1	0.001	0.3	93.1
1.A.1.a	Energy Industries – Public Electricity and Heat Production Solid Fuels	CO_2	474.8	445.7	0.001	0.3	93.4
1.A.4.b	Other Sectors – Residential Gaseous Fuels	CO_2	185.6	343.2	0.001	0.3	93.7
1.A.2.g.iii	Other (please specify) – Mining (excluding fuels) and Quarrying Liquid Fuels	CO_2	331.5	510.5	0.001	0.3	94.0
1.B.2.d	Other (please specify) – Geothermal	CH_4	54.8	172.8	0.001	0.3	94.3
2.F.4	Product Uses as Substitutes for ODS – Aerosols	HFCs	0.0	96.2	0.001	0.2	94.5
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Liquid Fuels	CO_2	265.9	411.2	0.001	0.2	94.8
2.B.8	Chemical Industry – Petrochemical and Carbon Black Production	CH_4	27.6	125.3	0.001	0.2	95.0

Note: Removals from the LULUCF sector are shown as negatives in this table. The absolute values for those removals were used for the calculations.

1.5.2   LULUCF activities under the Kyoto Protocol

Key categories under the Kyoto Protocol are identified by looking at the assessment of similar categories within the LULUCF sector as reported under the Convention. In 2016, *Afforestation and reforestation*, *Deforestation* and *Forest management* were all identified as key categories in both the level and trend assessment.

Table 1.5.4   Key categories under the Kyoto Protocol and corresponding categories under the Convention

Category as reported under the Convention	Article 3.3 and 3.4 activities under the Kyoto Protocol
Land Converted to Forest Land	Afforestation and reforestation
Land Converted to Grassland	Deforestation
Forest Land Remaining Forest Land	Forest management

1.6   Inventory uncertainty

1.6.1   Reporting under the Convention

Uncertainty estimates are an essential element of a complete inventory. The purpose of uncertainty information is not to dispute the validity of the inventory estimates but to help prioritise efforts to improve the accuracy of inventories and guide decisions on methodological choice (IPCC, 2006b). Inventories prepared in accordance with the 2006 IPCC Guidelines will typically contain a wide range of emission estimates, varying from carefully measured and demonstrably complete data on emissions, to order-of-magnitude estimates for highly variable emissions such as N_2O fluxes from soils and waterways (IPCC, 2006b).

In this inventory submission, New Zealand included a Tier 1 uncertainty analysis of the aggregated figures, as required by the Convention inventory reporting guidelines (UNFCCC, 2013a) and 2006 IPCC Guidelines (IPCC, 2006b). Uncertainties in the categories are combined to provide uncertainty estimates for all emissions for the latest reporting year and the uncertainty in the trend over time. Uncertainties for net emissions, where removals under LULUCF categories have been included as an absolute value, are included in annex 2 (table A2.1.1), and gross emissions excluding LULUCF are in annex 2 (table A2.1.2).

In most instances, the uncertainty values are determined by analysis of emission factors or activity data using expert judgement from sectoral or industry experts, or by referring to uncertainty ranges provided in the 2006 IPCC Guidelines (IPCC, 2006b). The uncertainty for CH_4 emissions from enteric fermentation was calculated by expressing the coefficient of variation according to the standard error of the CH_4 yield. A Monte Carlo simulation has been used to determine uncertainty for N_2O from agricultural soils. For the 2016 data, the uncertainty in the annual estimate was calculated using the 95 per cent confidence interval determined from the Monte Carlo simulation as a percentage of the mean value.

Gross emissions

Uncertainty in 2016

The uncertainty in gross emissions (excluding emissions and removals from the LULUCF sector) is ±9.5 per cent. This is a decrease of ±0.3 percentage points from 2015. Emissions of CH_4 from *Enteric fermentation* (±5.6 per cent), N_2O from *Agricultural soils* (±6.0 per cent) and CH_4 from *Solid waste disposal* (±4.6 per cent) categories contributed the highest levels of uncertainty to gross emissions in 2016. The uncertainty in these categories reflects the inherent variability when estimating emissions from natural systems.

Uncertainty in the trend

The trend uncertainty in gross emissions (excluding emissions and removals from the LULUCF sector) from 1990 to 2016 is ±14.2 per cent. This is a decrease of ±0.2 percentage points from 2015. The decrease in trend uncertainty is a result of revised activity and emission factor uncertainties.

Net emissions

Uncertainty in 2016

The uncertainty for New Zealand's inventory, including emissions and removals from the LULUCF sector, in 2016 is ±11.4 per cent. Emissions of CO_2 from the *Forest land* category were a major contribution to the net uncertainty for 2016, at ±8.3 per cent.

This is no change in uncertainty of net emissions from 2015.

Uncertainty in the trend

When emissions and removals from the LULUCF sector are included, the overall uncertainty in the trend from 1990 to 2016 is ±8.1 per cent. This is an increase of ±0.2 percentage points from 2015. Updated uncertainty estimates for activity data have contributed to this change.

1.6.2 LULUCF activities under the Kyoto Protocol

The combined uncertainty for net emissions from *Afforestation and reforestation* category activities in 2016 is ±23.7 per cent. The uncertainty for net emissions from the *Deforestation* category in 2016 is ±1.7 per cent. The uncertainty for net emissions from the *Forest management* category in 2016 is ±58.3 per cent. The uncertainty introduced into net emissions from *Forest management* is high because this category has large emissions from harvesting and large removals from forest growth leaving relatively small net change. Because the uncertainty is calculated on emissions and removals relative to net change, this results in a large uncertainty figure. Combining these uncertainties gives a total uncertainty estimate for LULUCF activities under the Kyoto Protocol of ±62.9 per cent.

Please refer to chapter 11, section 11.4.1, for further information on the uncertainty analysis for activities under the Kyoto Protocol and how this uncertainty analysis relates to the LULUCF sector.

1.7   Inventory completeness

1.7.1   Reporting under the Convention

The inventory for the period 1990 to 2016 is complete. In accordance with the 2006 IPCC Guidelines, New Zealand has focused its resources for inventory development in the key categories and non-key categories that are mandatory (IPCC, 2006b). Additional information regarding the use of the notation key 'NE' (not estimated) in the context of Article 37(b) of the UNFCCC reporting guidelines (UNFCCC, 2013b) is presented in annex 6.

1.7.2   LULUCF activities under the Kyoto Protocol

New Zealand has included all carbon pools in reporting for Article 3.3 activities and Article 3.4 *Forest management* activities under the Kyoto Protocol.

1.8   National registry

The national registry (New Zealand Emissions Trading Register or the Register), is New Zealand's online facility to manage the accounting, reporting and reconciliation of emissions, unit holdings and transactions as part of the NZ ETS. The EPA is designated as the agency responsible for the implementation and operation of New Zealand's national

registry under the Kyoto Protocol. The Register is electronic and accessible via the internet (www.emissionsregister.govt.nz).

In January 2008, New Zealand's national registry was issued with New Zealand's assigned amount of 309,564,733 metric tonnes CO_2-e. The commitment period reserve for the CP1 of 278,608,260 metric tonnes CO_2-e is 90 per cent of the assigned amount, and was fixed after the initial review in 2007. This is the number of units the national registry must hold during a commitment period.

At the end of the CP1 of the Kyoto Protocol (2008–12), New Zealand retired Kyoto units in its registry equal to its reported emissions and submitted its true-up report (available on both the MfE and UNFCCC websites) to meet CP1 Kyoto Protocol obligations. New Zealand does not have a target under the second commitment period (CP2) of the Kyoto Protocol. Instead, New Zealand joins countries that have made international pledges under the Convention (the Kyoto Protocol's parent body). As such, New Zealand has no assigned amount for the CP2; however, New Zealand has chosen to maintain a registry connected to the International Transaction Log (ITL). This is required because the Register continues to hold Kyoto Units, and these are required to be able to be reconciled via the ITL. New Zealand has also committed to the Kyoto accounting approach for the CP2.

Although most international unit transfers of Kyoto Units are no longer possible from or to the Register, it is still possible for direct issuance of Certified Emission Reduction Units (CERs) from the Clean Development Mechanism and voluntary unit Cancellation transactions to occur. Details of these transactions are included in the Standard Electronic Format (SEF) tables submitted to the UNFCCC as part of our National Inventory reporting. Also, changes to international trading may occur after the CP2 of the Kyoto Protocol ends and the new Paris Agreement comes into force.

New Zealand replaced its registry system in August 2016. Testing and a review involving UNFCCC secretariat staff took place during the period leading up to go-live of the new Register. No additional material changes have been made to New Zealand's national registry since the 2017 submission.

At the beginning of the calendar year 2017, New Zealand's national registry held 308,343,858 CP1 assigned amount units, 110,744,560 CP1 emissions reduction units, 21,685,909 CP1 certified emission reduction units and 100,845,399 CP1 removal units. The number and mix of units held at the end of 2017 were the same as at the beginning of 2017 because no international transactions occurred during this period and this value includes the units retired to meet CP1 obligations. No CP2 units were held by New Zealand in 2017.

New Zealand's national registry did not hold any temporary certified emission reduction units or long-term certified emissions reduction units during 2017.

For further information, please refer to chapters 12 and 14 of this inventory submission and the standard electronic format tables on New Zealand Emissions Trading Register holdings and transactions that were submitted to the UNFCCC along with this inventory submission.

1.9 New Zealand's Emissions Trading Scheme

The NZ ETS is New Zealand's principal policy response to climate change. The following sections explain how New Zealand's national registry was leveraged to create the NZ ETS register and how the data collected for the NZ ETS have been used to verify CO_2 emissions in the Energy and IPPU sectors.

The NZ ETS was reviewed between late 2015 and early 2017. As a result of the review, legislation was passed that set out a phased increase in surrender obligations from the start of calendar year 2017. This change will therefore not affect emissions reported in the 2018 inventory submission.

1.9.1 New Zealand Units

In 2008, New Zealand established the NZ ETS. The NZ ETS places obligations on certain industries to account for the greenhouse gas emissions that result from their activities. The Climate Change Response Act 2002 states the sectors that are mandatory participants in the NZ ETS – those that account for emissions and that have an obligation to surrender emission units. The NZ ETS is based on trading units that represent 1 tonne of CO_2-e. The primary unit of trade is the New Zealand Unit (NZU), which is the unit created and distributed by the New Zealand Government.

NZUs are issued into the New Zealand registry by the Government. New Zealand decided to leverage off and extend its national registry to incorporate the requirements under the NZ ETS. Most significantly, this meant the issuance of NZUs into the national registry and creation of Crown holding accounts to hold these NZUs. These changes were made in the early part of 2009 and were reported in the 2010 inventory submission.

The Government allocates NZUs to eligible individuals or firms in specific sectors, or awards them to individuals or firms conducting approved removal activities (such as the establishment of forests). The Government also has the authority to auction NZUs, but has not yet done so. The methods for estimating emissions are set out in regulations prescribed under the Climate Change Response Act 2002.

1.9.2 Verification

NZ ETS participants are required to record and report the greenhouse gas emissions for which they have obligations or the removals for which they can claim NZUs. Participants with obligations are also required to surrender NZUs to cover their emissions annually. How participants estimate their emissions is set out in the regulations prescribed under the Climate Change Response Act 2002. The schedule for sectors entering the NZ ETS is detailed in table 1.9.1.

For this submission, data collected for the NZ ETS were used to verify the inventory estimates for CO_2 emissions in the Energy and IPPU sectors (see chapters 3 and 4 for further detail of the verification). Data from the NZ ETS were used as a primary source in the IPPU sector for the cement and lime industries, and in the Waste sector for activity data on municipal waste disposal. Data reported under the Waste Minimisation Act 2008 have been used for verification and as primary data for smaller landfill sites (see chapter 7 for details).

The NZ ETS data are also used for LULUCF and Kyoto Protocol reporting. Forest age, area and deforestation as reported under the NZ ETS are used for verifying the areas of pre-1990 planted forest, post-1989 forest and deforestation.

Table 1.9.1   **Dates for sector entry into the New Zealand Emissions Trading Scheme**

Sector	Voluntary reporting	Mandatory reporting	Obligations
Forestry	–	–	1 January 2008
Transport fuels	–	1 January 2010	1 July 2010
Electricity production	–	1 January 2010	1 July 2010
IPPU	–	1 January 2010	1 July 2010
Synthetic gases	1 January 2011	1 January 2012	1 January 2013
Waste	1 January 2011	1 January 2012	1 January 2013
Agriculture	1 January 2011	1 January 2012	–

1.10 Improvements introduced

An important part of producing the inventory is improving the accuracy of estimates for emissions and removals. In this inventory, a number of recalculations have been made to the estimates due to improvements in:

- activity data

- emission factors and/or other parameters

- methodology

- availability of activity data and emission factors for sources that were previously reported as 'NE' (not estimated) because of insufficient data.

It is good practice to recalculate the whole time series, from 1990 to the latest reported year in the inventory, to ensure consistency across the time series. This means estimates of emissions in a given submission may differ from emissions reported in previous submissions. There may be exceptions to recalculating the entire time series and, where this has occurred, explanations are provided.

Chapter 10 provides a summary of all recalculations made to estimates of emissions and removals.

Improvements made to New Zealand's national registry are included in chapter 14.

No changes have been made in the legal or institutional arrangements in the national inventory system since the last (2017) inventory submission. However, changes are planned to the national inventory system in the period 2018 to 2020, as a result of New Zealand extending its ratification of the Convention and the Paris Agreement to include Tokelau.

New Zealand ratified the Paris Agreement on 4 October 2016, specifically excluding Tokelau. On 14 November 2017, New Zealand extended its ratification of the Convention and of the Paris Agreement to include Tokelau, with implications for including Tokelau in the obligatory climate change reporting managed by MfE. Delivering on this obligation, inter alia, means that New Zealand's greenhouse gas inventory would include the greenhouse gas estimates from Tokelau (see chapter 13).

Energy

A number of planned improvements were implemented for the Energy sector in the 2018 submission. Most of the changes to the Energy sector in the 2018 submission focused on recommendations from the expert review team as a result of the review of the 2016 and 2017 submissions of the inventory. Specific improvements include:

- disaggregation of activity data for fisheries and off-road activities within the category *Agriculture/forestry/fishing*

- validation of road transport fuel statistics with vehicle kilometre data by vehicle type.

The following improvements are planned for future submissions of the inventory:

- as the data set of verified unique emission factors for individual geothermal fields and coal mines obtained from the NZ ETS grows, New Zealand will consider methods of incorporating this data to improve the accuracy of estimates for the Energy sector.

All source-specific planned improvements are discussed in their corresponding sections in chapter 3.

IPPU

In the *Product uses as substitutes for ODS* source category, activity data and emissions for refrigeration and air conditioning are disaggregated by sub-application. For submissions up to 2015, only mobile air conditioning was reported separately.

For this submission, emissions from refrigeration and air conditioning for all years have been recalculated to better account for changes in the bank of refrigerant in operating equipment, refrigerant stockpiled by importers, and the timing of disposal.

Emissions from SF_6 in electrical equipment, in the *Other product manufacture and use* source category, have been recalculated due to better information on electrical equipment, but this has only a minor impact on the reported emissions.

Section 4.1.7 in chapter 4 contains more details about improvements and recalculations for the IPPU sector.

Agriculture

An improvement to the methodology used to estimate the areas of barley, oat and wheat crop residues that were burned between 2005 and 2016 was implemented in New Zealand's agriculture inventory for the 2018 submission. This change was proposed because a significant fall in the total crop residue burning area recorded for 2015 uncovered shortcomings in the previous method used to estimate crop residue burning areas for barley, oats and wheat. The Agriculture Inventory Advisory Panel met on 8 November 2017 and recommended that this proposed change be adopted. The impact of this improvement on reported emissions is minor.

Two errors were also identified and have been corrected for this submission.

- An overestimation of the amount of nitrogen retained in the production of wool by sheep was identified. Once corrected, total agricultural emission figures are 1.8 per cent higher in 2015 and 4.5 per cent higher in 1990 than in the 2017 inventory submission.

- During 2017, a further error was identified in the equation used to estimate the populations of deer in June for each year. The impact of this correction on reported emissions is minor.

Further details on these changes are outlined in chapter 5 (sections 5.1.5, 5.1.7, 5.2.5 and 5.5.5) and chapter 10 (section 10.1.3) of this inventory submission.

LULUCF

The main differences between this submission and estimates of New Zealand's LULUCF net removals reported in the previous inventory submission result from the following (in decreasing order of magnitude).

- New Zealand's *Harvested wood products* estimates now include market specific activity data and emission factors for exported raw materials.

- The post-1989 planted forest yield table has been revised for the 2018 submission. The revised yield table is based on three measurements of post-1989 planted forest permanent sample plots carried out in 2007–08, 2011–12 and the transition to a continuous inventory in 2016. The analysis of the data collected has provided a plot-based estimate of carbon stock and mean carbon density within this forest type.

- Emissions estimates from peat extraction are reported for the first time.

- An estimate for controlled burning in the *Grassland remaining grassland* category is provided for the first time in this submission. This activity involves the clearance of vegetation for pasture regeneration.

- Continued improvements have been made to the 1990, 2008 and 2012 land use maps. These improvements have led to a reduction in the total area of *Pre-1990 natural forest* (5,540 hectares) and *Post-1989 natural forest* (1,108 hectares) following a review that showed these areas were not succeeding to forest and are more accurately classified as *Grassland with woody biomass*.

Section 6.1.4 and the land use category specific sections in chapter 6 contain more details about improvements and recalculations for the LULUCF sector.

Waste

Numerous changes and improvements have been made in the Waste sector resulting in recalculations for several categories. These improvements are a combination of planned improvements and also responses to issues found during reviews of previous submissions. In addition, this chapter has been revised to improve the transparency of how emissions are calculated.

The most significant improvements have been made to the *Unmanaged waste disposal sites* source category. These resulted in a reduction in emissions for the waste sector of an average of 240 kt CO_2-e per year across the time series. The inclusion of an additional survey of farm wastes resulted in the downward revision of emissions from farm fills, and this change had the largest impact on emissions for the sector. Other changes in this category include revising methods for scaling data to a national level and revised waste composition.

Several corrections were also made to other categories in the Waste sector, including small improvements in activity data for the *Wastewater* category.

Further details can be found in chapter 7 and chapter 10 (section 10.1.5).

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Chapter 2: Trends in greenhouse gas emissions

2.1 Emission trends for aggregated greenhouse gas emissions

This chapter describes emission trends by sector and greenhouse gas (GHG).

2.1.1 National trends in greenhouse gas emissions

Gross emissions

Gross emissions include those from the Energy, Industrial Processes and Product Use (IPPU), Agriculture and Waste sectors but do not include net removals from the Land Use, Land-Use Change and Forestry (LULUCF) sector. Reporting of gross emissions excluding the LULUCF sector is consistent with the reporting under the United Nations Framework Convention on Climate Change (the Convention).

1990–2016

In 1990, New Zealand's gross GHG emissions were 65,814.8 kilotonnes carbon dioxide equivalent (kt CO_2-e). Between 1990 and 2016, gross GHG emissions increased by 12,912.1 kt CO_2-e (19.6 per cent) to 78,726.9 kt CO_2-e in 2016 (figure 2.1.1). From 1990 to 2016, the average annual growth in gross emissions was 0.7 per cent.

The emission categories that contributed the most to this increase in gross emissions were: *Enteric fermentation*[15] *from dairy cattle*, *Road transportation*, *Manufacturing industries and construction* (especially the categories *Chemicals* and *Food processing, beverages and tobacco*) and *Agricultural soils*.

2015–2016

New Zealand's gross emissions between 2015 and 2016 decreased by 1,976.1 kt CO_2-e (2.4 per cent). This reflected emissions decreases across all contributing sectors. The Energy sector showed the largest decrease (by 1,078.6 kt CO_2-e). This is primarily due to a decrease of emissions from the category *Public electricity and heat production* resulting from a lower use of thermal fuels (coal and gas) for electricity generation and increased hydroelectric generation. There was also a 174.3 kt CO_2-e decrease in emissions for the category *Fugitive emissions from fuels* due to decreased emissions from venting and flaring.

The emissions decrease in the Agriculture sector is attributed to a large fall in the sheep population of 1,537,154 animals (5.3 per cent) resulting in a 359.6 kt CO_2-e (3.3 per cent) decrease in emissions from sheep. The decline in sheep numbers between 2015 and 2016 was caused by drought conditions in the South Island, and relatively weak lamb and mutton prices. Sheep numbers in the North Island also declined because of a high incidence of facial eczema due to warmer and more humid conditions.

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[15] Methane emissions produced from the digestive process in ruminant livestock.

IPPU sector emissions in 2016 were 461.9 kt CO_2-e lower than emissions in 2015. The decreases were due to the closure of a cement plant, consolidation in the steel industry and a decrease in the import and use of hydrofluorocarbons (HFCs) for refrigeration and air conditioning.

Total Waste sector emissions decreased by 26.3 kt CO_2-e between 2015 and 2016. This decrease is the result of reductions in methane (CH_4) emissions in the *Solid waste disposal* category, largely due to ongoing improvements in municipal solid waste management and continued gradual reduction in the total waste disposed on farms.

Section 2.2 provides a more detailed summary of the sectoral emission trends.

Net emissions – reporting under the Convention

Net emissions include emissions from the Energy, IPPU, Agriculture and Waste sectors (gross emissions), together with emissions and removals from the LULUCF sector.

In 1990, New Zealand's net GHG emissions were 36,275.3 kt CO_2-e. Between 1990 and 2016, net GHG emissions increased by 19,678.0 kt CO_2-e (54.2 per cent) to 55,953.3 kt CO_2-e (figure 2.1.1). The four categories that contributed the most to the increase in net emissions between 1990 and 2016 were *Enteric fermentation from dairy cattle*, *Land converted to forest land*, *Road transportation* and *Forest land converted to grassland*.

Figure 2.1.1   New Zealand's gross and net emissions (under the Convention) from 1990 to 2016
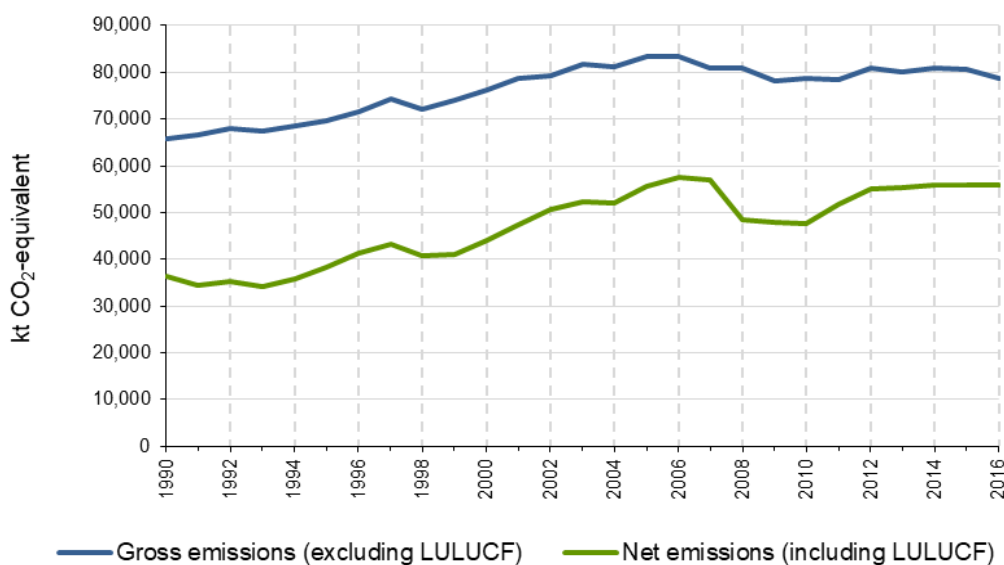
Accounting for New Zealand's 2020 target

New Zealand has taken a quantified economy-wide emissions reduction target under the United Nations Framework Convention on Climate Change in the period 2013 to 2020 to reduce emissions to 5.0 per cent below 1990 levels by 2020.[16]

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[16]   For the period 2013 to 2020, New Zealand has taken an unconditional target to reduce its greenhouse gas emissions under the Convention. New Zealand will apply the Kyoto Protocol framework of rules towards its target, to ensure New Zealand's actions are transparent and have integrity.

New Zealand's emissions budget for the period 2013 to 2020 is 509,774,982 tonnes CO_2-e.[17] This based on the gross emissions data for 1990 included in New Zealand's 2016 inventory submission (New Zealand's Initial Report, Ministry for the Environment, 2016). It is the number of years in the period (8 years) multiplied by gross emissions in 1990 from the Initial Report.

To account for New Zealand's 2020 target, annual gross emissions values from New Zealand's final submission for the period (National Inventory Report submitted in 2022) will be summed for 2013 to 2020, and this will represent the quantity of gross emissions that New Zealand is responsible for.

For the period so far (2013 to 2016), New Zealand's gross emissions sum to 320,458.2 kt CO_2-e. The contribution towards New Zealand's target from activities under the Kyoto Protocol is a net removal of 50,281.9 kt CO_2-e. This comprises net removals of 68,354.1 kt CO_2-e from *Afforestation and Reforestation* less emissions of 18,072.2 kt CO_2-e from *Deforestation* (see section 2.3 for further detail).

The accounting rules for land reported under Article 3.3 and Article 3.4 of the Kyoto Protocol are explained in chapter 11.

New Zealand tracks progress towards its 2020 target by regularly publishing a net position.[18]

2.2   Emission trends by sector

The five sectors New Zealand reports emissions and removals for are: Energy, IPPU, Agriculture, LULUCF and Waste.

2.2.1   New Zealand's emissions portfolio by sector and by gas in 2016

New Zealand's emissions portfolio by sector reflects the composition of the national economy. The Agriculture sector was the source of 49.2 per cent of New Zealand's gross emissions in 2016. New Zealand's Energy sector contributed 39.8 per cent to the national gross emissions, while the IPPU and Waste sectors contributed 6.2 per cent and 4.9 per cent respectively (figure 2.2.1). The LULUCF sector currently represents a sink with a net emissions value of –22,773.7 kt CO_2-e. This offsets 28.9 per cent of New Zealand's gross emissions.

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[17]   For more details, refer to *New Zealand's Initial Report to Facilitate the Calculation of its Emissions Budget for the Period 2013 to 2020* (www.mfe.govt.nz/sites/default/files/media/Climate%20Change/New%20 Zealand%27s%20Initial%20Report%20July%202016.pdf).

[18]   New Zealand's latest net position can be accessed from the Ministry for the Environment's website (www.mfe.govt.nz/climate-change/reporting-greenhouse-gas-emissions/latest-2020-net-position).

Figure 2.2.1   New Zealand's emissions by sector in 2016
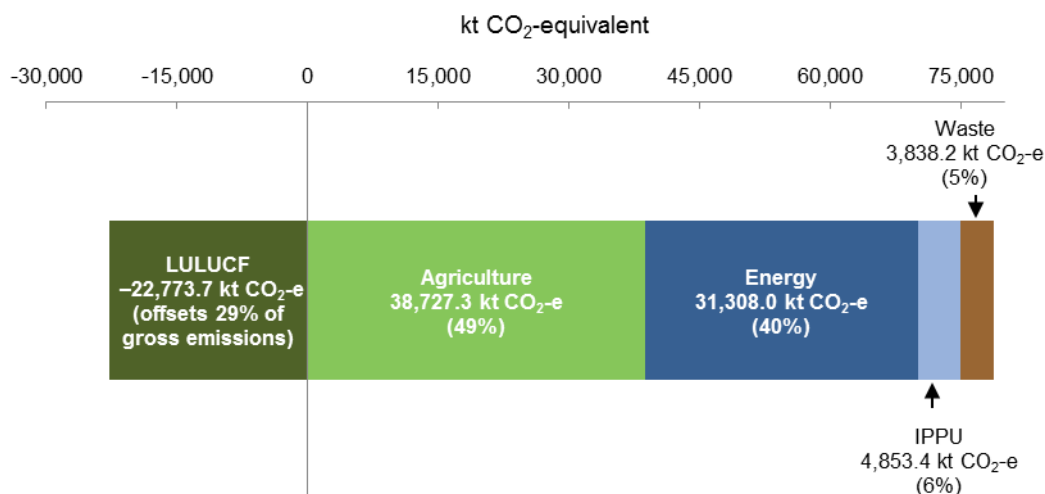
Note: The percentages may not add up to 100 per cent due to rounding.

Each of the sectors is dominated by one or two GHGs. Figure 2.2.2 shows New Zealand's gross emissions profile by gas.

Figure 2.2.2   New Zealand's gross emissions by gas in 2016
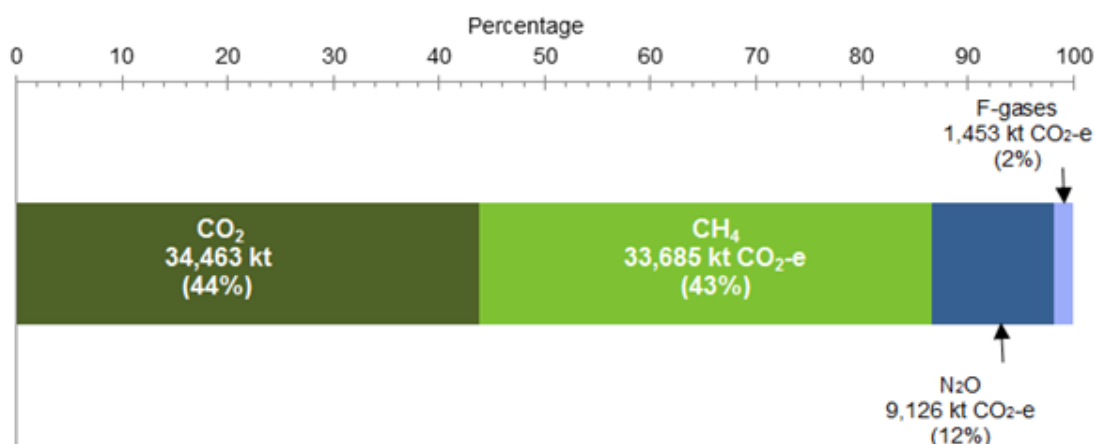
Note: CH_4 = methane; CO_2 = carbon dioxide; N_2O = nitrous oxide. The percentages may not add up to 100 per cent due to rounding.

Carbon dioxide (CO_2) contributes 43.8 per cent to New Zealand's gross emissions (34,462.9 kt) (figure 2.2.2). The Energy sector emits the largest amount of CO_2, at 30,156.7 kt (87.5 per cent of New Zealand's CO_2 emissions in 2016). The categories contributing most to CO_2 emissions in the Energy sector are *Transport* (14,860.3 kt CO_2, 43.1 per cent of New Zealand's CO_2 emissions) and *Manufacturing industries and construction* (6,799.4 kt CO_2, 19.7 per cent of New Zealand's CO_2 emissions). In 2016, the LULUCF sector was a CO_2 sink, sequestering 22,964.7 kt CO_2 (66.6 per cent) of CO_2 emissions produced by other sectors. This resulted in net CO_2 emissions of 11,498.2 kt in 2016.

The amount of CH_4 emitted annually in New Zealand (measured as CO_2-e) is 42.8 per cent of gross emissions (33,684.8 kt CO_2-e). Nitrous oxide (N_2O) at 11.6 per cent (9,126.2 kt CO_2-e) is the third-largest component in New Zealand's gross GHG profile. The Agriculture sector produces the largest amounts of both CH_4 and N_2O. In 2016, the contributions of the Agriculture sector to national emissions of CH_4 and N_2O were 85.9 per cent and 95.2 per cent respectively. The major source of CH_4 in the Agriculture sector is *Enteric fermentation*, a process that

produces CH_4 from livestock digestive systems (27,782.9 kt CO_2-e, 82.5 per cent of New Zealand's gross CH_4 emissions). Emissions from *Agricultural soils* (which come from adding nitrogen to soil, for example, manure or fertiliser) are the largest contributor to gross N_2O emissions (8,593.3 kt CO_2-e, 94.2 per cent of national N_2O emissions).

Methane is also the largest component of the Waste sector emissions, contributing 3,705.0 kt CO_2-e or 11.0 per cent of gross CH_4 emissions.

Fluorinated gases (HFCs, perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6))[19] collectively contribute 1.8 per cent to New Zealand's gross emissions. The IPPU sector is the only source of fluorinated gases in New Zealand. In 2016, the emissions of HFCs, PFCs and SF_6 were 1,453.0 kt CO_2-e. No production of any fluorinated chemicals occurs in New Zealand; they are all imported. Emissions of fluorinated gases are dominated by HFCs (95.5 per cent of all fluorinated gases). The PFCs and SF_6 contribute 3.4 per cent and 1.2 per cent to total emissions of fluorinated gases respectively. Almost all PFCs (99.99 per cent) are released during aluminium production.

2.2.2 Emission trends by sector from 1990 to 2016

Historically, the Agriculture and Energy sectors have dominated New Zealand's gross emissions portfolio, together producing almost 90 per cent of New Zealand's gross GHG emissions from 1990 to 2016. The IPPU and Waste sectors show relatively small contributions of GHGs to total gross emissions from 1990 to 2016. The total amount of annual emissions from these sectors was about 4 per cent to 7 per cent for each sector for the entire time series. Figure 2.2.3 shows the proportion that each inventory sector contributed to New Zealand's gross emissions as well as the proportion of the gross emissions offset by the LULUCF sector, which is a GHG sink, over the entire 1990–2016 period. Table 2.2.1 and figure 2.2.4 summarise each sectors' contribution to New Zealand's gross emissions in 1990 and 2016 as well as the change in emissions by sector between those years.

Figure 2.2.3   Percentage contribution by sector to New Zealand's gross emissions from 1990 to 2016
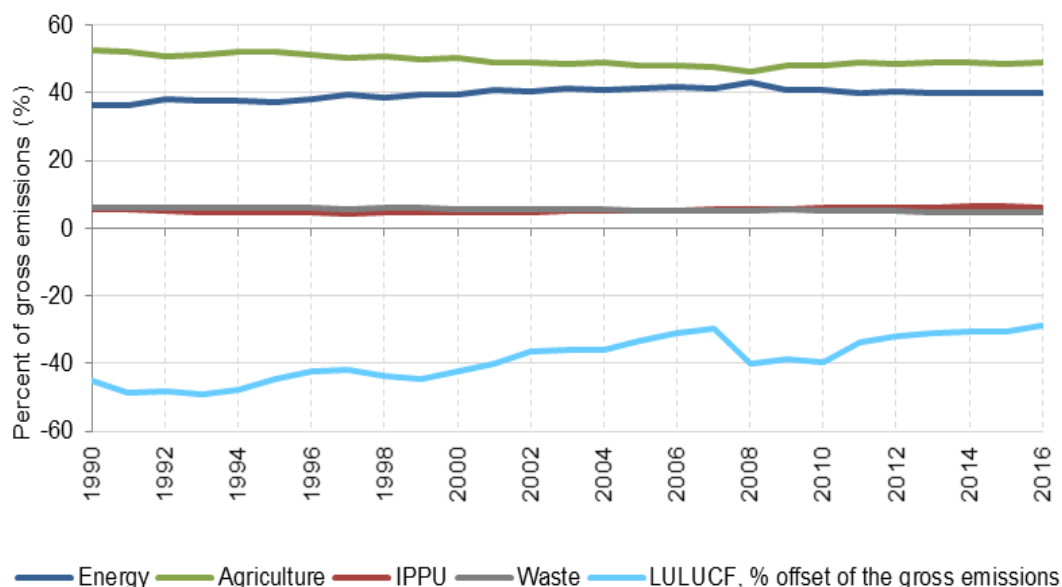
Note: Net removals from the LULUCF sector are as reported under the Convention (chapter 6).

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[19]   New Zealand does not produce or consume nitrogen trifluoride (NF_3).

Table 2.2.1   New Zealand's emissions by sector between 1990 and 2016

Sector	kt CO$_2$-equivalent 1990	2016	Change from 1990 (kt CO$_2$-equivalent)	Change from 1990 (%)
Energy	23,785.2	31,308.0	7,522.8	31.6
Industrial processes and product use	3,585.1	4,853.4	1,268.3	35.4
Agriculture	34,581.9	38,727.3	4,145.5	12.0
Waste	3,862.6	3,838.2	−24.4	−0.6
Gross (excluding LULUCF)	**65,814.8**	**78,726.9**	**12,912.1**	**19.6**
LULUCF	−29,539.5	−22,773.7	6,765.8	22.9
Net (including LULUCF)	**36,275.3**	**55,953.3**	**19,678.0**	**54.2**

Note: Net emissions from the LULUCF sector are as reported under the Convention (chapter 6). Columns may not sum due to rounding. Percentages presented are calculated from unrounded values.

Figure 2.2.4   Change in New Zealand's emissions by sector in 1990 and 2016
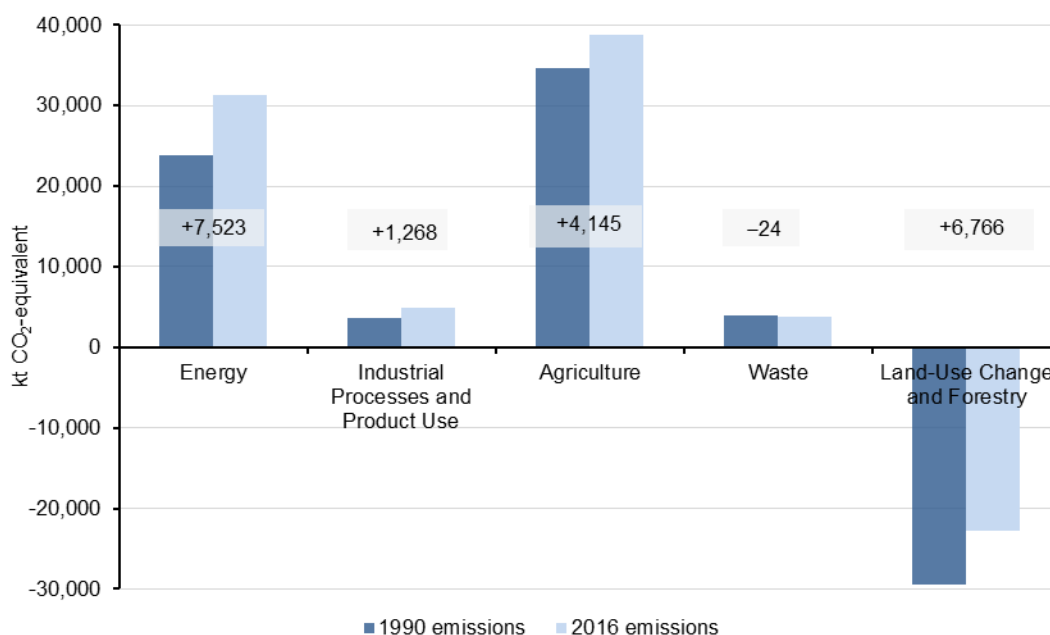
Figure 2.2.5 presents the absolute change in gross emissions for each sector (LULUCF is excluded from the estimate of gross emissions). The figure shows that the absolute changes in the New Zealand's gross emissions were mostly affected by changes in the Agriculture and Energy sectors. This is to be expected because they are the largest sectors of the New Zealand economy and show higher sensitivity to both changes in global economic status (e.g., the recent global economic recession) and severe weather conditions and natural disasters. For example, during droughts, the level of hydro inflow lakes is low resulting in a higher contribution of electricity production from fossil fuels to the national electricity grid and increased emissions from the Energy sector. Droughts also affect the animal population size and soil productivity, which usually result in reduced emissions from the Agriculture sector.

The figure also shows a decline in emissions from the Waste sector, which in 2016 decreased below the 1990 emission level from Waste.

Figure 2.2.5   Absolute change in New Zealand's gross emissions by sector from 1990 to 2016
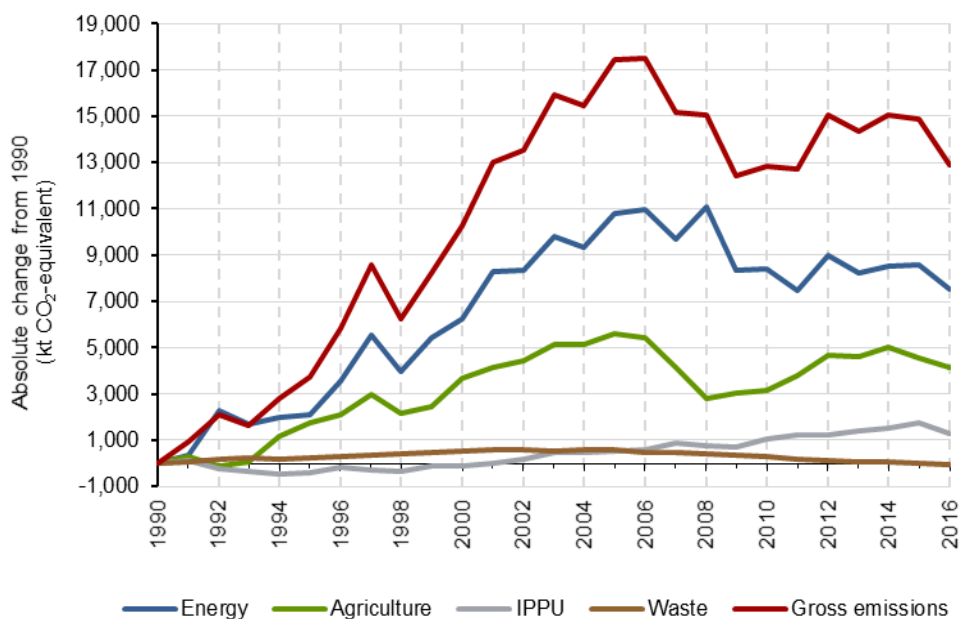
Note: Gross emissions exclude emissions from LULUCF.

Net emissions from the LULUCF sector fluctuate significantly over the time series. The fluctuations in net emissions from LULUCF (figure 2.2.6) are influenced by harvesting and deforestation rates (see LULUCF sector section below).

Figure 2.2.6   Absolute change in net emissions from the LULUCF sector from 1990 to 2016
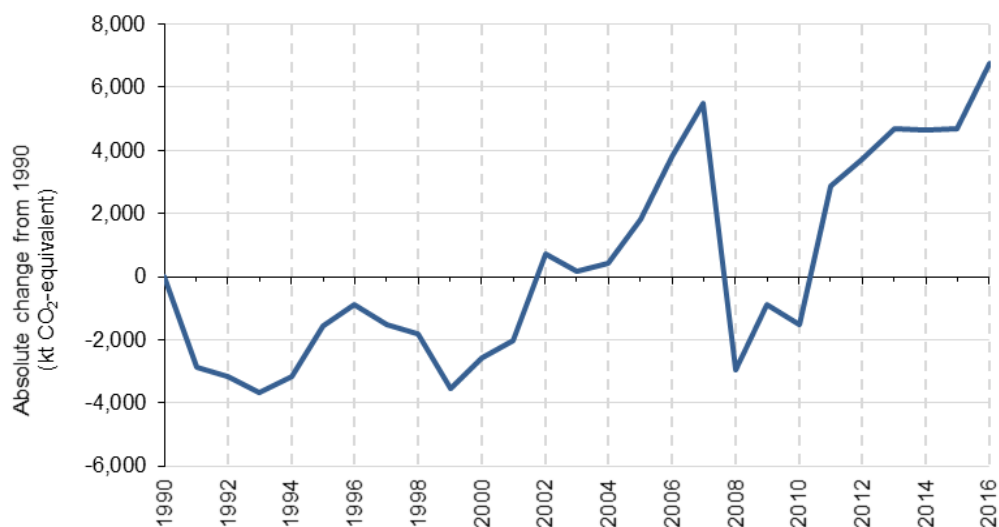
Energy sector

The Energy sector produces a large amount of CO_2 emissions (96.3 per cent of all emissions from the sector) and smaller amounts of CH_4 and N_2O (2.9 per cent and 0.8 per cent of all emissions from the sector respectively). The major source categories in the sector are *Road transportation* and *Public electricity and heat production*.

Emissions in the Energy sector are influenced not only by demand but also climatic conditions, because a lot of New Zealand's stationary energy needs are met by renewable sources such as hydro power.

In 2016, the Energy sector produced 31,308.0 kt CO_2-e, representing 39.8 per cent of New Zealand's gross GHG emissions. The largest sources of emissions in the Energy sector were *Road transportation*, contributing 13,612.6 kt CO_2-e (43.5 per cent), and *Public electricity and heat production*, contributing 3,038.6 kt CO_2-e (9.7 per cent) to energy emissions.

1990–2016

In 2016, emissions from the Energy sector had increased by 31.6 per cent (7,522.8 kt) above the 1990 level of 23,785.2 kt CO_2-e. This growth in emissions is primarily from *Road transportation*, which increased by 6,137.3 kt CO_2-e (82.1 per cent), *Chemicals*, which increased by 1,416.1 kt CO_2-e (256.0 per cent), and *Food processing, beverages and tobacco*, which increased by 1,126.8 kt CO_2-e (67.9 per cent). Emissions from the categories *Manufacture of solid fuels and other energy industries* and *Public electricity and heat production* both decreased appreciably below their 1990 levels, by 1,446.1 kt CO_2-e (−84.0 per cent) and 463.6 kt CO_2-e (−13.2 per cent) respectively. This decrease is primarily due to the cessation of synthetic gasoline production in New Zealand in 1997, combined with the falling dependence on coal and gas for public electricity generation.

Figure 2.2.7 shows the Energy sector emissions time series from 1990 to 2016. The trend shows emissions increasing up until 2008, after which there is a general decline.

Figure 2.2.7   **New Zealand's Energy sector emissions from 1990 to 2016**
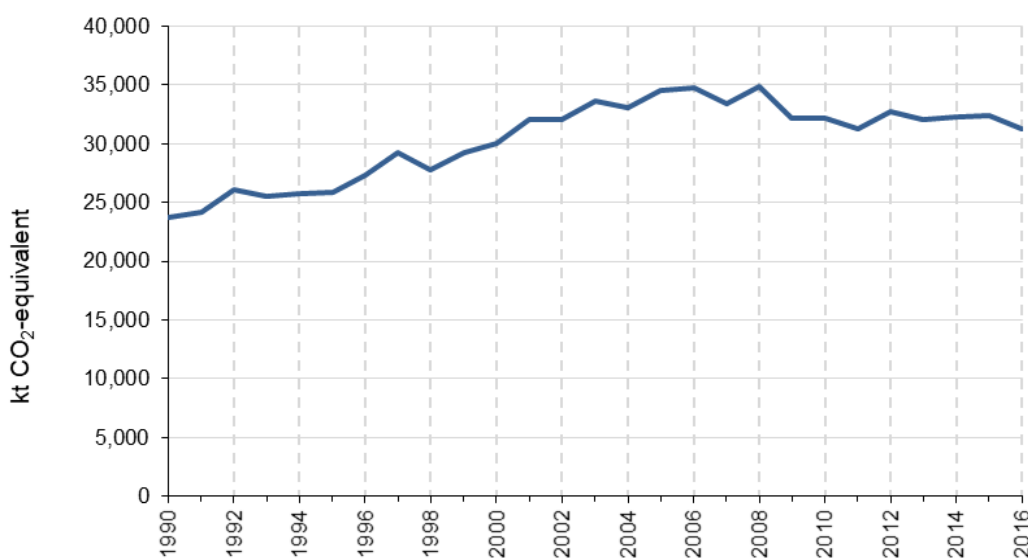
2015–2016

Between 2015 and 2016, emissions from the Energy sector decreased by 1,078.6 kt CO_2-e (3.3 per cent). Emissions from *Public electricity and heat production* decreased by 995.3 kt CO_2-e (24.7 per cent). This is mainly due to a 21.6 per cent decrease in coal- and gas-fired electricity generation. A lower use of thermal fuels (coal and gas) for electricity generation resulted in a higher proportion of hydroelectricity in the national grid.

The decrease of emissions from *Public electricity and heat production* was partially offset by an increase from category *Road transportation*, which increased by 327.7 kt CO_2-e (2.5 per cent).

There was also a 174.3 kt CO_2-e (8.0 per cent) decrease in emissions from the *Fugitive emissions from fuels* category. This was primarily due to a decrease in emissions from *Venting and flaring*.

IPPU sector

The IPPU sector in New Zealand produces CO_2 (66.3 per cent of IPPU sectoral emissions), fluorinated gases (29.9 per cent of the sector) and smaller amounts of CH_4 and N_2O (2.6 per cent and 1.2 per cent respectively). The major source categories in the IPPU sector are *Iron and steel production*, *Refrigeration and air conditioning* and *Cement production*.

Coal and natural gas are used on a significant scale for energy in the *Mineral industry*, *Chemical industry* and *Metal industry* source categories. Carbon dioxide and any other emissions from combustion of fuels in these industries are reported under the Energy sector.

2016

In 2016, emissions in the IPPU sector contributed 4,853.4 kt CO_2-e or 6.2 per cent of New Zealand's gross GHG emissions.

The largest source category is the *Metal industry*, with substantial CO_2 emissions from the *Iron and steel production* and *Aluminium production* categories. The *Mineral industry* and *Chemical industry* categories also contribute significant CO_2 emissions, and most of the non-CO_2 emissions come from the *Product uses as substitutes for ODS* (ozone-depleting substances) category.

1990–2016

IPPU sector emissions in 2016 were 1,268.3 kt CO_2-e (35.4 per cent) higher than emissions in 1990 (3,585.1 kt CO_2-e). This increase was mainly driven by increasing emissions from the *Product uses as substitutes for ODS* category due to the introduction of HFCs to replace ozone-depleting substances in refrigeration and air conditioning, and to the increased use of household and commercial air conditioning. Carbon dioxide emissions have also increased due to increased production of metals, lime and cement, but at a slower rate. There has been a substantial reduction in emissions of PFCs due to improved management of anode effects in the *Aluminium production* category, and some reduction in emissions of N_2O used for medical applications in the *Other product manufacture and use* category. The trends are shown in figure 2.2.8.

Figure 2.2.8   New Zealand's IPPU sector emissions from 1990 to 2016
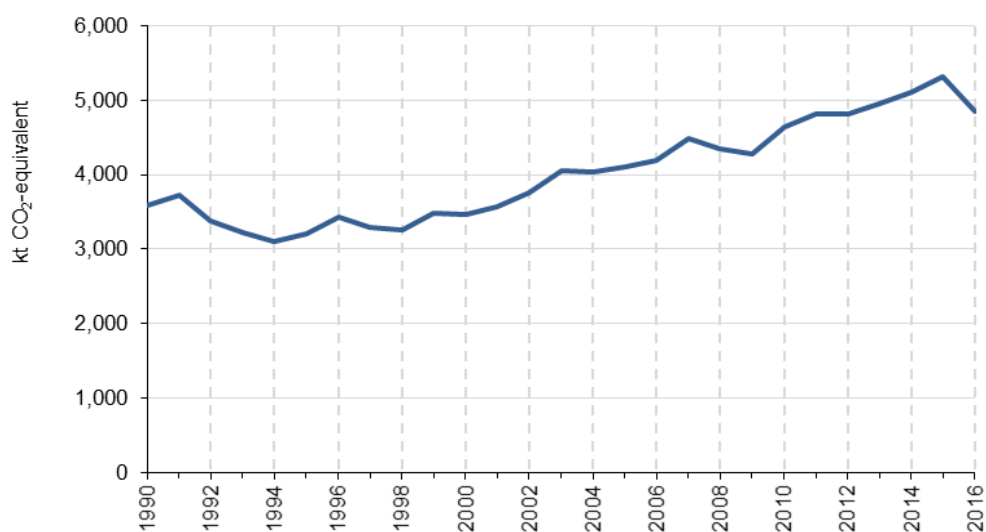
IPPU sector emissions in 2016 were 461.9 kt CO_2-e (8.7 per cent) lower than emissions in 2015. This change was a result of decreases in emissions from the *Product uses as substitutes for ODS* (down 173.3 kt CO_2-e or 11.1 per cent), *Mineral industry* (down 149.5 kt CO_2-e or 17.1 per cent), *Chemical industry* (down 72.4 kt CO_2-e or 18.6 per cent) and *Metal industry* (down 66.1 kt CO_2-e or 2.8 per cent) categories. The decreases were due to the closure of a cement plant, consolidation in the steel industry and a decrease in the import and use of HFCs for refrigeration and air conditioning.

Agriculture sector

The Agriculture sector in New Zealand produces CH_4 (74.8 per cent of all Agriculture sector emissions), N_2O (22.4 per cent of the sector) and smaller amounts of CO_2 (2.8 per cent of the sector).

The largest contributing categories in the Agriculture sector are *Enteric fermentation from dairy cattle* and *Agricultural soils*. Emissions from the Agriculture sector reflect not only livestock numbers but also the type of livestock farmed in New Zealand and their productivity.

The populations of the main types of livestock farmed in New Zealand have changed significantly over time. The number of dairy cattle has increased, while the populations of sheep and beef cattle have decreased as the relative profitability of dairy products (compared with sheep and beef products) has risen (see figures 5.1.3a and 5.1.3b in chapter 5).

Several drivers affect the animal population size and emission trends for both CH_4 and N_2O in the sector. These include:

- increased livestock productivity (milk and meat yield per head) achieved by New Zealand farmers since 1990 that results in increased feed intake per animal to meet higher energy demands. Increased feed intake results in increased CH_4 and N_2O emissions per animal

- the incidence of droughts and commodity price fluctuations. For example, droughts in 2008, 2013 and 2015–16 reduced agricultural production and emissions. The dairy sector was also affected by low milk prices in 2015, which reduced dairy cattle numbers, milk production and emissions

- the area of land used for agriculture. The Agriculture sector uses 46.0 per cent of New Zealand's land area, mostly for grazing. Since 1990, the area used for sheep and beef grazing has decreased, while the area used for dairy grazing has increased

- use of nitrogen fertiliser. The amount of synthetic nitrogen fertiliser applied to agricultural land has increased by over 600.0 per cent since 1990.

2016

In 2016, the Agriculture sector contributed 38,727.3 kt CO_2-e (49.2 per cent of New Zealand's gross emissions) (figure 2.2.9).

The largest source of emissions from the Agriculture sector in 2016 was CH_4 emissions from the *Enteric fermentation* category (71.7 per cent of the total emissions from the sector) and N_2O emissions from the *Agricultural soils* category (22.2 per cent of the total emissions from the sector).

Figure 2.2.9   New Zealand's Agriculture sector emissions from 1990 to 2016
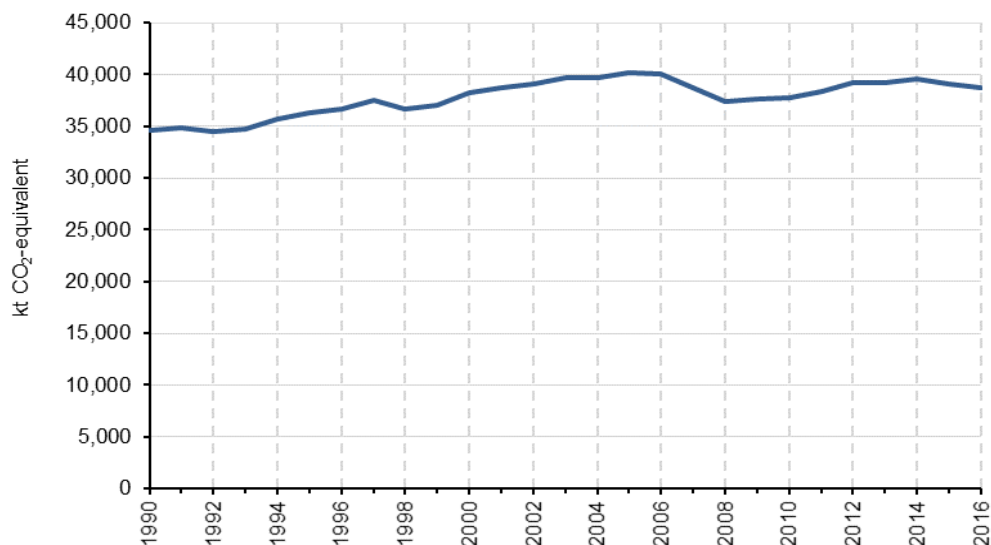
1990–2016

In 2016, New Zealand's Agriculture sector emissions were 4,145.5 kt CO_2-e (12.0 per cent) above the 1990 level of 34,581.9 kt CO_2-e. This increase is primarily due to a 1,895.8 kt CO_2-e (28.3 per cent) increase in N_2O emissions from the *Agricultural soils* category and a 1,064.7 kt CO_2-e (4.0 per cent) increase in CH_4 emissions from the *Enteric fermentation* category. The main drivers for this change in emissions are an approximately 600.0 per cent increase in synthetic nitrogen fertiliser applied since 1990 and an increase of 92.4 per cent (3.2 million animals) in the size of the national dairy herd over this same period. Falls of 52.3 per cent in the sheep population and 23.1 per cent in the non-dairy cattle population partially offset these increases.

2015–2016

Total agricultural emissions in 2016 were 409.3 kt CO_2-e (1.0 per cent) less than those in 2015, mostly due to a decrease in sheep emissions of CH_4 and N_2O. Emissions from sheep decreased by 359.6 kt CO_2-e (3.3 per cent), and the sheep population decreased by 5.3 per cent between 2015 and 2016 (see figure 5.1.3b in chapter 5).

There was a 58.1 kt CO_2-e (0.3 per cent) decrease in emissions from dairy cattle in 2016, compared with emissions in 2015 (emissions fell from 18,075.8 kt CO_2-e in 2015 to 18,017.7 kt CO_2-e in 2016). The size of the national dairy herd increased between 2015 and 2016 by 133,265 animals (2.1 per cent), although total milk production decreased by 1.0 per cent.

Emissions from deer were 34.0 kt CO_2-e (5.6 per cent) lower in 2016 compared with 2015, because the deer population fell by 7.3 per cent in this period.

Emissions from non-dairy (beef) cattle were 24.7 kt CO_2-e (0.4 per cent) higher in 2016, despite a slight decrease in the non-dairy cattle population of 0.4 per cent. The carcass weights of beef animals increased by around 2.5 per cent between 2015 and 2016.

In 2016, there was an increase in N_2O emissions from synthetic nitrogen fertiliser of 52.7 kt CO_2-e (3.4 per cent), compared with 2015. Emissions of CO_2 from agricultural liming and urea use fell by 21.9 kt CO_2 (4.1 per cent) and 33.8 kt CO_2-e (5.6 per cent) respectively.

LULUCF sector

The following information on LULUCF summarises reporting under the Convention. LULUCF activities under the Kyoto Protocol are covered in section 2.3.

2016

In 2016, the LULUCF sector under the Convention was a sink with a net emission value of –22,773.7 kt CO_2-e. This offsets 28.9 per cent of New Zealand's gross emissions. The category contributing the most to both removals and emissions is *Forest land remaining forest land*. This is because large removals of CO_2 result from tree growth in this category and there are large emissions from the sustainable harvest of New Zealand's plantation forests.

1990–2016

For the entire period 1990–2016, the LULUCF sector represented a net sink, that is, the total removals from the sector surpassed its total emissions. As a result, the total net emissions from the sector were negative for each reported year.

From 1990 to 2016, net emissions from LULUCF increased by 6,765.8 kt CO_2-e (22.9 per cent) from the 1990 level of –29,539.5 kt CO_2-e (see figure 2.2.10). The increase in net emissions in the *Forest land* category is due to higher levels of harvesting occurring in 2016, because a larger proportion of the production forest estate is at harvest age. The increase in net emissions in the *Grassland* category is due to higher levels of deforestation occurring in 2016 than in 1990.

The fluctuations in net removals from LULUCF (see figure 2.2.6) are influenced by harvesting and deforestation rates. Harvesting rates are driven by a number of factors, particularly tree age and log prices. Deforestation rates are driven largely by the relative profitability of forestry compared with alternative land uses. The increase in net emissions between 2004 and 2007 was largely due to the increase in planted forest deforestation that occurred leading up to 2008, immediately prior to the introduction of the New Zealand Emissions Trading Scheme.[20] Emissions were subsequently markedly lower in 2008. The level of harvesting initially remained fairly flat but has been on an increasing trend since 2011.

Figure 2.2.10   New Zealand's LULUCF sector net emissions from 1990 to 2016
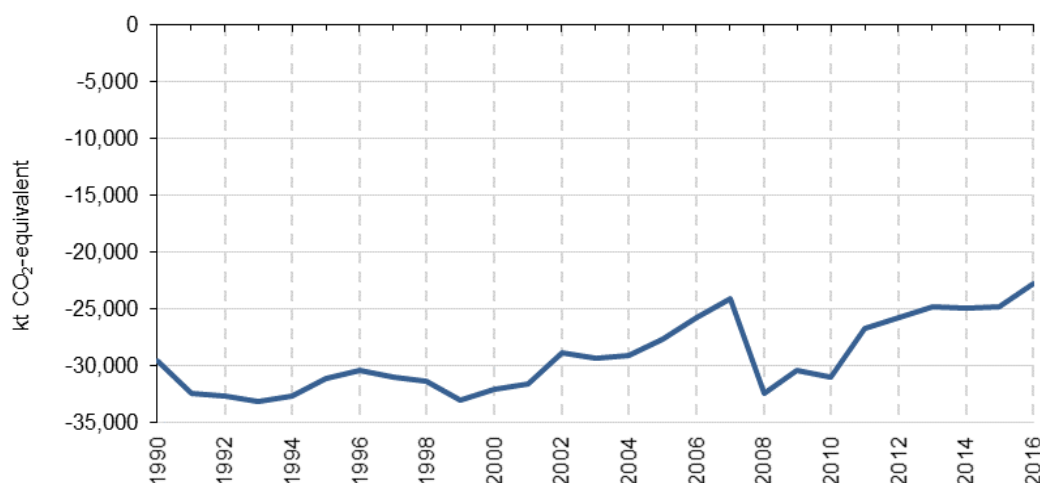
2015–2016

Between 2015 and 2016, net emissions from the LULUCF sector increased by 2,087.4 kt CO_2-e (8.4 per cent). The largest change occurred within the *Forest land* category, because harvesting increased between 2015 and 2016. Emissions from the *Grassland* category decreased slightly, following a reduction in deforestation. This was largely compensated for by an increase in emissions in the *Harvested wood products* category.

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[20]   The New Zealand Emissions Trading Scheme included the Forestry sector as of 1 January 2008.

There was an increase in emissions in *Forest land*. This was caused by an increased harvest rate and reduced deforestation rate. The increase in emissions in *Forest land* due to the reduction in deforestation occurs because the emissions associated with harvest are reported in the *Forest land* category instead of being reported in the *Grassland* category, had the land been deforested after harvest.

Waste sector

The Waste sector in New Zealand produces mainly CH_4 emissions (96.5 per cent) followed by N_2O emissions (3.4 per cent) and CO_2 emissions (0.03 per cent). There are also emissions of CO_2 from the disposal of solid waste, but these are of biogenic origin and are not reported.

2016

In 2016, emissions from the Waste sector contributed 3,838.2 kt CO_2-e or 4.9 per cent of New Zealand's gross GHG emissions. The largest source category is the *Solid waste disposal* category.

1990–2016

Total Waste sector emissions in 2016 were 24.4 kt CO_2-e (0.6 per cent) below 1990 emissions of 3,862.6 kt CO_2-e. Annual emissions increased between 1990 and 2002, peaking at about 4,500.0 kt CO_2-e in 2002, and have decreased since that time. The increase between 1990 and 2002 was the result of ongoing growth in population and economic activity. This resulted in increasing volumes of solid waste and wastewater for the whole of the time series. Waste sector emissions have been trending down since 2005, in spite of these increasing volumes. This is due to improvements in the management of solid waste disposal at municipal landfills, particularly increased CH_4 recovery. The trends are shown in figure 2.2.11 and figures 7.1.1 and 7.1.2 in chapter 7.

Figure 2.2.11   New Zealand's Waste sector emissions from 1990 to 2016
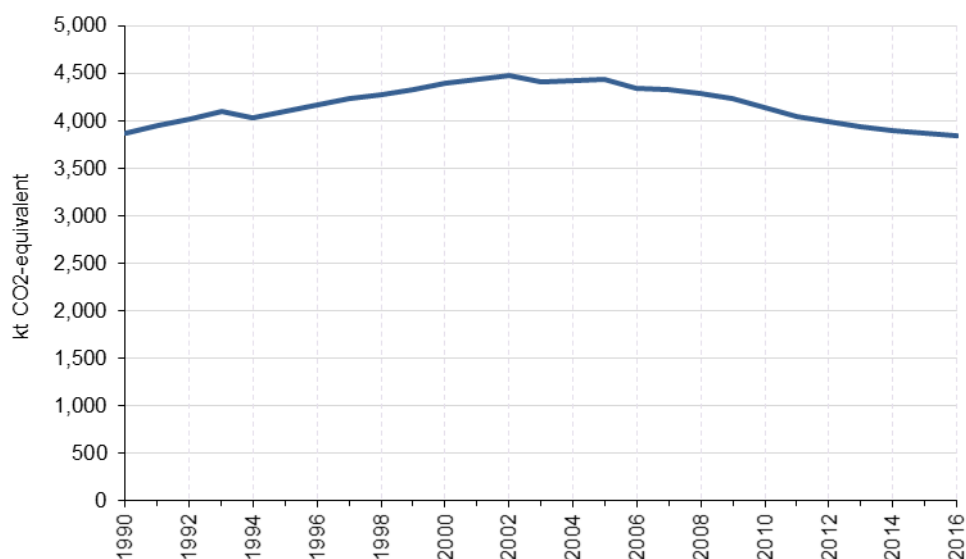
2015–2016

Total Waste sector emissions in 2016 were 26.3 kt CO_2-e (0.7 per cent) lower than emissions in 2015. This decrease is the result of reductions in CH_4 emissions in the *Solid waste disposal* category, largely due to ongoing improvements in municipal solid waste management and the continuation of a gradual reduction in the total waste disposed on farms.

2.3   Activities under Article 3.3 and Article 3.4 of the Kyoto Protocol

In 2016, net emissions from land subject to Article 3.3 and Article 3.4 activities under the Kyoto Protocol were –29,569.0 kt CO_2-e[21] (see table 2.3.1). This estimate includes net removals from the growth of all forest types and emissions from:

- decay of harvested wood products from *Afforestation and reforestation* and *Forest management* land

- *Deforestation* of all forest types

- conversion of land to post-1989 forest

- *Biomass burning*

- soil disturbance associated with land-use conversion.

New Zealand's estimates under the Kyoto Protocol do not include emissions associated with nitrogenous fertiliser use on afforested and reforested land, because these are reported and accounted for in the Agriculture sector. The notation key IE (included elsewhere) is used for this in the common reporting format tables.

Accounting rules apply to activities under the Kyoto Protocol. One of these called carbon equivalent forests means that the area of new forest planting is different from the area of *Afforestation* for some years, and the area of forest clearance and land conversion is different from the area of *Deforestation*. These accounting rules are explained further in chapter 11.

Afforestation and reforestation

The net area of post-1989 forest as at the end of 2016 is 655,323 hectares.[22] The net area is the total area of new forest established since 1990 (682,054 hectares) minus the *Deforestation* of post-1989 forest that has occurred since 1 January 1990 (26,731 hectares). Net removals for land included under *Afforestation and reforestation* in 2016 are 16,897.1 kt CO_2-e, including 1,343.5 kt CO_2-e from the *Harvested wood products* category.

Deforestation

The area deforested between 1 January 1990 and 31 December 2016 is 191,682 hectares.[23] The area subject to *Deforestation* in 2016 is estimated as 3,713 hectares.[8] In 2016, net emissions from *Deforestation* were 2,186.2 kt CO_2-e, compared with 3,409.1 kt CO_2-e in 2015 (a 35.9 per cent decrease).

Forest management

The total area reported under *Forest management* as at the end of 2016 was 9,249,653 hectares, equivalent to 34.4 per cent of New Zealand's total land area. This category includes all land that was forest at 1 January 1990 and has not been deforested since 1990. Net removals on this land in 2016 were 14,858.1 kt CO_2-e, including net removals of 9,500.1 kt CO_2-e from the *Harvested wood products* category.

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[21] In climate change literature, negative emissions are often referred to as 'removals' because they indicate removing carbon dioxide from the atmosphere as a net result. This report uses the term 'removal' or 'net removal' where it will make the relevant sections easier to understand.

[22] The carbon equivalent forest provision creates a misalignment for the afforestation and deforestation area reported under the Kyoto Protocol and the UNFCCC sections of the inventory. The carbon equivalent forest provision is not recognised under the UNFCCC and is reported as *Land converted to forest land* (afforestation) and *Forest land converted to other land* uses (deforestation).

[23] *Deforestation* includes deforestation of natural forest, pre-1990 planted forest and post-1989 forest.

Accounting quantity

For the second commitment period of the Kyoto Protocol, there are new rules for accounting under the Kyoto Protocol. These include:

- the ability to account for changes in the *Harvested wood products* category for *Afforestation and reforestation* and *Forest management land*

- the ability to exclude from accounting emissions and removals due to natural disturbance

- the ability to account for emissions and removals on land that meets the criteria of carbon equivalent forests under *Forest management* that would otherwise be accounted for under *Afforestation and reforestation* and *Deforestation*

- the ability to account for *Forest management* against a forest management reference level

- the ability to set the *Forest management* cap at 3.5 per cent of a country's base year emissions excluding LULUCF multiplied by the number of years in the commitment period.

New Zealand's accounting quantity has been presented in table 2.3.1 as the sum of emissions and removals from *Afforestation and reforestation* and *Deforestation*. This is because forest management accounting rules mean that emissions for *Forest management* are expected to equal the reference level over the commitment period if business-as-usual levels of harvesting (based on estimates as at 2009) are maintained.

Table 2.3.1   New Zealand's net emissions and removals from land subject to activities under Article 3.3 and forest management under Article 3.4 of the Kyoto Protocol

	2013	2014	2015	2016
Afforestation and reforestation				
Net cumulative area since 1990 (hectares)	644,706	648,700	651,567	655,323
Area in calendar year (hectares)	4,838	4,847	3,742[P]	4,302 [P]
Net emissions in calendar year (kt CO_2-e)	−17,044.7	−17,239.6	−17,172.8	−16,897.1
Deforestation				
Net cumulative area since 1990 (hectares)	173,684	182,552	187,969	191,682
Area in calendar year (hectares)	9,589	8,868	5,417 [P]	3,713 [P]
Net emissions in calendar year (kt CO_2-e)	6,200.8	6,276.1	3,409.1	2,186.2
Forest management				
Area included (hectares)	9,264,580	9,256,565	9,252,023	9,249,653
Net emissions in calendar year (kt CO_2-e)	−21,697.1	−20,585.1	−18,119.7	−14,858.1
Total area included (hectares)	**10,082,970**	**10,087,817**	**10,091,559**	**10,096,658**
Net emissions in calendar year (kt CO_2-e)	**−32,541.0**	**−31,548.6**	**−31,883.4**	**−29,569.0**
Accounting quantity (kt CO_2-e)	**−10,843.9**	**−10,963.5**	**−13,763.7**	**−14,710.9**

Note: The areas stated are as at 31 December 2016. They are net areas, that is, areas of afforestation and reforestation that were deforested during the period are only included in the figures as deforestation. P = provisional figure. *Afforestation and deforestation* areas differ from those reported in chapter 6 because the carbon equivalent forest provision has been applied to some of these areas and they are reported under *Forest management*. This is explained in more detail in chapter 11. Net removals are expressed as a negative value to help clarify that the value is a removal and not an emission. Columns may not total due to rounding.

The accounting quantity is calculated as the sum of emissions and removals from afforestation, reforestation and deforestation given the changes to the accounting rules for the second commitment period.

Chapter 2: Reference

Ministry for the Environment. 2016. *New Zealand's Initial Report to Facilitate the Calculation of its Emissions Budget for the Period 2013 to 2020*. Wellington: Ministry for the Environment.

Chapter 3: Energy

3.1 Sector overview

3.1.1 Introduction

In New Zealand, the Energy sector covers both:

- combustion emissions resulting from fuel being burned to produce useful energy
- fugitive emissions, for example:
    - production, transmission and storage of fuels
    - non-productive combustion
    - venting of carbon dioxide (CO_2) at natural gas treatment plants
    - emissions from geothermal fields.

Historically, combustion emissions from *Road transportation* and *Public electricity and heat production* constituted the largest share of domestic emissions from the Energy sector in New Zealand. New Zealand has one of the highest rates of car ownership among members of the Organisation for Economic Co-operation and Development (OECD) and a relatively old vehicle fleet (average age of light passenger fleet was approximately 14 years in 2016). Most freight is transported by emission-intensive trucks rather than by rail or coastal shipping.

Due to its sparse population and rural-based economy, New Zealand's domestic transport emissions per capita are high, when compared with many other Annex I countries.

Electricity generation from the combustion of coal, oil and gas supports New Zealand's highly renewable electricity system. In 2016, fossil fuel thermal plants provided 15 per cent of New Zealand's total electricity supply, which is very low by international standards. This is due to the high proportion of demand met by hydro generation, as well as other renewable sources such as geothermal and wind. While this provides a strong base in good hydro years, electricity emissions remain sensitive to rainfall in the key catchment areas. New Zealand has low levels of hydro lake storage, compared with other countries where hydro features prominently in their electricity supply.

Fugitive emissions present a relatively minor portion of New Zealand's energy emissions profile. The main sources of New Zealand's fugitive emissions include coal mining operations, production and processing of natural gas (largely venting and flaring) and geothermal operations (largely for electricity generation).

2016

In 2016, the Energy sector produced 31,308.0 kilotonnes carbon dioxide equivalent (kt CO_2-e) emissions, representing 39.8 per cent of New Zealand's gross greenhouse gas emissions. The largest sources of emissions in the Energy sector were *Road transportation*, contributing 13,612.6 kt CO_2-e (43.5 per cent), and *Public electricity and heat production*, contributing 3,038.6 kt CO_2-e (9.7 per cent) to energy emissions.

In 2016, emissions from the Energy sector had increased by 31.6 per cent (7,522.8 kt) above the 1990 level of 23,785.2 kt CO_2-e. This growth in emissions is primarily from *Road transportation*, which increased by 6,137.3 kt CO_2-e (82.1 per cent), *Chemicals*, which increased by 1,416.1 kt CO_2-e (256.0 per cent), and *Food processing, beverages and tobacco*, which increased by 1,126.8 kt CO_2-e (67.9 per cent). Emissions from the categories 1.A.1.c *Manufacture of solid fuels and other energy industries* and 1.A.1.a *Public electricity and heat production* both decreased appreciably below their 1990 levels, by 1,446.1 kt CO_2-e (−84.0 per cent) and 463.6 kt CO_2-e (−13.2 per cent) respectively. This decrease is primarily due to the cessation of synthetic gasoline production in 1997, combined with the falling dependence on coal and gas for public electricity generation.

Figure 3.1.1 shows the time series from 1990 to 2016. Clearly, the trend of emissions was increasing until around 2005, after which there has been a general decline.

Figure 3.1.1   New Zealand's Energy sector emissions
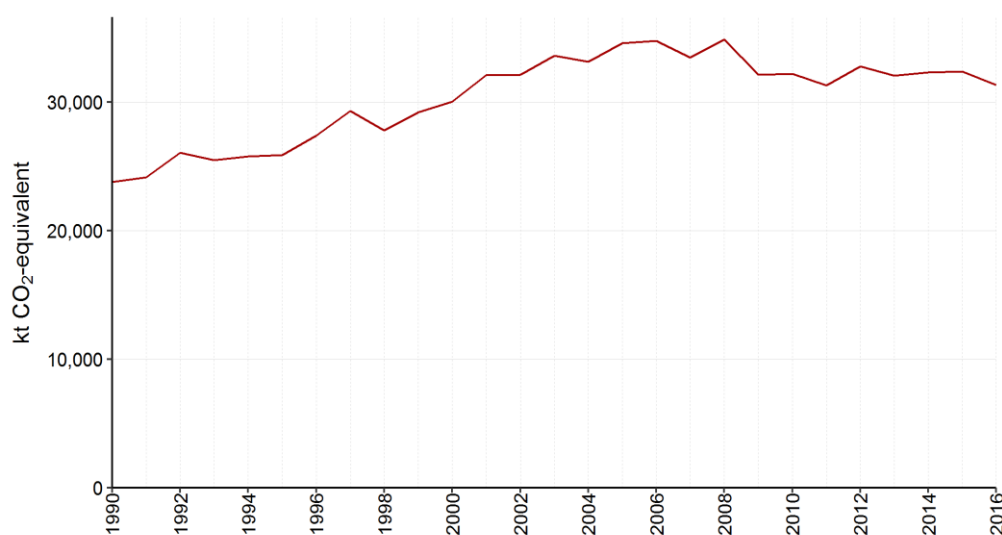
2015–16

Between 2015 and 2016, emissions from the Energy sector decreased by 1,078.6 kt CO_2-e (−3.3 per cent). This is primarily due to emissions from category 1.A.1.a *Public electricity and heat production*, which decreased by 995.3 kt CO_2-e (−24.7 per cent) due to the decrease in use of thermal fuels (coal and gas) for electricity generation. Coal- and gas-fired electricity generation decreased by 21.6 per cent over the same period, with hydroelectric generation increasing to cover the shortfall. The decrease was partially offset by an increase from category 1.A.3.b *Road transportation*, which increased by 327.7 kt CO_2-e (2.5 per cent).

There was also a 174.3 kt CO_2-e (–8.0 per cent) decrease in emissions for category 1.B *Fugitive emissions from fuels*. This was primarily due to a decrease in emissions in category 1.B.1.c *Venting and flaring*.

3.1.2   Key categories for Energy sector emissions

Details of New Zealand's key category analysis are in chapter 1, section 1.5. The key categories in the Energy sector are listed in table 3.1.1.

Table 3.1.1   **Key categories in the Energy sector**

CRF category code	IPCC categories	Gas	Criteria for identification
1.A.1.a	Energy Industries – Public Electricity and Heat Production Gaseous Fuels	CO_2	L1, T1
1.A.1.a	Energy Industries – Public Electricity and Heat Production Solid Fuels	CO_2	L1, T1
1.A.1.b	Energy Industries – Petroleum Refining Liquid Fuels	CO_2	L1, T1
1.A.1.b	Energy Industries – Petroleum Refining Gaseous Fuels	CO_2	T1
1.A.1.c	Energy Industries – Manufacture of Solid Fuels and Other Energy Industries Gaseous Fuels	CO_2	L1, T1
1.A.2.c	Manufacturing Industries and Construction – Chemicals Gaseous Fuels	CO_2	L1, T1
1.A.2.d	Manufacturing Industries and Construction – Pulp, Paper and Print Gaseous Fuels	CO_2	L1
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Solid Fuels	CO_2	L1, T1
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Gaseous Fuels	CO_2	L1, T1
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Liquid Fuels	CO_2	L1, T1
1.A.2.f	Manufacturing Industries and Construction – Non-metallic Minerals Solid Fuels	CO_2	L1, T1
1.A.2.g.iii	Other (please specify) – Mining (excluding fuels) and Quarrying Liquid Fuels	CO_2	L1, T1
1.A.2.g.viii	Other (please specify) – Other (please specify) Liquid Fuels	CO_2	L1, T1
1.A.2.g.viii	Other (please specify) – Other (please specify) Solid Fuels	CO_2	T1
1.A.3.a	Domestic Aviation – Jet Kerosene	CO_2	L1, T1
1.A.3.b	Transport – Road Transportation Liquid Fuels	CO_2	L1, T1
1.A.3.b	Transport – Road Transportation Gaseous Fuels	CO_2	T1
1.A.3.d	Domestic Navigation – Residual Fuel Oil	CO_2	L1
1.A.4.a	Other Sectors – Commercial/Institutional Gaseous Fuels	CO_2	L1, T1
1.A.4.a	Other Sectors – Commercial/Institutional Liquid Fuels	CO_2	L1, T1
1.A.4.b	Other Sectors – Residential Gaseous Fuels	CO_2	L1, T1
1.A.4.b	Other Sectors – Residential Liquid Fuels	CO_2	L1
1.A.4.b	Other Sectors – Residential Solid Fuels	CO_2	T1
1.A.4.c	Other Sectors – Agriculture/Forestry/Fishing Liquid Fuels	CO_2	L1, T1
1.B.1.a.1	Coal Mining and Handling – Underground Mines	CH_4	T1
1.B.2.b.5	Natural Gas – Distribution	CH_4	L1, T1
1.B.2.c.1.ii	Venting – Gas	CO_2	L1, T1
1.B.2.c.2.iii	Flaring – Combined	CO_2	L1, T1
1.B.2.d	Other (please specify) – Geothermal	CO_2	L1, T1
1.B.2.d	Other (please specify) – Geothermal	CH_4	T1

Note: L1 means a key category is identified under the level analysis – approach 1 and T1 is trend analysis – approach 1. See chapter 1 for more information.

3.2   Background information

3.2.1   New Zealand sectoral methodology

Greenhouse gas emissions from the Energy sector are calculated using a detailed sectoral approach. This bottom-up approach is demand based; it involves processing energy data collected on a regular basis through various surveys. For verification, New Zealand has also applied the Intergovernmental Panel on Climate Change (IPCC) reference approach to estimate CO_2 emissions from fuel combustion for the time series 1990–2016 (see annex 4).

The activity data used for the sectoral approach are referred to as 'observed' energy-use figures. These are based on surveys and questionnaires administered by the Ministry of Business, Innovation and Employment (MBIE). The differences between 'calculated' and 'observed' figures are reported as statistical differences in the energy balance tables released along with *Energy in New Zealand* (MBIE, 2017). Note that, due to the intervening time between the publication of *Energy in New Zealand* and the preparation of this submission, some data revisions may have occurred.

3.2.2   International bunker fuels

The data on fuel use by international transportation are collected and published online by MBIE (2017). This data release uses information from oil company monthly survey returns (*Delivery of Petroleum Fuels by Industry* (DPFI) and *Monthly Oil Supply* (MOS) as explained below) provided to MBIE.

Data on fuel use by domestic transport are sourced from the quarterly DPFI survey, conducted by MBIE.

Some of the international bunkers data in common reporting format (CRF) table 1.A.b are from the MOS survey, whereas the international bunkers data in CRF table 1.D are from the DPFI survey. The DPFI survey is a quarterly sectoral breakdown of observed demand (i.e., actual sales figures for different industries, one of which is international bunkers). The MOS survey is collected monthly and is a liquid fuels supply balance provided by companies selling fuels, of which one category is 'international bunkers'. Companies that respond to the DPFI survey are asked to reconcile their figures with their figures in the MOS survey. Discrepancies between the surveys are usually very small, and the companies explain differences between the two data sets as the MOS survey following a top-down approach and the DPFI following a bottom-up approach. Furthermore, the MOS and DPFI surveys are usually completed by different sections from within the fuel companies. Also, note that the *Other fuels* category is not covered in the DPFI so data must come from the MOS.

International bunker fuel is not subject to goods and services tax (GST) in New Zealand, whereas fuel sold for fishing vessels, coastal shipping and so on is subject to GST. The liquid fuel retailers are able to accurately eliminate international bunker sales because GST is not charged on these sales.

3.2.3   Feedstock and other non-energy use of fuels

For some industrial companies, the fuels supplied are used both as fuels for combustion and as feedstocks. In these instances, process-related emissions are calculated by taking the fraction of carbon stored or sequestered in the final product (based on industry production and chemical composition of the product) and subtracting this from the fuel supplied as feedstock. This difference is assumed to be the amount of carbon emitted as CO_2 and is reported both in the Industrial Processes and Product Use (IPPU) sector and in CRF table 1.AD. Other fuel

materials, such as bitumen, also contribute to emissions that are reported in the IPPU sector and (where appropriate) in table 1.AD.

In New Zealand, these non-energy fuels are as follows.

- The carbon in the natural gas used as feedstock to produce methanol is all considered to be stored in the product and therefore has no associated CO_2 emissions. The balance of the carbon is oxidised and results in CO2. Emissions from fuel used for combustion are reported in 1.A.2.c.

- All ammonia produced in New Zealand is processed into urea. Carbon dioxide emissions from the use of natural gas in ammonia production (feedstock) are reported under the IPPU sector and are included in CRF table 1.AD. Emissions from fuel used for combustion are reported in 1.A.2.c.

- Bitumen produced in New Zealand is not used as a fuel but rather by the companies Fulton Hogan and Downer EDI as a road construction material (non-energy use). Bitumen therefore has no associated direct emissions. Indirect emissions are reported in the IPPU sector.

- Coal used in steel production at New Zealand Steel Limited is used as a reductant, which is part of an industrial process. Therefore, all emissions from this coal are reported under the IPPU sector rather than the Energy sector.

For the four industries using natural gas as feedstock, the fraction of carbon stored is given in table 3.2.1. Emissions for individual products are withheld because of confidentiality concerns.

Table 3.2.1   Use of natural gas as a feedstock in New Zealand

Product	Percentage of carbon stored	Energy use reported under	Non-energy use reported under
Methanol	100	1.A.2.c.	N/A
Urea	80–93[24]	1.A.2.c.	2.B.1
Hydrogen	0	1.A.2.c.	2.B.10
Steel	0	1.A.2.a	2.C.1

The available data on natural gas supplied for methanol production do not allow feedstock to be clearly distinguished from gas for combustion. The quantity of feedstock gas is therefore calculated using a carbon balance based on the quantity of methanol produced. Natural gas used for energy generation is then calculated as total gas consumed minus feedstock gas. These figures may differ slightly from those reported online by MBIE, which are based on natural gas energy use and non-energy use as reported by the plant operator. Regarding urea, the split of feedstock gas and fuel gas is provided by the company. Although most of the carbon in feedstock gas used for urea production is stored in the product, this carbon is later emitted when the urea is used on farms as fertiliser. These emissions are reported in the Agriculture sector under urea application (all ammonia produced in New Zealand is processed into urea).

Emissions from synthetic gasoline production are reported under the *Manufacture of solid fuels and other energy industries* category. Synthetic gasoline production in New Zealand ceased in 1997.

The split of natural gas consumed for energy use versus non-energy use across the time series is shown in figure 3.2.1. Details of natural gas use for the various non-energy uses are covered under the IPPU sector (chapter 4).

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[24]   For urea production, the fraction of carbon stored varies across the time series depending on the composition of the feedstock gas.

Figure 3.2.1   Natural gas consumption by end use type
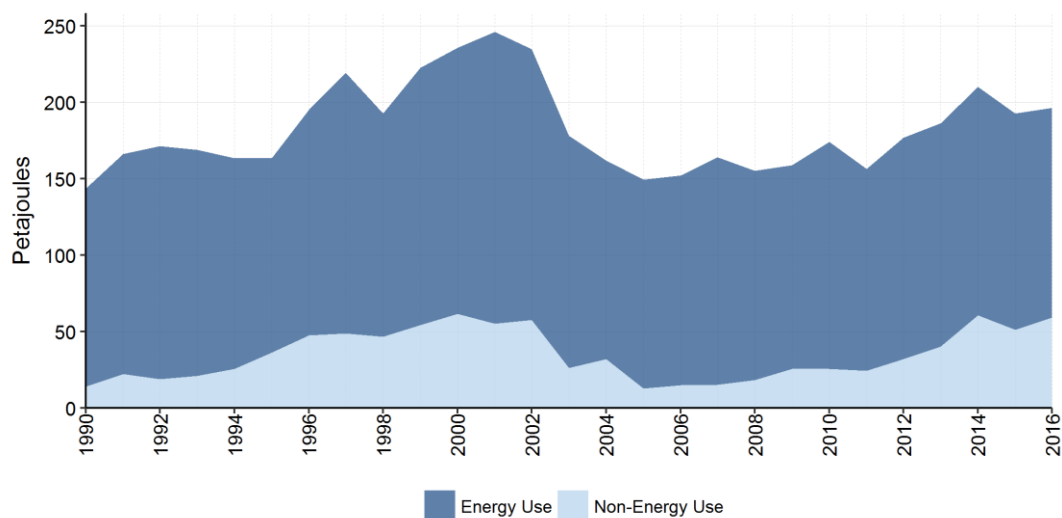
3.2.4   Carbon dioxide capture from flue gases and subsequent carbon dioxide storage

There was no CO_2 capture from flue gases and subsequent CO_2 storage occurring in New Zealand between 1990 and 2016.

3.2.5   Country-specific issues

Reporting for the Energy sector presents some issues related to the IPCC Guidelines (IPCC, 2006). The issues that exist are listed below.

Sectoral approach – Methanol production

The sector activity data does not include non-energy use of fuels. As a result, subtraction of emissions is not needed to account for the sequestration of carbon in methanol. Also, due to confidentiality concerns raised by New Zealand's sole methanol producer, emissions from methanol production were previously reported under 1.A.2.c *Chemicals*, rather than in the IPPU sector. Following the 2013 expert review team (ERT) recommendation, the natural gas used for production of methanol was split into fuel gas and feedstock gas. The emissions from the fuel portion are reported in the CRF category 1.A.2.c *Chemicals* in the Energy sector, and the emissions from the feedstock portion are described in chapter 4 (IPPU sector), section 4.3.2.

3.2.6   New Zealand energy balance

New Zealand's energy balance, along with comprehensive information and analysis of energy supply and demand, is published annually in *Energy in New Zealand* (MBIE, 2017). It covers energy statistics, including supply and demand by fuel types, energy balance tables, pricing information and international comparisons.

An electronic copy of this report is available online at: www.mbie.govt.nz/info-services/sectors-industries/energy/energy-data-modelling/publications/energy-in-new-zealand.

3.3 Fuel combustion (CRF 1.A)

3.3.1 Sector-wide information

Description

The *Fuel combustion* category reports all fuel combustion activities from 1.A.1 *Energy industries*, 1.A.2 *Manufacturing industries and construction*, 1.A.3 *Transport* and 1.A.4 *Other sectors* categories (see figure 3.3.1). These categories use common activity data sources and emission factors. The CRF tables require energy emissions to be reported by category. Apportioning energy activity data across categories is not as accurate as apportioning activity data by fuel type because of difficulties in allocating liquid fuel to the appropriate categories.

Information about methodologies, emission factors, uncertainty, and quality control and assurance for each of the categories is discussed below.

Figure 3.3.1   Change in New Zealand's emissions from the fuel combustion categories (1990–2016)
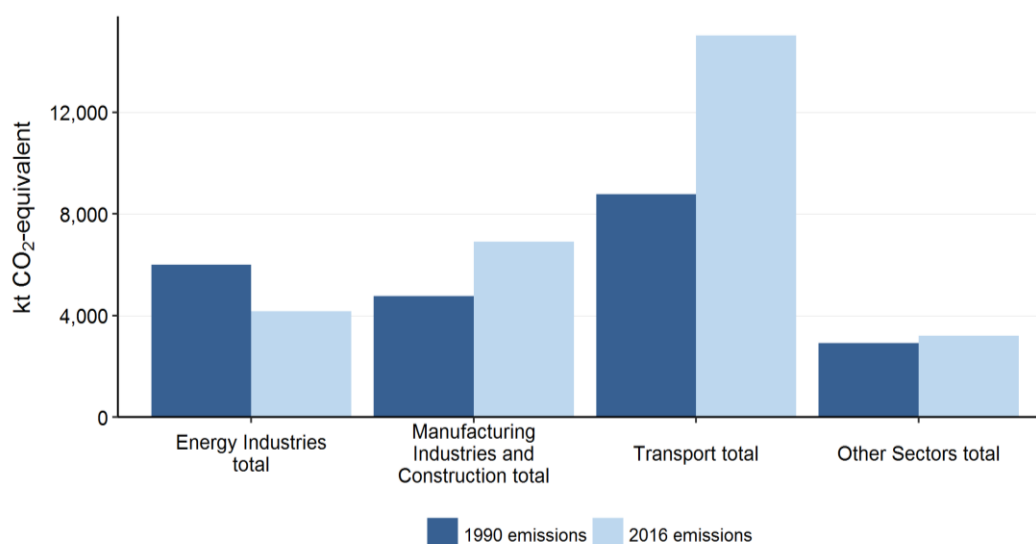
Methodological issues

Energy emissions are compiled using MBIE's energy statistics along with relevant New Zealand-specific emission factors. Unless otherwise noted in the relevant section, CO_2 emissions are calculated by multiplying a country-specific emission factor for the given fuel by the relevant activity data using an IPCC 2006 Tier 2 method. Non-CO_2 emissions are calculated using IPCC 2006 default emission factors, unless otherwise noted.

Activity data

Liquid fuels

The primary source of liquid fuel consumption data is the DPFI. MBIE began conducting the DPFI in 2009. Before this, the survey was conducted by Statistics New Zealand. The quarterly survey includes liquid fuel sales data collected from the four major oil companies and an independent oil company. The purpose of the survey is to provide data on the amount of fuel delivered by all oil companies to end users and other distribution outlets. Each oil company in New Zealand supplies MBIE with the volume of petroleum fuels delivered to resellers and the industrial, commercial and residential sectors.

Petroleum fuels data are currently collected in volume units (thousand litres). Before 2009, data were collected in metric tonnes. Year-specific calorific values are used for all liquid fuels, reflecting changes in liquid fuel properties over time. Annual fuel property data are provided by New Zealand's sole refinery.

Emissions from fuel sold for use in international transport (e.g., international bunker fuels) are reported separately as a memo item, as required (IPCC, 2006).

An MBIE-commissioned survey in 2008 on liquid fuel use (MBIE, 2008) found that there were, at the time, 19 independent fuel distribution companies operating in New Zealand that resell fuel bought wholesale from the oil companies. It further found that this on-selling resulted in over-allocation of liquid fuel activity data to the *Transport* category, as most fuel purchased from the distribution companies was used by the *Agriculture/ Forestry/Fishing* category. The study recommended starting an annual survey of deliveries of gasoline and diesel to each sector by independent distributors. These data were then used to correctly allocate sales of liquid fuels by small resellers to the appropriate sector.

The *Annual Liquid Fuel Survey* was started in 2009 (for the 2008 calendar year) and found that the independent fuel distribution companies delivered 18 per cent of New Zealand's total diesel consumption and 3 per cent of New Zealand's total gasoline consumption. Using these data, each company's deliveries between 1990 and 2006 were estimated, as no information was available for these years. The report *Delivering the Diesel – Liquid Fuel Deliveries in New Zealand 1990–2008* (MBIE, 2010) outlines in further detail the methodology employed to perform this calculation.

Solid fuels

Since 2009, MBIE has conducted the *New Zealand Quarterly Statistical Return of Coal Production and Sales*, previously conducted by Statistics New Zealand. The survey covers coal produced and sold by coal producers in New Zealand. The three grades of coal surveyed are bituminous, sub-bituminous and lignite.

The *Quarterly Statistical Return of Coal Production and Sales* splits coal sold into over 20 industries, using the Australian and New Zealand Standard Industrial Classification 2006 (Australian Bureau of Statistics and Statistics New Zealand, 2006). Before 2009, when Statistics New Zealand ran the survey, coal sold was attributed to seven sectors.

All solid fuel used for iron and steel manufacture is reported under the IPPU sector, to avoid double counting.

Gaseous fuels

MBIE receives activity data on gaseous fuels from a variety of sources. Individual natural gas field operators provide information on the amount of gas extracted, vented, flared and for own use at each gas field. Information on processed gas, including the Kapuni gas field, and information on gas transmission and distribution throughout New Zealand, is provided by Vector, as the operator of the Kapuni Gas Treatment Plant and gas distribution network.

Large users of gas, including electricity generation companies, provide their activity data directly to MBIE. Finally, MBIE surveys retailers and wholesalers on a quarterly basis to obtain activity data from industrial, commercial and residential natural gas users.

In response to ERT recommendations, this submission disaggregates all fuel combustion for electricity auto-production into the appropriate sector, rather than in 1.A.2.g *Manufacturing industries and construction – other* as in previous submissions. This improvement has resulted

in a reduction in unallocated industrial emissions, and increases in various manufacturing and construction categories. For further information, see section 3.3.7.

Biomass

Activity data for the use of biomass come from a number of different sources. Electricity and co-generation data are received by MBIE from electricity generators.

- New Zealand reports emissions from landfill gas, sewage waste gas and sludge gas (derived from cattle effluent at the Tirau dairy processing facility), and commercial biogas use. Before 2013, New Zealand only reported emissions from landfill gas, sewage waste gas and commercial biogas use.

- New Zealand's gas biomass emissions are estimates based on electricity generation data (some of which are also estimated). No direct data are available on gas biomass emissions from landfills or sewage treatment facilities. See below for details of the estimation methodology of landfill gas and sewage waste gas.

- Gas biomass is also thought to be used by some local government councils; however, MBIE has no information on this use. At some point, information was collected, but the small quantities and materially insignificant emissions mean that the Ministry has not focused on collecting these data for many years. A standing estimate (unchanged) has been included since 2006, but the source of this number is unknown. Emissions continue to be reported under this category to ensure there is no under-reporting, given there is anecdotally some use outside of electricity generation and industry.

- No information is collected on flared gas biomass.

- The only gas biomass direct-use that data have been collected for is the Tirau dairy processing facility (and only one data point, which has been used for all years where it is believed the plant has emitted).

Information on how gas biomass emissions are estimated based on electricity generation data

- Electricity generation data are collected for 15 individual plants. At 31 December 2012, New Zealand gas biomass generation was known to include the following:

  – 11 landfill facilities, totalling 29.4 megawatts (MW). These facilities are electricity only (some landfill gas was used to heat a swimming pool in Christchurch before the Christchurch earthquake of February 2011, but that facility suffered major earthquake damage and has been removed)

  – four wastewater treatment facilities, totalling 11.3 MW. These are all co-generation facilities that provide heat and electricity for the processing of sewage.

  Note: Accurate information is not available on the exact type of generation plant used at these individual facilities, although it is known to be a combination of gas turbines, internal combustion engines and some steam turbine facilities.

- Generation data are collected for each year ending 31 March, with generation assumed to be distributed equally across quarters to estimate December year-end generation.

  – Generation data are usually collected from all 15 plants. However, in some years, estimates are made based on the previous year's generation.

- Fuel input information for generation is not collected for small generators (those less than 10 MW), to minimise the burden on respondents and ensure MBIE receives some information rather than nothing. Estimates of fuel input are made on the assumption of 30 per cent efficiency based on gross generation.

- All generation data collected are assumed to be net generation – that is, parasitic load has already been excluded. They are then scaled up using default net to gross generation factors sourced from the International Energy Agency. For all thermal generation, the net to gross factor is assumed to be 1.07 (i.e., an additional seven per cent of electricity is generated but used within the plant itself). Fuel input estimates are then calculated based on the gross generation using a default electrical efficiency factor of 30 per cent. This estimated quantity of biogas is used as total biogas for energy purposes. Biogas use estimates for landfill gas and sewage waste gas are calculated and reported in petajoules (PJ).

- Energy quantities of gas biomass are then converted into greenhouse gas emissions using default IPCC emission factors. These factors are as follows:

  - CO_2 – 13.4 kt carbon/PJ or 49.17 kt CO_2/PJ. This is derived from the IPCC default net emission factor (it is assumed that the net emission factor is 10 per cent less than the gross emission factor)

  - methane (CH_4) – 0.9 t/PJ

  - nitrous oxide (N_2O) – 0.09 t/PJ.

- Emissions from gas biomass are a very small part of New Zealand's emissions inventory. Given this situation, MBIE believes the current process is sufficient for estimating emissions from gas biomass. Efforts to improve emissions quality would be better focused on other areas.

Residential biomass data are estimated based on information on the proportion of households with wood burner heaters (Census of Population and Dwellings, see below) and data from the Building Research Association of New Zealand (BRANZ, 2002) on the average amount of energy used by households that use wood for heating. Finally, industrial biomass data are based on the report *Heat Plant in New Zealand* (Bioenergy Association of New Zealand, 2011).

The census is the official count of how many people and dwellings are in New Zealand. It takes a snapshot of the people in New Zealand and the places where people live. Up until 2006, the census was undertaken every five years from the end of World War Two. In 2011, the national census was cancelled due to the Christchurch earthquakes, which caused major disruption. In March 2013, a new census was held (after seven years). The next census is scheduled for 2018.

For this inventory, complete data from the 2006 census were used (see http://archive.stats.govt.nz/Census/2006-census.aspx). The census collects information on the heating fuels used for housing in New Zealand.

In 2006, 40.9 per cent of households used wood at some stage as a heating fuel. Based on 2006 census population figures, this equates to 574,482 households in 2006. The 2002 BRANZ Household Energy End-use Project (HEEP) found that, on average, households using wood used 13.7 gigajoules (GJ) per annum (BRANZ, 2002). For the wood-use numbers, the estimated number of households using wood has been multiplied by the estimated use of wood per household. So, in 2006: 574,482 households × 13.7 GJ/household = 7.8 PJ.

Since 2006, the trends have been extrapolated (declining percentage of households using wood). Once new data from the 2013 census are processed, numbers from 2007 will need to be revised. Calorific values used in the HEEP study are not available.

Liquid biofuel activity data are based on information collected under the *Petroleum or Engine Fuel Monitoring Levy* as reported in MBIE quarterly online data releases.

Electricity auto-production

In response to ERT recommendations, this submission disaggregates all combustion for electricity auto-production into the appropriate sector, rather than in 1.A.2.g *Manufacturing industries and construction – other* as in previous submissions. This improvement has resulted in a reduction in unallocated industrial emissions and increases in various manufacturing and construction categories.

Emission factors

New Zealand emission factors are based on gross calorific values. A list of emission factors for CO_2, CH_4 and N_2O for all fuel types is provided in annex 4, tables A4.1 to A4.4. The characteristics of liquid, solid and gaseous fuels and biomass used in New Zealand are described under each of the fuel sections below. Where a New Zealand-specific value is not available, New Zealand uses either the IPCC value that best reflects New Zealand conditions or the mid-point value from the IPCC range. All emission factors from the IPCC are converted from net calorific value to gross calorific value. New Zealand adopts the OECD and International Energy Agency assumptions to make these conversions.

- Gaseous fuels: Gross Emission Factor = 0.90 x Net Emission Factor

- Liquid and solid fuels: Gross Emission Factor = 0.95 x Net Emission Factor

- Wood: Gross Emission Factor = 0.80 x Net Emission Factor

Liquid fuels

Where possible, CO_2 emission factors for liquid fuels are calculated on an annual basis. Carbon dioxide emission factors are calculated from Refining New Zealand data on the carbon content and calorific values of the fuels that they produce. For non-CO_2 emissions, IPCC default values are used unless otherwise specified in the relevant section. Annex 4, section A4.1, includes further information on liquid fuel emission factors, including a time series of gross calorific values.

Solid fuels

Emission factors for solid fuels were updated for the 2016 submission across the time series from 1990 to 2008, in response to a 2013 ERT recommendation (FCCC/ARR/2013/NZL, paragraph 32) (UNFCCC, 2014). A comprehensive list of carbon content by coal mine is not currently available. A review of New Zealand's coal emission factors in preparation for the New Zealand Emissions Trading Scheme (NZ ETS) (CRL Energy Ltd, 2009) recommended re-weighting the current default emission factors to 2007 production rather than continuing with those in the *New Zealand Energy Information Handbook* (Baines, 1993). However, following the recommendation of the ERT review (FCCC/ARR/2013/NZL, paragraph 32) (UNFCCC, 2014) of New Zealand's 2013 submission, the emission factors between 1990 and 2008 have been interpolated.

Also, the emission factor used to calculate emissions from coal use in the public electricity and heat production sector has been weighted to reflect the combustion of imported coal. A time series of the effect of this weighting is included in annex 4 (table A4.2).

Gaseous fuels

New Zealand's gaseous fuel emission factors are above the IPCC 2006 default range, because New Zealand natural gas fields tend to have higher CO_2 content than most international gas fields. This is verified by regular gas composition analysis. Emission factors for 2016 from all fields, along with the production weighted average, are included in annex 4.

The annual gaseous fuel emission factor is the calculated weighted average for all of the natural gas production fields. The emission factor takes into account gas compositional data from all gas fields. This method provides increased accuracy because the decline in production from both the Maui and Kapuni gas fields has been replaced by other new gas fields (for example, Pohokura) coming on stream. This emission factor fluctuates slightly from year to year, mainly due to the relative production volume at different gas fields in a given year.

The Kapuni gas field has particularly high CO_2 content. Historically, this field has been valued by the petrochemicals industry as a feedstock. However, most of the gas from this field is now treated, and the excess CO_2 is removed at the Kapuni Gas Treatment Plant. Consequently, separate emission factors were used to calculate emissions from Kapuni treated and untreated gas, due to the difference in carbon content (see annex 4, table A4.1). Carbon dioxide removed from raw Kapuni gas then vented is reported under 1.B.2.b.2 *Production/processing*.

Biomass

The emission factors for wood combustion are calculated from the IPCC 2006 default emission factors. This assumes that the net calorific value is 20 per cent lower than the gross calorific value (IPCC, 2006). Carbon dioxide emissions from wood used for energy production are reported as a memo item and are not included in the estimate of New Zealand's total greenhouse gas emissions (IPCC, 2006). Carbon dioxide emission factors for liquid biofuels are sourced from the *New Zealand Energy Information Handbook* (Baines, 1993), while CH_4 and N_2O emission factors are IPCC 2006 default emission factors.

3.3.2   Sector-wide improvements

The system for tracking and calculating emissions within the Energy sector was migrated to the R programming language. This migration allowed for improved checking and correction of existing calculations and records, especially for historical data.

All source-specific improvements are discussed in their corresponding sections.

3.3.3   Sector-wide planned improvements

All source-specific planned improvements are discussed in their corresponding sections.

MBIE will continue to examine the use of more specific solid fuel CO_2 emission factors.

3.3.4   Sector-wide quality assurance/quality control (QA/QC)

In the preparation of this inventory, the *Fugitive* category underwent Tier 1 quality-assurance and quality-control checks as recommended in the 2006 IPCC Guidelines. These include regular control sums throughout systems to verify system integrity, time-series consistency checks on activity data and consistency checks on implied emission factors at the industry–plant level, where possible. Figure 3.3.2 describes the quality control process map for the Energy sector.

Figure 3.3.2   Energy sector quality control process map

Energy
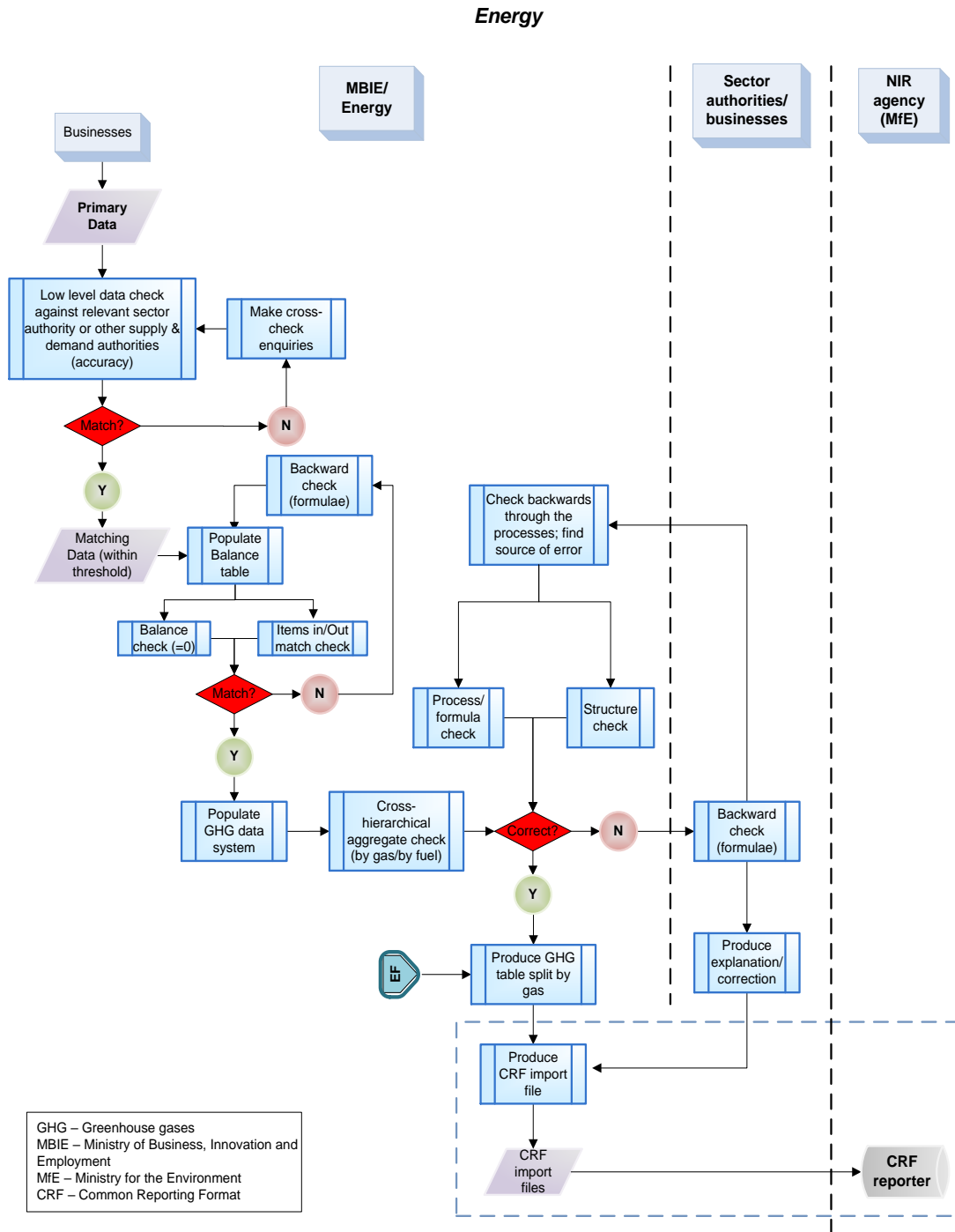
As discussed in section 3.1, the reference approach provides a good, high-level quality check for activity data. A significant deviation (greater than 5 per cent) indicates a likely issue.

Implied CO_2 emission factors for combustion of liquid, solid and gaseous fuels from this inventory were compared with those in the IPCC Emission Factor Database, 2012, and converted to gross values for comparability with the New Zealand energy system.

Figure 3.3.3, figure 3.3.4 and figure 3.3.5 weight the upper, lower and middle IPCC 2006 emission factor ranges according to observed fuel consumption in New Zealand for the given year. For example, the top of the IPCC range for liquid fuels was calculated using the top of the

IPCC 2006 emission factor range for each liquid fuel and observed New Zealand activity data for each liquid fuel.

The sum of all these emissions was then divided by the total observed liquid fuel combustion to obtain an implied emission factor weighted by New Zealand liquid fuel use. This was repeated for all fuel groups and years for the high, low and mid-points of the IPCC 2006 ranges.

With the exception of gaseous fuels (as discussed in section 3.3.1), each fuel type falls within the IPCC default range.

Figure 3.3.3   Carbon dioxide implied emission factor (IEF) – Liquid fuel combustion
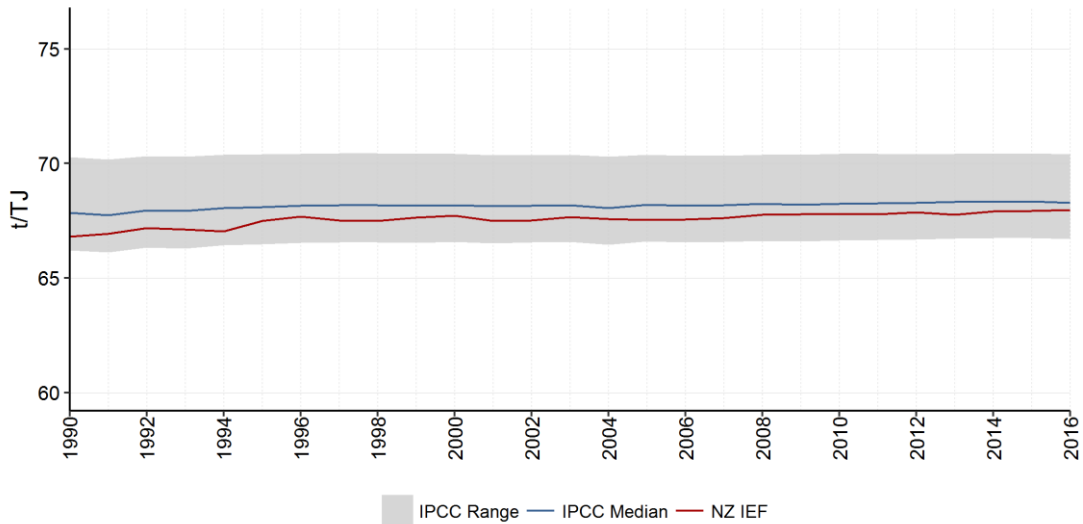
Figure 3.3.4   Carbon dioxide implied emission factor (IEF) – Solid fuel combustion
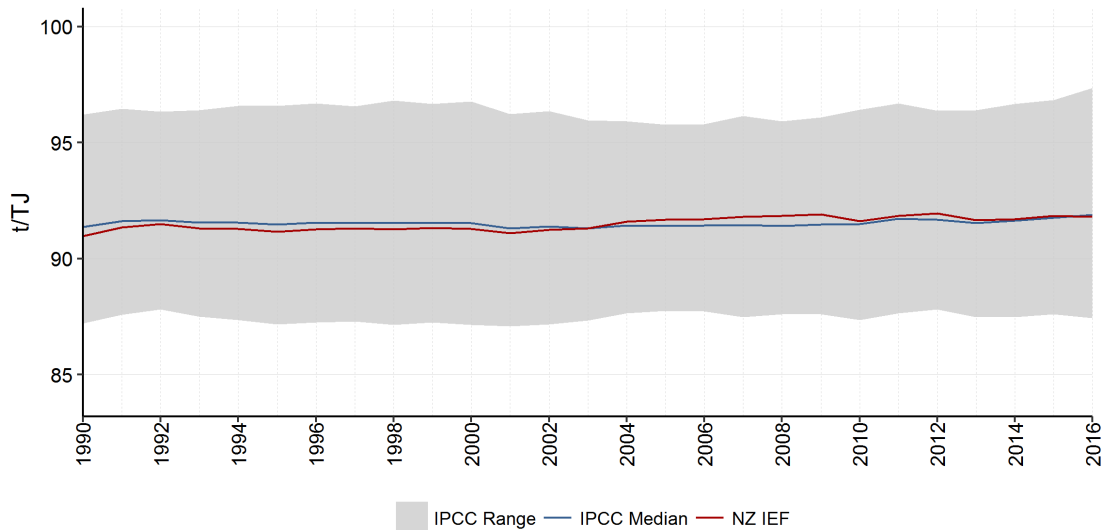
Figure 3.3.5   Carbon dioxide implied emission factor (IEF) – Gaseous fuel combustion
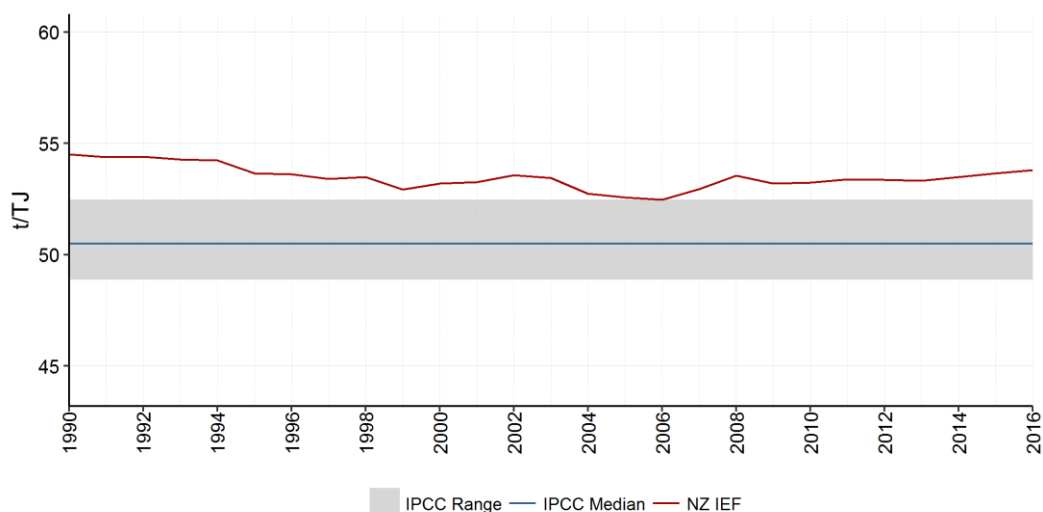
Note: As discussed in section 3.3.1 under 'Emission factors', carbon dioxide emission factors for New Zealand natural gas fields are established through gas composition analysis and are known to be high by international standards.

3.3.5   Uncertainties and time-series consistency

Uncertainty in greenhouse gas emissions from fuel combustion varies, depending on the type of greenhouse gas. The uncertainty of CO_2 emissions is relatively low. This is important because CO_2 emissions comprised 96.3 per cent of CO_2-e emissions from fuel combustion in New Zealand in 2016. By comparison, emissions of the non-CO_2 gases are much less certain because emissions vary with combustion conditions. Uncertainties for CO_2, CH_4 and N_2O activity data and emission factors are supplied in table 3.3.1. Many of the non-CO_2 emission factors used by New Zealand are the IPCC default values. Further detailed information around uncertainties for each fuel type can be found in annex 4, sections A4.1, A4.2 and A4.3.

Table 3.3.1   Uncertainty for New Zealand's Energy sector emission estimates

		Activity data uncertainty (%)	Emission factor uncertainty (%)
CO_2	Liquid fuels	1.5	±0.5
	Solid fuels	1.2	±2.2
	Gaseous fuels	−0.7	±2.6
	Fugitive – geothermal	5.0	±5.0
	Fugitive – venting/flaring	−0.7	±2.6
	Fugitive – oil and gas production and transport	5.0	±100.0
	Fugitive – transmission and distribution	−0.7	±100.0
CH_4	Liquid fuels	1.5	±50.0
	Solid fuels	1.2	±50.0
	Gaseous fuels	−0.7	±50.0
	Biomass	50.0	±50.0
	Fugitive – geothermal	5.0	±5.0
	Fugitive – venting/flaring	−0.7	±50.0
	Fugitive – coal mining and handling	0.7	±50.0
	Fugitive – transmission and distribution	−0.7	±100.0
	Fugitive – oil and gas exploration and production	−0.7	±100.0
	Fugitive – oil transportation	5.0	±50.0

		Activity data uncertainty (%)	Emission factor uncertainty (%)
N$_2$O	Liquid fuels	1.5	±50.0
	Solid fuels	1.2	±50.0
	Gaseous fuels	−0.7	±50.0
	Fugitive – venting/flaring	5.0	±100.0
	Biomass	50.0	±50.0

New Zealand uses the percentage difference between annual calculated consumer energy from supply-side surveys and annual observed consumer energy from demand-side surveys to estimate activity data uncertainty. As a result, activity data uncertainty can vary significantly from year to year.

3.3.6   Fuel combustion: Energy industries (CRF 1.A.1)

Description

This category includes combustion for public electricity and heat production, petroleum refining and the manufacture of solid fuels and other energy industries. The latter category includes estimates for natural gas in oil and gas extraction and from natural gas in synthetic gasoline production. The excess CO_2 removed from Kapuni gas at the Kapuni natural gas treatment plant has also been reported under the *Manufacture of solid fuels and other energy industries* category because of confidentiality concerns.

In 2016, emissions in category 1.A.1 *Energy industries* totalled 4,162.5 kt CO_2-e (13.3 per cent of the Energy sector emissions). Emissions from energy industries have decreased by 1,841.4 kt CO_2-e (–30.7 per cent) since the 1990 level of 6,003.9 kt CO_2-e. Category 1.A.1.a *Public electricity and heat production* accounted for 3,038.6 kt CO_2-e (73.0 per cent) of the emissions from the *Energy industries* category in 2016. This is a decrease of 463.6 kt CO_2-e (–13.2 per cent) from the 1990 level of 3,502.3 kt CO_2-e.

Changes in emissions between 2015 and 2016

Between 2015 and 2016, there was a decrease of 995.3 kt CO_2-e (–24.7 per cent) in emissions from 1.A.1.a *Public electricity and heat production*. This was largely because the share of electricity generated from renewable energy sources was 84.8 per cent in 2016, up from 80.8 per cent in 2015. This resulted in decreased gas and coal-fired generation over the year, which together decreased 21.6 per cent from 2015.

Key categories identified in the 2016 level assessment from the *Energy industries* category include CO_2 emissions from:

- Public electricity and heat production – solid fuels

- Public electricity and heat production – gaseous fuels

- Manufacture of solid fuels and other energy industries – gaseous fuels

- Petroleum refining – liquid fuels.

Key categories identified in the 1990–2016 trend assessment from the *Energy industries* category include CO_2 emissions from:

- Public electricity and heat production – solid fuels

- Public electricity and heat production – gaseous fuels

- Petroleum refining – liquid fuels

- Petroleum refining – gaseous fuels

- Manufacture of solid fuels and other energy industries – gaseous fuels.

New Zealand's electricity generation is dominated by hydroelectric generation. For the 2016 calendar year, hydro generation provided 60.4 per cent of New Zealand's electricity generation. A further 17.5 per cent came from geothermal, 5.4 per cent from wind, 1.4 per cent from biomass and 0.1 per cent from solar. The remaining 15.1 per cent was provided by fossil fuel thermal generation plants using gas, coal and oil (MBIE, 2017).

Greenhouse gas emissions from the *Public electricity and heat production* category show large inter-annual fluctuations between 1990 and 2016. These fluctuations can also be seen over the time series for New Zealand's gross emissions. The fluctuations are influenced by the close inverse relationship between thermal and renewable generation (see figure 3.3.6). In a dry year, where low rainfall affects most of New Zealand's hydroelectric lake levels, the shortfall is made up by thermal electricity generation. New Zealand's hydro resources have limited storage capacity; total reservoir storage is only around ten per cent of New Zealand's annual demand. Hence, regular rainfall throughout the year is needed to sustain a high level of hydro generation. Electricity generation in a 'normal' hydro year does not require significant use of natural gas and coal, while a 'dry' hydro year necessitates higher utilisation of natural gas and coal.

Figure 3.3.6   New Zealand's electricity generation by source
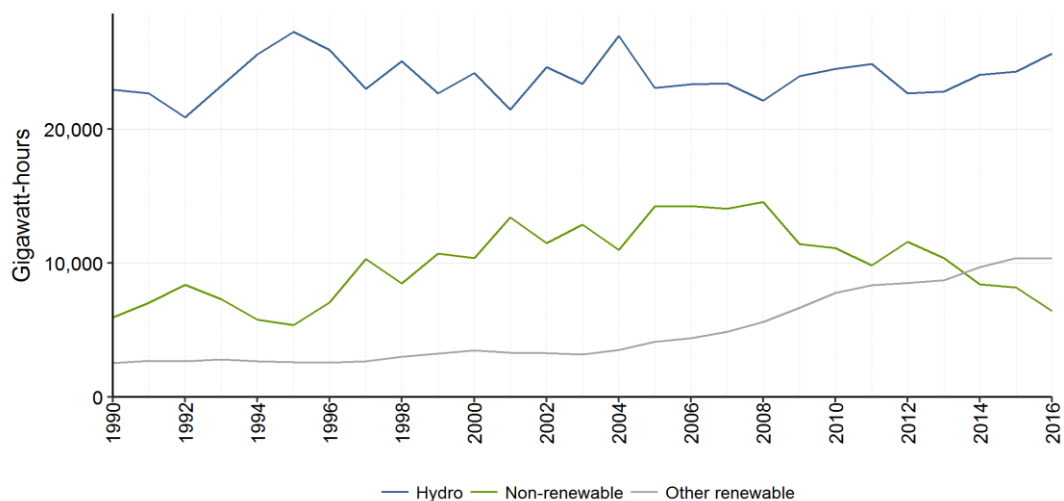
Methodological issues

1.A.1.c Manufacture of solid fuels and other energy industries

Methanex New Zealand produced synthetic gasoline until 1997. A Tier 2 methodology was used to estimate CO_2 emissions based on the annual weighted average gas emission factor.

In this submission, combustion related to pipeline transport has been recategorised from 1.A.1.c to 1.A.3.e.i *Pipeline transport*.

Activity data

1.A.1.a Public electricity and heat production

All thermal electricity generators provide figures to MBIE for the amount of coal, natural gas and oil used for electricity generation. Greenhouse gas emissions from geothermal electricity generation are reported under 1.B.2.d.

Around 5 per cent of New Zealand's electricity is supplied by co-generation (also known as combined heat and power) (MBIE, 2017). Most of the major co-generation plants are attached to large industrial facilities that consume most of the generated electricity and heat.

Six co-generation plants that fit the IPCC 2006 definition of public electricity and heat production produce electricity as their primary purpose. The emissions from these plants are included under the *Public electricity and heat production* category, while emissions from other co-generation plants are included within the *Manufacturing industries and construction* category (section 3.3.7).

To establish a consistent approach to on-site generation, MBIE developed a decision tree to guide the allocation of associated fuel consumption and identify whether the plant is a main activity electricity generator or an autoproducer (see figure 3.3.7).

Figure 3.3.7   Decision tree to identify a main activity electricity generator or an autoproducer
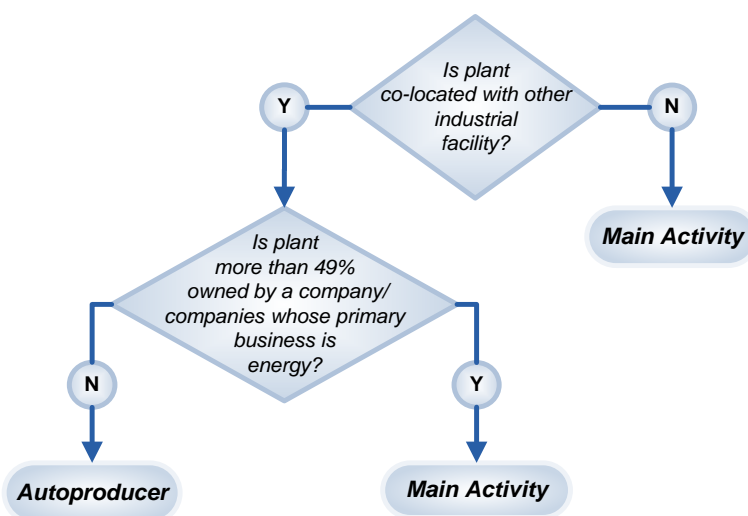
1.A.1.b Petroleum refining

Refining New Zealand provides annual activity data and emission factors for each type of fuel being consumed at the site. The fuel-type specific emission factors were adopted under the Government's Projects to Reduce Emissions in 2003 (Ministry for the Environment, 2009).

Refinery gas is obtained during the distillation of crude oil and production of oil products. As a result, emissions from its combustion are implicitly included under liquid fuels in the reference approach.

1.A.1.c.ii Manufacture of solid fuels and other energy industries – Other energy industries

Activity data for the useful combustion (own use) of natural gas during oil and gas extraction are provided to MBIE by each individual gas and/or oil field operator. Some crude oil is also combusted (own use) during oil and gas extraction. The quantity is reported directly by the oil and/or gas field operator to MBIE.

Emissions from natural gas combustion (own use) for the purpose of natural gas transmission are reported directly by the transmission network operator to MBIE. Emissions from natural gas combustion (own use) for the purpose of natural gas processing are reported directly by the plant operator to MBIE.

Emission factors

Gaseous fuels

As mentioned in section 3.3.1, New Zealand's natural gas emission factor fluctuates from year to year, mainly due to the different mixture of gas fields that produced gas in that year. New Zealand gas fields also have higher CO_2 content than most international gas fields. This is particularly evident in the *Public electricity and heat production* category.

Uncertainties and time-series consistency

Uncertainties in emissions and activity data estimates for this category are relevant to the entire Fuel combustion sector (see table 3.3.1).

Source-specific QA/QC and verification

In the preparation of this inventory, the *Energy industries* category underwent Tier 1 quality-assurance and quality-control checks as recommended in the 2006 IPCC Guidelines. These include regular control sums throughout systems to verify system integrity, and consistency checks on implied emission factors.

Source-specific recalculations

Updated activity data have been provided by some plant operators for the quantity of natural gas consumed for electricity generation. This has resulted in some recalculations for recent years.

3.3.7 Fuel combustion: Manufacturing industries and construction (CRF 1.A.2)

Description

This category comprises emissions from fossil fuels combusted in iron and steel, other non-ferrous metals, chemicals, pulp, paper and print, food processing, beverages and tobacco, and other uses. Emissions from co-generation plants that do not meet the definition of co-generation as provided in the IPCC Guidelines are included in this category.

In 2016, emissions from the 1.A.2 *Manufacturing industries and construction* category accounted for 6,906.2 kt CO_2-e (22.1 per cent) emissions from the Energy sector. Emissions from this category were 2,146.0 kt CO_2-e (45.1 per cent) above the 1990 level of 4,760.2 kt CO_2-e. A decline in methanol production in 2003–04 caused a significant reduction in emissions from this category. Methanol production is the largest source of emissions in category 1.A.2.c *Chemicals*. Methanex New Zealand has restarted previously mothballed plants, and operated all three of its plants during 2016, averaging 89 per cent of full capacity over the year, up from 76 per cent for 2015.

Changes in emissions between 2015 and 2016

Between 2015 and 2016, emissions from the *Manufacturing industries and construction* category increased by 97.3 kt CO_2-e (1.4 per cent). This was driven chiefly by an increase in emissions from the *Chemicals* category, up 230.8 kt CO_2-e (13.3 per cent) from 2015.

Key categories identified in the 2016 level assessment from the *Manufacturing industries and construction* category include CO_2 emissions from:

- Chemicals – gaseous fuels

- Food processing, beverages and tobacco – gaseous fuels

- Food processing, beverages and tobacco – liquid fuels
- Food processing, beverages and tobacco – solid fuels
- Pulp, paper and print – gaseous fuels
- Other – mining and construction – liquid fuels
- Other – non-metallic minerals – solid fuels
- Other – other non-specified – liquid fuels

Key categories identified in the 1990–2016 trend assessment from the *Manufacturing industries and construction* category include CO_2 emissions from:

- Chemicals – gaseous fuels
- Food processing, beverages and tobacco – gaseous fuels
- Food processing, beverages and tobacco – liquid fuels
- Food processing, beverages and tobacco – solid fuels
- Other – mining and construction – liquid fuels
- Other – non-metallic minerals – solid fuels
- Other – other non-specified – liquid fuels
- Other – other non-specified – solid fuels.

Methodological issues

To ensure there is no double counting of emissions, in some instances, emissions from the use of solid fuels and gaseous fuels are excluded from this category because they are accounted for under the IPPU sector. New Zealand Steel Limited uses coal as a reducing agent in the steel-making process. In accordance with 2006 IPCC Guidelines, the emissions from this are included in the IPPU sector rather than the Energy sector. In a number of instances, natural gas is excluded from the *Manufacturing industries and construction* category because it is accounted for under the IPPU sector. This includes urea production, hydrogen production and some of the natural gas used by New Zealand Steel (New Zealand Steel separately reports its emissions from natural gas as part of the combustion process and natural gas as part of the chemical process).

Activity data

The previous submission further disaggregated emissions formerly reported under category 1.A.2.g *Manufacturing industries and construction – other* into specific categories. This resulted in the *Other* category becoming much smaller.

Energy balance tables released with *Energy in New Zealand* (MBIE, 2017) split out industrial uses of energy using the Australian and New Zealand Standard Industrial Classification 2006. This was possible because of the collection of more detailed information from the various surveys used to compile the energy balance tables since 2009.

This has allowed a further disaggregation of the *Manufacturing industries and construction* category and, therefore, greater transparency. Where actual survey data are not available at the required level, estimates of the energy use across these categories have been made to ensure time-series consistency. These are described in further detail below.

Solid fuels

In 2010, the disaggregation of the *Manufacturing industries and construction* category for coal was implemented within the energy greenhouse gas data system. This was the first time this

category was disaggregated and it was applied from 2009. These percentage splits, based on 2009 data, were applied to activity data for the annual inventory submission across the whole time series (back to 1990). However, during 2014, the coal data system at MBIE was revised to internally disaggregate manufacturing industries based on a 2011 survey of major coal users. Therefore, applying the disaggregation procedure previously used within the greenhouse gas data system is no longer necessary.

From 2009 onwards, the coal sales survey conducted by MBIE provides data at a more disaggregated level.

Solid biomass

The Bioenergy Association of New Zealand conducted a 2006 Heat Plant Survey of New Zealand (Bioenergy Association of New Zealand, 2011) to gain information on heat plant (boiler) capacity and use in New Zealand. One area this survey examined was solid biomass use in New Zealand industrial companies (see table 3.3.2). The survey shows that most solid biomass in New Zealand is used by the wood processing industry. The industrial splits from the survey were used to separate out solid biomass activity data for the inventory. These splits were applied across the whole time series (back to 1990) for activity data and CO_2, CH_4 and N_2O emissions.

Table 3.3.2   **Solid biomass splits for 2006 that were used to disaggregate the Manufacturing industries and construction category between 1990 and 2016**

CRF category code	Manufacturing industries and construction category	Per cent
1.A.2.a	Iron and steel	NO
1.A.2.b	Non-ferrous metals	NO
1.A.2.c	Chemicals	NO
1.A.2.d	Pulp, paper and print	99.94
1.A.2.e	Food processing, beverages and tobacco	0.05
1.A.2.g	Other – mining and construction	NO
1.A.2.g	Other – textiles	NO
1.A.2.f	Other – non-metallic minerals	NO
1.A.2.f	Other – manufacturing of machinery	NO
1.A.2.g	Other – non-specified	0.01

Note: NO = not occurring. Survey data indicate that solid biomass combustion does not occur in the sectors.

Gas biomass

Sludge gas is produced at the Tirau dairy processing facility. Cattle effluent is used to produce sludge gas that is used to raise heat for the milk processing facility, which is open from September through to December each year. See section 3.3.1 (Biomass) for further information.

Sludge gas is not metered or analysed at the site, but estimates of flow rate and CH_4 content were obtained from the facility manager for the 2011 reporting year. MBIE then used these data to calculate an estimate of the total energy content, which was then confirmed by the facility manager.

The facility has operated in the same fashion since its construction in the late 1980s. Therefore this estimate was assumed to be valid across the time series.

Liquid fuels (diesel, gasoline and fuel oil)

As mentioned in section 3.3.1 (Liquid fuels), New Zealand uses the *Annual Liquid Fuel Survey* to capture sales by independent distributors. With this information, some liquid fuel demand

that would otherwise be allocated to national transport is reallocated to the correct sector's demand. In terms of the Energy sector emission estimates, emissions attributed to category 1.A.3 *Transport* decrease by around 20 per cent as a result of this reallocation, and emissions attributed to other categories, such as 1.A.4.c *Agriculture/forestry/fishing*, increase significantly.

Following ERT recommendations (2007 in-country review), New Zealand began to disaggregate liquid fuel combustion in the 1.A.2 *Manufacturing industries and construction* category for the 2011 inventory. Diesel and gasoline consumption were disaggregated for the 2012 submission, and the method has been extended to include fuel oil for this submission.

While data are not collected at this level of detail in energy surveys for liquid fuels, New Zealand has produced estimates based on Statistics New Zealand survey data. Statistics New Zealand conducted a manufacturing energy use survey (Statistics New Zealand, 2017), which assessed energy consumption and end use across manufacturing industries for the 2016 calendar year.

These splits, along with category gross domestic product (GDP) data from Statistics New Zealand for the period, were used to calculate implied energy intensities (PJ per unit of GDP) for each category for diesel, gasoline and fuel oil. These intensities were then applied to Statistics New Zealand GDP data across the time series and scaled to match the fuel sales reported for all manufacturing industries and construction to estimate activity data for each category.

By disaggregating into categories, more accurate estimates of stationary versus mobile combustion for diesel were also able to be made, resulting in small changes to the emissions from manufacturing industries and construction.

Disaggregating the *Manufacturing industries and construction* category for solid fuels, solid biomass, gasoline and diesel has led to a significant decrease in the *Other – not specified* category (1.A.2.g) under *Manufacturing industries and construction*. The splits are shown in figure 3.3.8, figure 3.3.9 and figure 3.3.10.

Figure 3.3.8   Splits used for Manufacturing industries and construction category – Gasoline
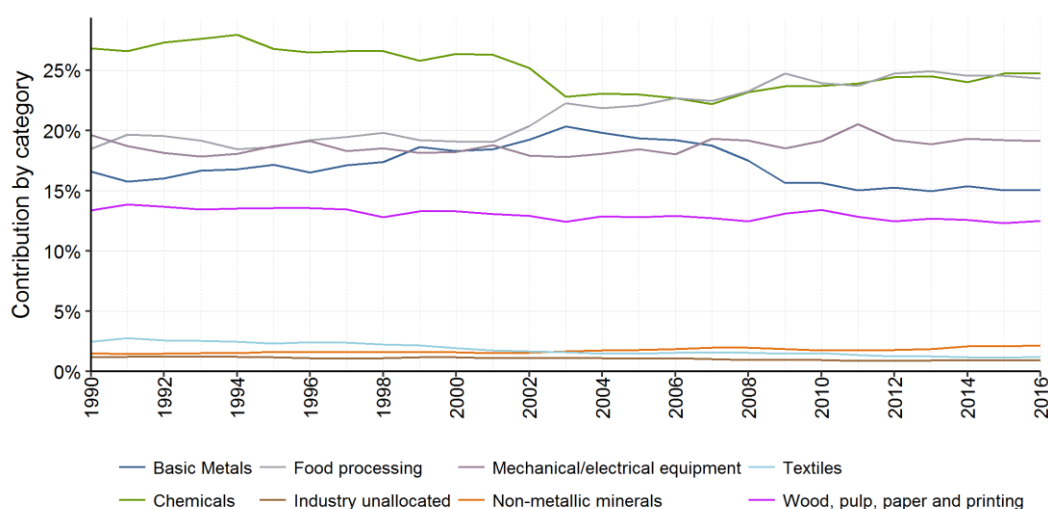
Figure 3.3.9   Splits used for Manufacturing industries and construction category – Diesel (1990–2016)
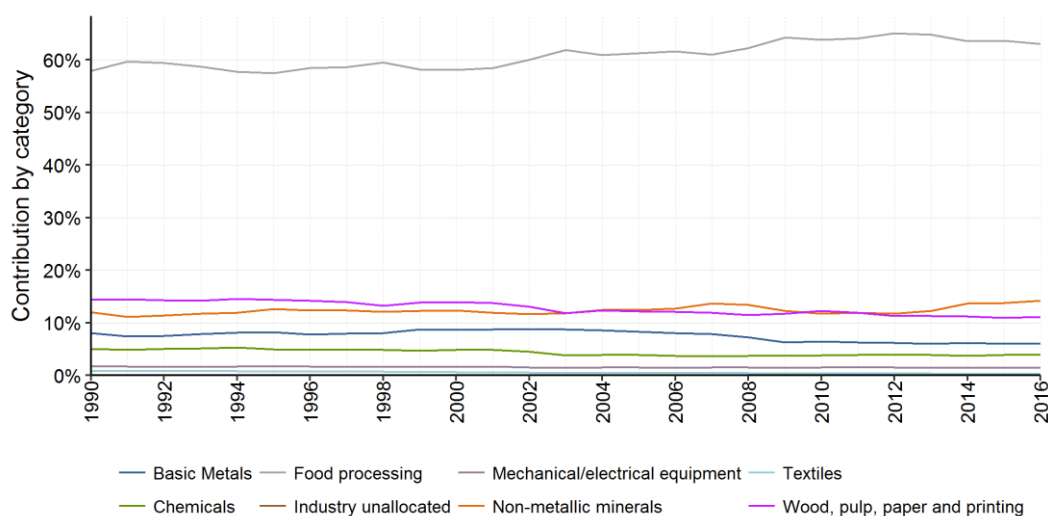
Figure 3.3.10   Splits used for Manufacturing industries and construction category – Fuel oil (1990–2016)
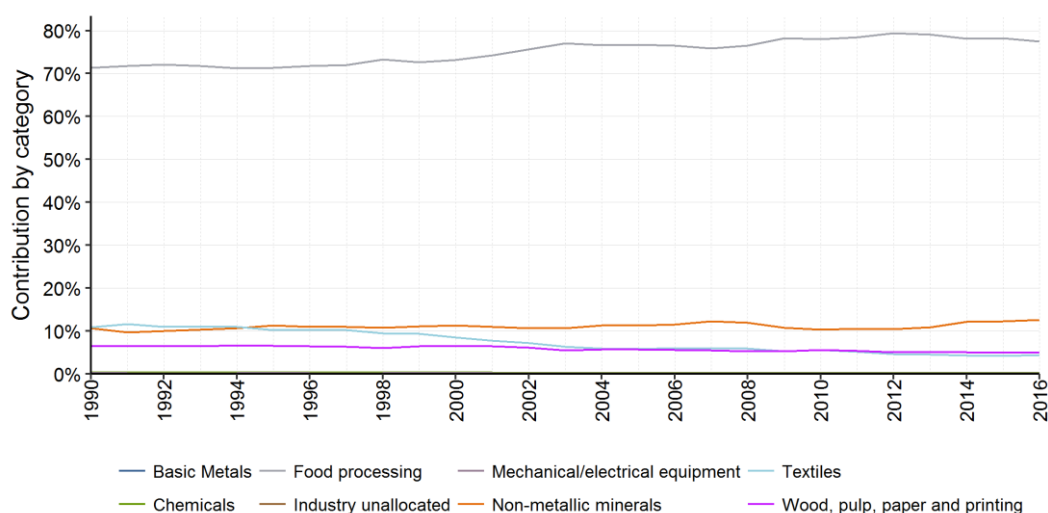
Gaseous fuels

Annual natural gas consumption statistics are published by MBIE. A review of the allocation of natural gas consumption data was undertaken in 2011 by MBIE. The purpose of this review was to address time-series discontinuities in the sectoral breakdown for some sectors prior to 2006. Several inconsistencies in sector reporting were found, along with a considerable amount of missing data for sectoral breakdowns. Inconsistencies from 2003–05 were due to changing surveys over time. Inconsistencies or missing data prior to 2003 were re-worked and re-estimated. These missing data comprised around 40 per cent of total natural gas use (which was not altered at a total level but only reallocated by sector).

Where necessary, new estimates of gas consumption were made depending on data availability. The chosen data source in order of preference was as follows.

- Data from major consumers of natural gas were used if available because they are more reliable, accurate and easily classified by sector.

- Where these data were not available, natural gas retailers' reported sales by sector were used.

- If these data were also not available, then estimates based on regressions using GDP data were used. GDP output/production data were used along with assumptions about energy intensity/consumption of categories (to as detailed a level as possible).

Because there are a number of sector classifications represented by only one or two major natural gas consumers, data from major consumers were sometimes able to be used as the first preference, but not always. Where there are industries with many major natural gas consumers, gas retailers' reported sales by sector were used, though these can at times exhibit data-quality issues.

A review was also undertaken in 2014 by MBIE covering data going back to 1999. Several sales previously identified as wholesale sales (i.e., gas bought to be on-sold) were in fact sold to consumers, but at 'wholesale' (lower) prices. Work was done to correct the classifications of these sales, based on customer name, to their relevant sectors.

1.A.2.a Iron and steel

Activity data for coal used in iron and steel production are reported to MBIE by New Zealand Steel Limited. A considerable amount of coal is used in the production of iron. Most of the coal is used in the direct reduction process to remove oxygen from iron-sand. However, all emissions from the use of coal are included in the IPPU sector because the primary purpose of the coal is to produce iron (IPCC, 2006). A small amount of natural gas is used in the production of iron and steel to provide energy for the process and is reported under the Energy sector in 1.A.2.a *Iron and steel*.

1.A.2.c Chemicals

The *Chemicals* category includes estimates from the following sub-industries:

- industrial gases and synthetic resin

- organic industrial chemicals

- inorganic industrial chemicals, other chemical production, rubber and plastic products.

The quantity of natural gas used for the production of methanol and ammonia (and subsequently urea) has been split into feedstock gas, which is included in 2.B.8.a and 2.B.1 respectively, and energy-use gas, which is included in 1.A.2.c *Chemicals*. Further details are included in chapter 4 (IPPU sector).

The activity data for methanol production are supplied directly by Methanex New Zealand. Until 2004, methanol was produced at two plants by Methanex New Zealand. In November 2004, production at the Motunui plant was halted and the plant re-opened in late 2008. Methanex New Zealand exports most of this methanol.

Methanex is the sole methanol producer in New Zealand and considers its natural gas consumption to be commercially sensitive information. New Zealand takes a Tier 2 (IPCC, 2006) approach to estimating emissions from methanol production that uses natural gas consumption at the plant along with country- and field-specific emission factors to calculate potential emissions before deducting the carbon sequestered in the end product.

The major non-fuel-related emissions from the methanol process are CH_4 and non-methane volatile organic compounds.

As mentioned in section 3.3.1, on-site electricity generation is allocated to either the *Public electricity and heat production* category or the sector in which the associated plant operates, using the decision tree shown in figure 3.3.7.

Uncertainties and time-series consistency

Uncertainties in emission and activity data estimates are those relevant to the entire Energy sector (annex 4, sections A4.1, A4.2 and A4.3).

Source-specific QA/QC and verification

In the preparation of this inventory, the *Manufacturing industries and construction* category underwent Tier 1 quality-assurance and quality-control checks as recommended in the 2006 IPCC Guidelines. These include regular control sums throughout systems to verify system integrity, and time-series consistency checks.

Source-specific recalculations

Some historical energy demand data may have been revised due to revisions in data provided by companies. This has resulted in minor revisions in activity data and corresponding emissions for some years.

3.3.8   Fuel combustion: Transport (CRF 1.A.3)

Description

This category includes emissions from fuels combusted during domestic transportation, such as civil aviation, road, rail and domestic marine transport. Emissions from international marine and aviation bunkers are reported as memo items and are not included in New Zealand's total emissions.

In 2016, category 1.A.3 *Transport* was responsible for 15,027.8 kt CO_2-e (48.0 per cent of emissions from the Energy sector), or 19.1 per cent of gross national emissions. Emissions have increased 6,255.5 kt CO_2-e (71.3 per cent) from the 8,772.3 kt CO_2-e emitted in 1990. The transport emissions profile in 2016 was dominated by emissions from category 1.A.3.b *Road transportation*. In 2016, road transport accounted for 13,612.6 kt CO_2-e (90.6 per cent) of total transport emissions. This is an increase of 6,137.3 kt CO_2-e (82.1 per cent) from the 1990 level of 7,475.3 kt CO_2-e.

Changes in emissions between 2015 and 2016

Between 2015 and 2016, emissions from transport increased by 265.0 kt CO_2-e (1.8 per cent).

Key categories identified in the 2016 level assessment from the *Transport* category include CO_2 emissions from:

- Domestic Aviation – jet kerosene

- Road Transportation – liquid fuels

- Domestic Navigation – residual fuel oil.

Key categories identified in the 1990–2016 trend assessment from the *Transport* category include CO_2 emissions from:

- Domestic Aviation – jet kerosene

- Road Transportation – liquid fuels

- Road Transportation – gaseous fuels.

Methodological issues

1.A.3.a Civil aviation

A Tier 1 approach (IPCC, 2006) that does not use landing and take-off cycles has been taken to estimate emissions from the *Civil aviation* category. Given the uncertainty surrounding CH_4 and N_2O emission factors for landing and take-off cycles, a Tier 2 approach to estimating non-CO_2 emissions would not necessarily reduce uncertainty (IPCC, 2006).

1.A.3.b Road transportation

The IPCC 2006 Tier 2 approach was used to calculate CO_2 emissions from *Road transportation* using New Zealand-specific emission factors. The emission factors were calculated using data provided by New Zealand's sole oil refinery for oil products and the weighted average emission factor of New Zealand natural gas fields for compressed natural gas (CNG).

Since the 2012 submission, New Zealand has used a Tier 3 (IPCC, 2006) methodology to estimate CH_4 and N_2O emissions from road transport. Data collected by New Zealand's Ministry of Transport provide comprehensive information on vehicle-kilometres-travelled by vehicle class and fuel type from 2001–16. Before 2001, insufficient data were available, so good practice guidance was used in choosing the splicing method to ensure time-series consistency.

The current New Zealand vehicle fleet is split evenly between vehicles:

- manufactured in New Zealand[25] or imported for sale as new vehicles

- produced and used in Japan and then imported into New Zealand.

This split has been relatively constant for the past eight years.

For this reason, when estimating emissions from road transport, the New Zealand vehicle fleet (and associated CH_4 and N_2O emissions) is split into the 'new vehicle fleet' and 'used vehicle fleet' (based on a vehicle's year of manufacture rather than when they are first added to the New Zealand fleet).

New vehicles were allocated an appropriate vehicle class from the COPERT 4 model (European Environment Agency, 2007), and used Japanese vehicles were allocated emission factors as per categories from the Japanese Ministry of the Environment. These emission factors are broken down by:

- vehicle type

- fuel type

- vehicle weight class

- year of manufacture.

Due to the presence of expensive catalysts, many used vehicles imported into New Zealand had their catalytic converters removed before being exported from Japan. The Ministry of Transport undertook several testing studies to determine the proportion of catalytic converters that are removed in Japan before export.

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[25]   As of 2016, New Zealand only manufactures a small number of buses and heavy trucks.

Information on non-CO_2 emission factors can be found in annex 4, table A4.7.

Vehicle-kilometres-travelled were sourced from national six-monthly warrant of fitness inspections. These were further split into travel type (urban, rural, highway, motorway) using New Zealand's Road Assessment and Maintenance Management system.

The *New Zealand Travel Survey* (Ministry of Transport, 2010) is used to further split the 'urban' travel type into cold and hot starts. This survey provides detailed trip-by-trip information on travel type. These data were used to establish the percentage of light-vehicle urban travel that was cold and hot starts.

MBIE and the Ministry for the Environment met with the Australian inventory reporting team in July 2011 to conduct a review of proposed methodologies for calculating emissions of CH_4 and N_2O emissions associated with road transport. New Zealand's Tier 3 approach for road transport was presented, resulting in a recommendation from the Australian team that the new methodology be adopted for the 2012 submission, and that New Zealand attempt to use the IPCC-recommended approach to selecting splicing techniques to choose an appropriate splicing method. In this, New Zealand applied splicing techniques following the 2006 IPCC Guidelines on the method selection approach.

Figure 3.3.11 and figure 3.3.12 each compare the previously used Tier 1 method with the method for estimation of non-CO_2 emissions from gasoline combustion with the Tier 3 method used in this submission.

Figure 3.3.11   Methane emissions from road transport – Gasoline
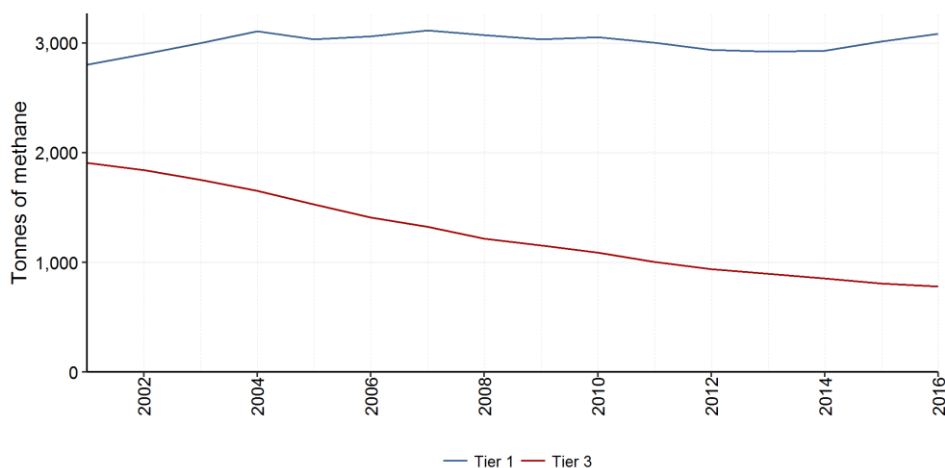
Figure 3.3.12   Nitrous oxide emissions from road transport – Gasoline
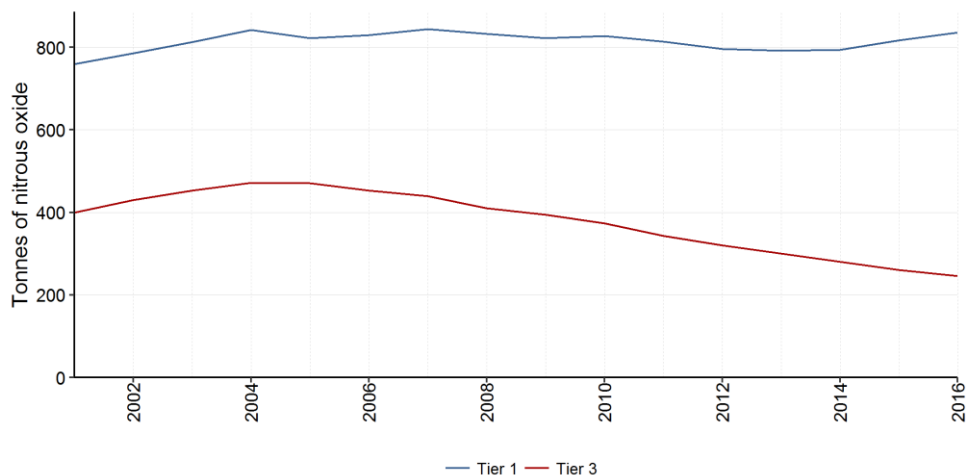
Time-series consistency

The data available for applying the Tier 3 methodology between 1990 and 2000 were insufficient, so combining the methods to form a complete time series (splicing) was necessary. To establish the most appropriate splicing method, emissions were calculated using the Tier 1 methodology for the period 2001–16. These emissions were compared against those calculated using the Tier 3 methodology, to determine the relationship between the two series (see figure 3.3.13). The guidance for the method selection process is provided in table 5.1 (volume 2) of the 2006 IPCC Guidelines.

Figure 3.3.13   Splicing method decision tree for gasoline emissions

Note: 'EF' = emission factor;
'AD'= activity data
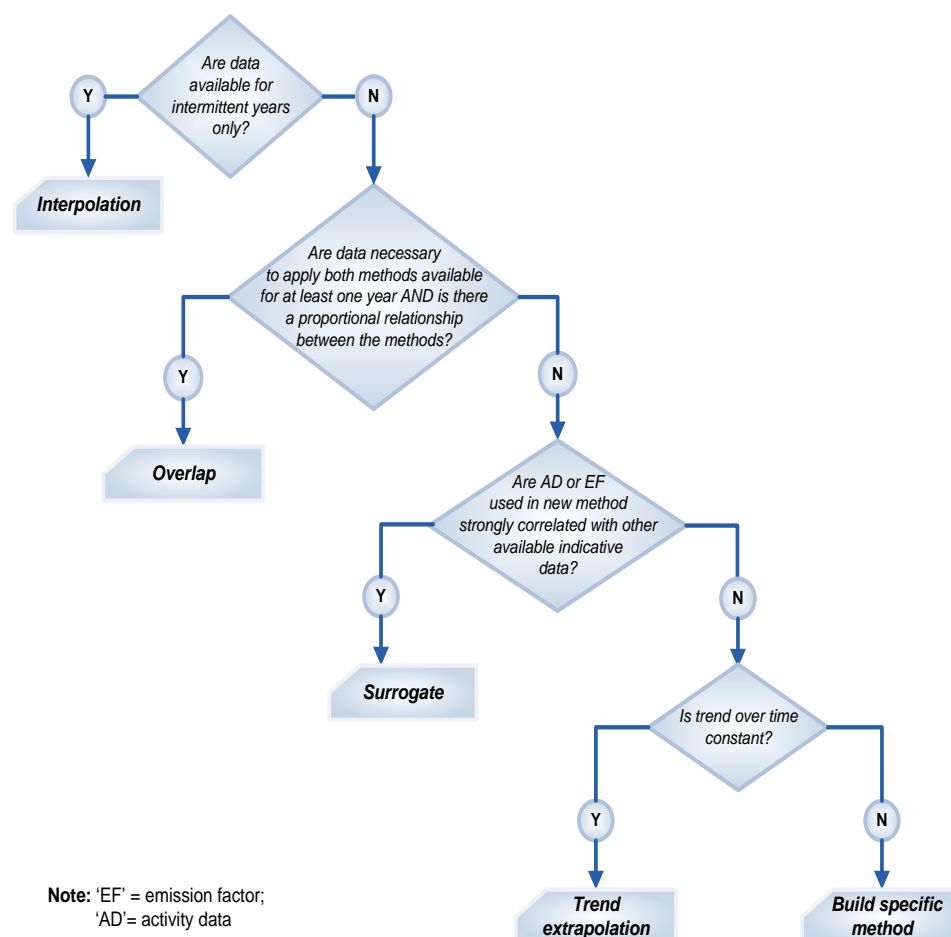
For all fuels, interpolation was considered inappropriate due to the size of the block of unavailable data and the lack of data from before the missing block (1990–2000).

For emission estimates from liquefied petroleum gas (LPG), the relationship between Tier 1 and Tier 3 appears nearly constant for both N_2O and CH_4 from 2001 until 2002. As a result, the overlap method was used (IPCC, 2006), with:

$$y_t = x_t \left(\sum_{i=m}^{n} y_i \Big/ \sum_{i=m}^{n} x_i \right)$$

Where: y_t is the recalculated emission estimate computed using the overlap method

x_t is the estimate developed using the previous method

y_i and x_i are the estimates prepared using the new and previously used methods during the period of overlap, as denoted by years m through n.

However, for gasoline and diesel vehicles, the ratio Tier 3:Tier 1 appears to change approximately linearly with time. While surrogates for Ministry of Transport data were available (fuel consumption), their use resulted in a step-change that is unlikely to be representative of road transport emissions for the period. While the trend in emissions was not consistent over time, the trend of the Tier 3:Tier 1 ratio emission estimates showed a strong linear relationship with time. As a result, a hybrid method of overlap and trend extrapolation was chosen with:

$$y_t = (at + b)x_t$$

Where: t is the year for which a new estimate is required

a is the slope of the line achieved by regressing Tier 3:Tier 1 for the overlap period

b is the intercept of the line achieved by regressing Tier 3:Tier 1 for the overlap period

x_t is the estimate for year t using the previous methodology.

The relationship between Tier 3 and Tier 1 emissions is linear from 2001 to 2005 (inclusive) for both CH_4 and N_2O. This relationship was extrapolated back to the beginning of the time series to derive a factor by which to multiply the Tier 1 estimate for a given year.

A quality check was necessary to confirm that extrapolation of this trend over such a long period did not result in a New Zealand-implied emission factor diverging significantly from international observation. An international average implied emission factor was calculated using the IPCC Emission Factor Database. For the purposes of this calculation, all countries using default emission factors – including New Zealand – were removed from the calculation.

Figure 3.3.14 and figure 3.3.15 indicate that the implied emission factor resulting from the new methodology and splicing is consistent with those observed internationally across the time series. The agreement is poorer for N_2O emissions, due to the more complicated effect of changing technology and the lack of data at key stages in the technology update.

International estimates show a peak in implied emission factors for N_2O between the mid-1990s and the early 2000s. This peak is consistent with the tendency of first-generation emission control technology to reduce particulate and CH_4 emissions but increase N_2O emissions. In later years, as more advanced emission control technologies enter the fleet, N_2O emission factors decline.

First-generation emission control technology could be damaged by leaded gasoline. Lead was removed from all gasoline in New Zealand in 1996, therefore, it is likely that N_2O emission factors were flat for the early 1990s and began to increase some time shortly after this. However, as data for this period are not available, the trend from 2001 to 2004 was extrapolated back to 1990. This is a conservative approach that is likely to overestimate rather than underestimate N_2O emissions.

Figure 3.3.14   Nitrous oxide implied emission factors – Gasoline road transport
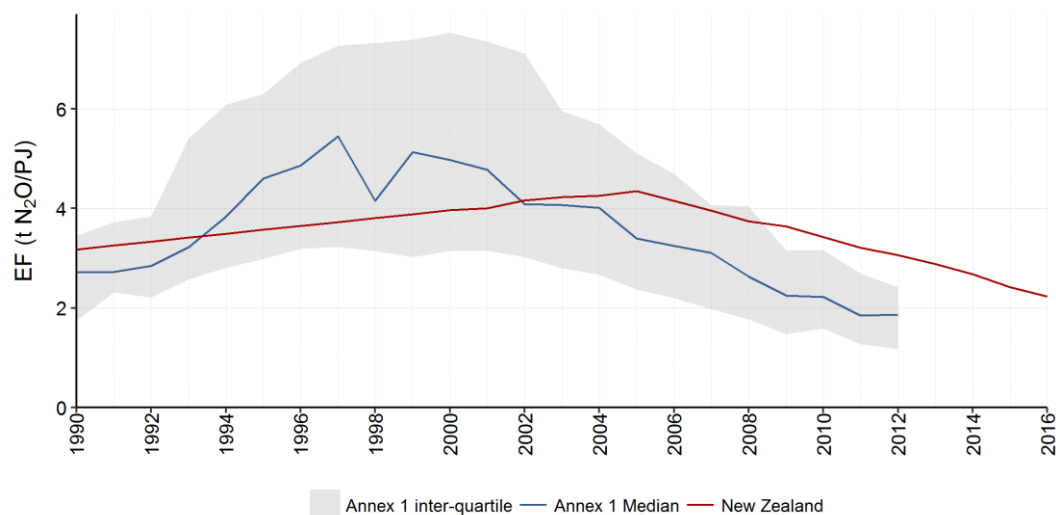
Note: Only 1990–2012 data were available for Annex I Parties at the time of the inventory compilation.

Figure 3.3.15   Methane implied emission factors – Gasoline road transport
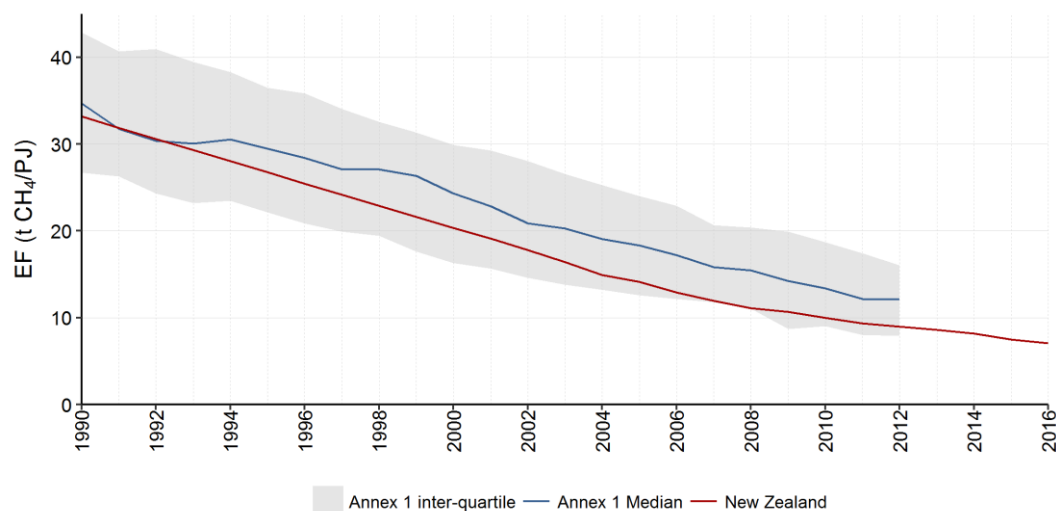
Note: Only 1990–2012 data were available for Annex I Parties at the time of the inventory compilation.

Dual-fuel vehicles

Vehicle-kilometres-travelled data collected by the Ministry of Transport allocate vehicles using dual fuels (LPG–gasoline and CNG–gasoline) to the *Gasoline* category. Historically, non-CO_2 emission factors have been lower for LPG than those for gasoline. Analysis undertaken to remove activity data from gasoline to be allocated to LPG resulted in a slight decrease in overall emissions. As a result, the reallocation was not made due to a desire to be conservative when applying methods that would lead to net emission reductions.

The amount of natural gas used in vehicles on New Zealand roads was significantly larger in 1990 than it was in 2016. In 2016, almost all natural gas in road transport was used in buses. For the purposes of time-series consistency, the new methodology was considered incomparable with the previous methodology due to fundamental differences in the type of activity that the two methods represent. The CH_4 emission factors (tonnes CH_4/PJ) from a purpose-built natural gas (CNG) bus are known to be significantly lower than those from a light passenger vehicle built to run on gasoline then converted to use natural gas.

To ensure that emissions were not underestimated, an estimate of the energy used in CNG buses was made. The remaining natural gas was then assumed to be combusted in converted light passenger vehicles, and an IPCC default emission factor was used to estimate the associated emissions.

Blended biofuels

Small volumes of bio-gasoline and biodiesel are sold blended with mineral oil products and combusted in the *Road transportation* category. To ensure that liquid biofuel combustion is considered in the inventory, the energy split was calculated (i.e., gasoline as a share of combined gasoline and bio-gasoline or mineral diesel as a share of mineral diesel and biodiesel). The new estimate was then multiplied by this factor to account for gasoline and diesel not combusted. The emissions from the combustion of biofuels were then estimated using a Tier 1 methodology, as in previous inventories.

1.A.3.c Railways

Non-CO_2 emissions from the *Railways* category (including both liquid and solid fuels) were estimated using a Tier 1 approach (IPCC, 2006).

1.A.3.d Navigation (domestic marine transport)

Non-CO_2 emissions from the *Navigation* category in New Zealand were estimated using a Tier 1 approach (IPCC, 2006).

1.A.3.e Other transportation

Combustion related to pipeline transport has been recategorised from 1.A.1.c to 1.A.3.e.i *Pipeline transport* in response to feedback received from the ERT during the 2016 review week.

Activity data

1.A.3.a Civil aviation

MBIE currently collects aviation fuels used for international and domestic aviation through the DPFI. The respondents to this survey are New Zealand's five main oil companies, namely, BP, Z Energy (formerly Shell), ExxonMobil, Chevron and Gull (Gull participates only in gasoline and diesel sales).

The distinction between domestic and international flights is based on refuelling at the domestic and international terminals of New Zealand airports. The allocation of aviation fuels between domestic and international segments has previously been raised by the ERT. A previous centralised review stated (UNFCCC, 2009):

> The National Inventory Report (NIR) reports that the allocation of fuel consumption between domestic and international air transport is based on refuelling at the domestic and international terminals of New Zealand's airports. Currently splitting the domestic and international components of fuels used for international flights with a domestic segment was not considered; however, the number of international flights with a domestic segment is considered to be negligible. The Expert Review Team (ERT) notes that in 2006, New Zealand began consultations with the airlines to clarify the situation and improve the relevant Activity Data (AD), and is currently working on a methodology that will allow for better international and domestic fuel use allocation. New Zealand is encouraged to adopt the new approach and report the outcome in its 2010 submissions.

In the DPFI, the oil companies report quantities of different fuels (jet A1, aviation gasoline and kerosene, among others) used for the purposes of international and domestic transport. The

companies allocate the fuel to international or domestic transport based on whether or not they charge GST on the fuel sold – GST is not charged when the destination of a flight is outside of New Zealand.

Some international flights from New Zealand contain a domestic leg, for example, Christchurch–Auckland–Tokyo. Industry practice is to refuel at both points with sufficient fuel to reach the next destination so that the domestic leg will be coded appropriately. By this logic, fuel used for the domestic leg will attract GST and therefore be coded as domestic, and the international leg, which does not attract GST, will be coded as international.

Although this is a supply-side approach, MBIE believes the split of international and domestic transport to be accurate because BP, Z, ExxonMobil and Chevron control 100 per cent of the aviation fuels market in New Zealand. Based on the above findings and consultation, MBIE believes that the current data collection methodology is sufficiently robust to ensure all the domestic aviation fuels are reported accordingly and to avoid missing or misallocation of domestic fuel use.

1.A.3.b Road transportation

Activity data for the *Road transportation* category are provided by the Ministry of Transport's six-monthly fleet data and MBIE's national energy statistics. For more information on the use of vehicle fleet data for estimating non-CO_2 emissions, see methodological issues above.

Activity data on the consumption of fuel by the *Transport* category were sourced from the DPFI conducted by MBIE. LPG and CNG consumption figures are reported online by MBIE.

As mentioned in section 3.3.1, this inventory continues to use the results of the *Annual Liquid Fuel Survey* that began in 2009. The purpose of this survey is to capture the allocation of fuel resold by small independent resellers. In recent years, these independent resellers have accounted for around 30 per cent of national diesel sales and around 8.0 per cent of national gasoline sales.

As a result of resale data captured by the *Annual Liquid Fuel Survey*, emissions that would otherwise be reported under category 1.A.3.b *Road transportation* are allocated to the correct category.

For time-series consistency, these reallocations were also made from 1990–2008, before the collection of data on the resale of liquid fuel by independent distributors.

The diesel activity data for the *Road transport* category are assumed to be the diesel reported for domestic transport, less that reported by KiwiRail in 1.A.3.c *Railways* and 1.A.3.d *Domestic navigation*, discussed below.

The fuel sold data have been validated by estimating fuel consumption based on vehicle kilometres using a vehicle fleet model. Over the past decade, the fuel quantity from the fuel use data has been larger than that estimated using kilometres travelled. There are a number of factors that can contribute to differences between the two methods, for example, fuel sold by retailers that is then used for off-road purposes, and the real-world fuel efficiencies of vehicles differing from assumptions used in the vehicle fleet model. Across the time series (2001–15), the average absolute difference is 1.5 per cent for petrol and 4.8 per cent for diesel, which shows that the methods align very closely.

1.A.3.c Railways

Activity data for fuel used in this category are obtained directly from KiwiRail, the operator of national rail services. This also includes diesel sold to the metropolitan service operated by Veolia in Auckland.

1.A.3.d Domestic navigation

Fuel oil activity data on fuel use by domestic transport are sourced from the quarterly DPFI conducted by MBIE. The DPFI provides monthly marine diesel supply figures that are added to automotive diesel consumption data provided by KiwiRail, the operator of diesel ferries, to obtain total diesel consumption in the *Domestic navigation* sector. New Zealand-specific emission factors have been used to estimate CO_2 emissions and, because of insufficient data, the IPCC 2006 default emission factors have been used to estimate CH_4 and N_2O emissions.

Fuel sales to domestic navigation and international marine bunkers are reported separately in national energy data surveys. The companies allocate the fuel to international or domestic transport based on whether or not they charge GST on the fuel sold – GST is not charged when the destination of a voyage is outside of New Zealand.

Historically, the Marsden Point oil refinery produced marine diesel oil (MDO). Production of MDO at the refinery stopped in late 2006. Data collected from the operators of the Interislander Ferry service (KiwiRail) have not included MDO use since 2006. The end to the collection of these data coincided with this operator ceasing a 'fast ferry' service between the North Island and South Island – this ferry ran on MDO – whereas the remainder of its fleet runs on fuel oil. There is no significant quantity of diesel used for commercial domestic navigation in New Zealand. There may be smaller quantities of diesel used in private and/or recreational vessels, but this is difficult to measure. The DPFI would capture these sales as road transport.

Uncertainties and time-series consistency

Uncertainties in emission estimates from the *Transport* category are relevant to the entire *Fuel combustion* sector (see table 3.3.1).

Source-specific QA/QC and verification

In the preparation of this inventory, the *Transport* category underwent Tier 1 quality-assurance and quality-control checks as recommended in the 2006 IPCC Guidelines. These include regular control sums throughout systems to verify system integrity, and time-series consistency checks.

Comparisons of international implied emission factors across the time series (1990–2012), and those resulting from the new Tier 3 methodology for CH_4 and N_2O emissions from road transport, were made using data from the UNFCCC website.

Source-specific recalculations

Minor revisions to historical data have been made within the oil data system at MBIE. The method used to model emissions for the *Road transportation* category in the period 1990–2000 has been updated to improve consistency between fuels and vehicle types.

Source-specific improvements

Emissions for the *Road transportation* category have been disaggregated by vehicle type for the period 2001–16. Emissions from gaseous fuels in this category have also been disaggregated by vehicle type for the period 1990–2000.

Source-specific planned improvements

A project has been initiated in conjunction with the Ministry of Transport to incorporate the results of a new aviation emissions model in the inventory estimates. Progress will be reported in the next annual submission.

3.3.9 Fuel combustion: Other sectors (CRF 1.A.4)

Description

The category 1.A.4 *Other sectors* comprises emissions from fuels combusted in the *Commercial/institutional*, *Residential* and *Agriculture/forestry/fishing* categories.

In 2016, the *Fuel combustion – other sectors* category accounted for 3,202.7 kt CO_2-e (10.2 per cent of the emissions from the Energy sector). This is an increase of 291.1 kt CO_2-e (10.0 per cent) from the 1990 value of 2,911.7 kt CO_2-e.

Changes in emissions between 2015 and 2016

Between 2015 and 2016, emissions from 1.A.4 *Other sectors* decreased by 142.7 kt CO_2-e (–4.3 per cent).

Key categories identified in the 2016 level assessment from the *Other sectors* category include CO_2 emissions from:

- Agriculture/forestry/fishing – liquid fuels
- Commercial/institutional – gaseous fuels
- Commercial/institutional – liquid fuels
- Residential – gaseous fuels
- Residential – liquid fuels.

Key categories identified in the 1990–2016 trend assessment from the *Other sectors* category include CO_2 emissions from:

- Commercial/institutional – gaseous fuels
- Commercial/institutional – liquid fuels
- Residential – gaseous fuels
- Residential – solid fuels.

Methodological issues

There are no notable methodological issues in this category.

Activity data

Liquid fuels

As mentioned in section 3.3.1, this inventory continues to use the results of the *Annual Liquid Fuel Survey* that began in 2009. The purpose of this survey is to capture the allocation of fuel resold by small independent resellers. In recent years, these independent resellers accounted for around 30 per cent of national diesel deliveries and around 8 per cent of national gasoline deliveries.

As the result of resale data captured by the *Annual Liquid Fuel Survey*, emissions that would otherwise be reported under category 1.A.3.b *Road transportation* are allocated to the correct category.

For time-series consistency, these reallocations are also made from 1990 to 2008, before the collection of data on the resale of liquid fuel by small, independent distributors began.

As mentioned in section 3.3.7 (Activity data, Liquid fuels), historical national energy sales surveys captured fuel use by mining operations under 'other primary industry'. For consistency with the IPCC Guidelines, this inventory uses data provided by Statistics New Zealand's *Energy Use Survey* (Statistics New Zealand, 2017) to estimate the split of historical 'other primary industry' activity for fuel oil between forestry and logging, and mining (see table 3.3.3). There is insufficient historical data to extrapolate a historical trend for this split: instead, activity splits are interpolated between the two surveys and assumed to be constant for the period 1990–2008.

Table 3.3.3   Split of fuel oil activity for 'other primary industry'

Activity	EUS 2008 (%)	EUS 2016 (%)
Forestry and logging	51.3	9.1
Mining	48.7	90.9

Note: EUS = Energy Use Survey.

Solid fuels

In 2010, it was discovered that some coal reported as sold to the commercial sector was in fact being on-sold. As a result, some activity previously reported under the *Commercial* category has been reallocated to the Agriculture sector. This on-selling is assumed to continue across the time series 1990–2016.

Solid biomass

New Zealand estimates residential combustion of biomass using household number estimates from Statistics New Zealand along with five-yearly census figures estimating the percentage of households using biomass for heating. Interpolation is used to estimate shares for intermediate years.

The energy content of biomass burned in each household that uses biomass for heat was estimated by the study *Energy Use in New Zealand Households* (BRANZ, 2002).

Gaseous fuels

Annual natural gas consumption statistics are published by MBIE. Reviews of all natural gas consumption data were undertaken in 2011 and 2014 by MBIE. For further information, see section 3.3.7 (Activity data, Gaseous fuels).

Uncertainties and time-series consistency

Uncertainties in emission estimates for data from other sectors are relevant to the entire Energy sector (see table 3.3.1).

Source-specific QA/QC and verification

In the preparation of this inventory, the *Other sectors* category underwent Tier 1 quality-assurance and quality-control checks as recommended in the 2006 IPCC Guidelines. These include regular control sums throughout systems to verify system integrity, and consistency checks of implied emission factors.

Source-specific recalculations

Some minor recalculations may have occurred across the time series due to revisions of activity data provided by the energy data team at MBIE.

Source-specific improvements

Activity and emissions data for the *Agriculture/forestry/fishing* category are now reported separately by activity (stationary combustion, mobile use, and fishing).

Source-specific planned improvements

A project has been initiated to apply appropriate data techniques to disaggregate activity data for fisheries and off-road activities within the 1.A.4.c *Agriculture/forestry/fishing* category, in order to estimate CH_4 and N_2O emissions along with the use of appropriate emission factors. Progress will be reported in the next annual submission.

3.4   Fugitive emissions from fuels (CRF 1.B)

Fugitive emissions arise from the production, processing, transmission, storage and use of fossil fuels, and from non-productive combustion. This category comprises two subcategories: *Solid fuels* and *Oil and natural gas*.

In 2016, fugitive emissions from fuels accounted for 2,008.7 kt CO_2-e (6.4 per cent) of emissions from the Energy sector. This is an increase of 671.5 kt CO_2-e (50.2 per cent) from the 1990 level of 1,337.1 kt CO_2-e.

Changes in emissions between 2015 and 2016

Between 2015 and 2016, fugitive emissions from fuels decreased by 174.3 kt CO_2-e (–8.0 per cent). This was primarily the result of decreased activity in category 1.B.2 *Oil and natural gas.*

Key categories identified in the 2016 level assessment from the *Fugitive emissions* category include CO_2 emissions from:

- Oil and natural gas and other emissions from energy production – other – geothermal
- Venting – gas
- Flaring – combined.

A key category identified in the 2016 level assessment from the *Fugitive emissions* category was CH_4 emissions from:

- Natural gas – distribution.

Key categories identified in the 1990–2016 trend assessment from the *Fugitive emissions* category include CO_2 emissions from:

- Oil and natural gas and other emissions from energy production – other – geothermal
- Venting – gas
- Flaring – combined.

Key categories identified in the 1990–2016 trend assessment from the *Fugitive emissions* category include CH_4 emissions from:

- Natural gas – distribution
- Fugitive – coal mining and handling – underground
- Oil and natural gas and other emissions from energy production – other – geothermal.

3.4.1 Fugitive emissions from fuels: Solid fuels (CRF 1.B.1)

Description

In 2016, fugitive emissions from the *Solid fuels* category produced 171.8 kt CO_2-e (8.6 per cent) of emissions from the *Fugitive emissions* category. This is a decrease of 156.4 kt CO_2-e (–47.7 per cent) from the 328.2 kt CO_2-e reported for 1990.

Between 2015 and 2016, fugitive emissions from the *Solid fuels* category decreased by 18.0 kt CO_2-e (−9.5 per cent) as a result of decreased production from both underground and surface mines.

New Zealand's fugitive emissions from the *Solid fuels* category are a by-product of coal-mining operations. Methane is created during coal formation. The amount of CH_4 released during coal mining is dependent on the coal grade and the depth of the coal seam. In 2016, 66.1 per cent of the CH_4 from coal mining came from underground mining. This includes the emissions from post-underground mining activities such as coal processing, transportation and use. In 2016, New Zealand coal production was 2.9 million tonnes, a 15.3 per cent decrease from the 2015 production level.

At the end of 2016, there was no known flaring of CH_4 at coal mines in New Zealand, and CH_4 captured for industrial use was negligible. Pilot schemes of both coal seam gas and underground coal gasification began in 2012, but these projects have not progressed.

Methodological issues

The *Underground mining* category dominates fugitive emissions from coal mining. The New Zealand-specific emission factor for underground mining of sub-bituminous coal is used to calculate CH_4 emissions (Beamish and Vance, 1992). The sub-bituminous emission factor (EF) derived from Beamish and Vance is considered to be reliable because the EF (12.1 t/kt) is:

a. well within the 2006 IPCC default range of 6.7–16.75 t/kt

b. largely based on data for the most significant sub-bituminous coal mine in New Zealand (Huntly East mine), which has continued production since 1988 and has remained the most significant producing mine.

The EF for underground mining of bituminous coal is taken from the 2006 IPCC Guidelines. It is noted that any bituminous EF derived from Beamish and Vance (1992) would not be reliable, and should not be used, for the following reasons.

a. The derived EF (35.28 t CH_4/kt) is more than double the high default 2006 IPCC value. Using such an EF that is so far out of line with the default values would require a strong justification.

b. New Zealand already has the highest implied EF for underground mining among Annex I Parties. Dramatically increasing the EF further still would not be in the interests of comparability.

c. The bituminous data are based on production of only 125 kt and so represent a very small sample size (this is different with the sub-bituminous mines, where the data are based on production of 655 kt). The small sample size significantly increases the uncertainty.

d. Beamish and Vance's study is based on data from 1988, for just eight bituminous coal mines. These data are out of date, because all of these mines are no longer producing, and bituminous coal production comes from entirely different underground mines, to which the suggested EFs may not be applicable.

Emission factors for the other subcategories, for example, surface mining, are sourced from the 2006 IPCC Guidelines.

Activity data

Activity data for this category are collected from MBIE's coal production survey. This survey gathers quarterly data on coal production by mine type (underground and/or surface) and rank (coking, bituminous, sub-bituminous, lignite).

Abandoned underground mines (1.B.1.a.1.iii)

MBIE, in conjunction with New Zealand Petroleum and Minerals, has been conducting an investigation and seeking expert advice to ascertain whether or not activity in this category is occurring. According to the 2006 IPCC Guidelines, mines of only a few acres in size should be disregarded, and, additionally, non-gassy mines and flooded mines are presumed to have negligible emissions. Most New Zealand mines are small by European standards and can be disregarded. The first stage of the project was completed in 2016, and concluded that the activity is not occurring (NO) in the North Island: details are given in table 3.4.1. The second stage of the project, focusing on the South Island, remains ongoing, but early indications suggest it is likely that the activity is also NO for most of the time series. Activity data in the form of CH_4 output derived from mine ventilation measurements have been obtained from mine operators for those mines where data exist. These emissions are reported in this submission. Source-specific details are not provided so as to maintain confidentiality.

Table 3.4.1   Details of abandoned underground mines in the North Island

Region/coalfield	Significant mine	Status
Northland	Kamo	Only one significant mine; flooded
Waikato	Rotowaro mines	Underground mines either flooded or subsequently opencast mined
	Huntly West	Flooded
	Taupiri/Ralphs	Mines under Huntly township; flooded
Taranaki	Tatu	Only one significant mine; flooded

Uncertainties and time-series consistency

Uncertainties in fugitive emissions are relevant to the entire Energy sector (see table 3.3.1).

Source-specific QA/QC and verification

In the preparation of this inventory, the *Fugitive emissions* category underwent Tier 1 quality-assurance and quality-control checks, as recommended in the 2006 IPCC Guidelines. These include regular control sums throughout systems to verify system integrity, and consistency checks of implied emission factors.

Source-specific recalculations

Historical coal production data have been revised due to revisions in data provided by companies. This has resulted in minor revisions in activity data and corresponding emissions for some years.

Source-specific planned improvements

The assessment of abandoned underground mines in the South Island is ongoing and an update will be reported in the next annual submission.

3.4.2 Fugitive emissions from fuels: Oil and natural gas and other emissions from energy production (CRF 1.B.2)

Description

In 2016, fugitive emissions from the *Oil and natural gas* category contributed 1,836.9 kt CO_2-e (91.4 per cent) to emissions from the *Fugitive emissions* category. This is an increase of 828.0 kt CO_2-e (82.1 per cent) from 1,008.9 kt CO_2-e in 1990.

The main source of emissions from the production and processing of natural gas is the Kapuni Gas Treatment Plant (KGTP). Emissions from the KGTP are not technically due to flaring, and are included under this category because of data confidentiality concerns. The plant removes CO_2 from a portion of the Kapuni gas (a high CO_2 gas when untreated) before it enters the national transmission network.

The large increase in CO_2 emissions from the KGTP between 2003 and 2004 and between 2004 and 2005 is related to the drop in methanol production. Carbon dioxide previously sequestered during this separation process is now released as fugitive emissions from venting at the KGTP.

While emissions from the KGTP may include traces of CH_4, the level of these emissions has been determined to be insignificant in comparison with national emissions: a conservative estimate (using default emission factors from the 2006 IPCC guidelines) gives approximately 1.5 kt CO_2-e per year.

Carbon dioxide is also produced when natural gas is flared at the wellheads of other fields. The combustion efficiency of flaring is 95 per cent to 99 per cent, leaving some fugitive CH_4 emissions as a result of incomplete combustion.

Fugitive emissions also occur in transmission and distribution within the natural gas transmission pipeline system. However, these emissions are relatively minor in comparison with those from venting and flaring.

The *Oil and natural gas* category also includes estimates for emissions from geothermal operations. While some of the energy from geothermal fields is transformed into electricity, emissions from geothermal electricity generation are reported under the *Fugitive emissions* category because they are not the result of fuel combustion, unlike the emissions reported under the *Energy industries* category. Geothermal facilities supplying geothermal fluid for generating electricity or industrial heat are subject to the Climate Change (Stationary Energy and Industrial Processes) Regulations 2009, and are required to participate in the NZ ETS. Geothermal sites, where there is no use of geothermal steam for energy production, have been excluded from the inventory. Operations falling outside the scope of the regulations are not included in the inventory due to a lack of data, methodology and emission factors. Besides this, such sites – rather than using high temperature geothermal steam – use low temperature hot water, which does not carry high levels of dissolved gases, and any emissions are not significant. Naturally occurring sites do not contribute any anthropogenic emissions.

In 2016, emissions from geothermal operations were 832.0 kt CO_2-e, an increase of 548.6 kt CO_2-e (193.6 per cent) from the 1990 level of 283.4 kt CO_2-e.

Between 2015 and 2016, emissions from geothermal sources decreased by 2.3 per cent.

Methodological issues

Unless noted otherwise, CO_2 and CH_4 emissions from sources within this category have been calculated using the IPCC Tier 2 approach, and N_2O emissions were calculated using the default Tier 1 approach (IPCC, 2006).

Ozone precursors and sulphur dioxide from oil refining

New Zealand has only one oil refinery that has a hydro cracker rather than a catalytic cracker. Therefore, no emissions come from fluid catalytic cracking but they do come from sulphur recovery plants and storage and handling.

1.B.2.c Venting and flaring

Oil and natural gas fields in New Zealand produce a mixture consisting of variable ratios of natural gas, crude oil, condensate and natural gas liquids. Hence emissions for this category are reported under 'combined'. The activity data are directly reported by field operators.

Venting of CO_2 resulting from hydrogen production at oil refineries is included in the IPPU sector so as to protect the confidentiality of individual companies (see chapter 4, for further information).

1.B.2.d Geothermal

When geothermal fluid is discharged, some CO_2 and small amounts of CH_4 are also released. The emissions released during electricity generation using geothermal fluid are reported in this inventory. Figure 3.4.1 shows a schematic diagram of a typical New Zealand geothermal flash power station.

Estimates of CO_2 and CH_4 emissions for the *Geothermal* category are obtained directly from the geothermal power companies. There are currently 13 geothermal power stations in New Zealand – most of these are owned (or partly owned) by two major power companies. Two examples of methodologies used to estimate emissions by these companies are explained below.

Figure 3.4.1 **Schematic diagram of the use of geothermal fluid for electricity generation – as at Wairakei and Ohaaki geothermal stations (New Zealand Institute of Chemistry, 1998)**
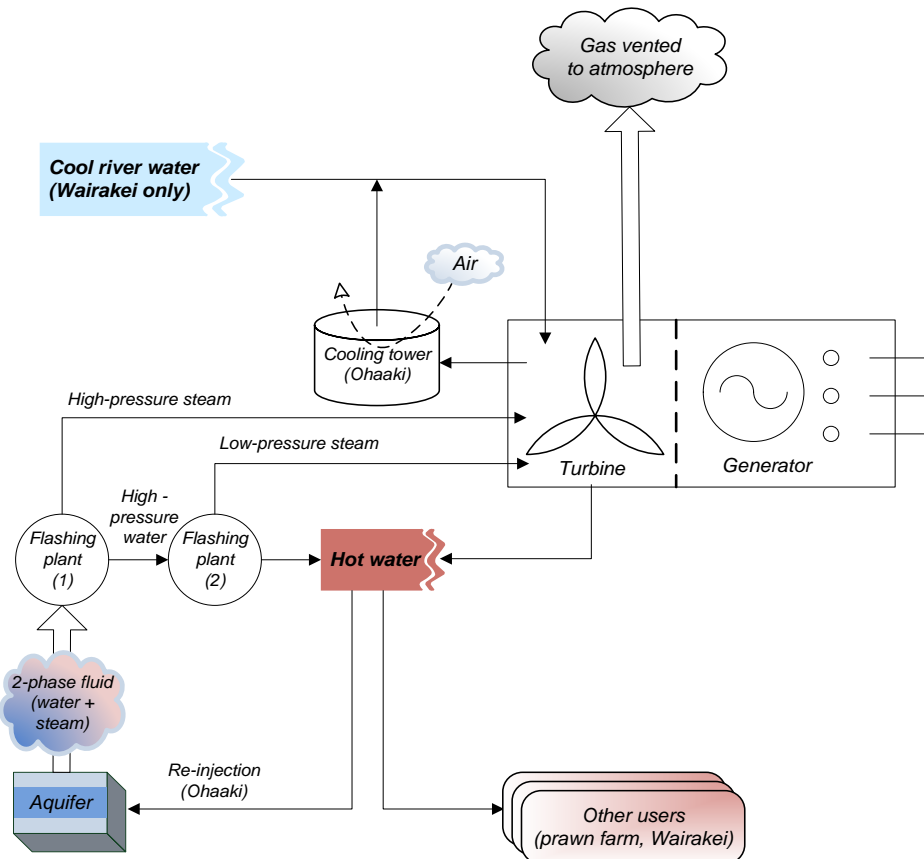
Emissions from geothermal have increased greatly in recent years. These increases are driven by an increase in geothermal emissions related to electricity generation, particularly with the additions of the 100 MW Kawerau geothermal plant since late 2008, Nga Awa Purua and Te Huka since 2010, Ngatamariki since 2013 and Te Mihi since 2014.

The schedules to the Climate Change Response Act 2002 create obligations for people carrying out certain activities to report greenhouse gas emissions as part of the NZ ETS. The Climate Change (Stationary Energy and Industrial Processes) Regulations 2009 and Climate Change (Liquid Fossil Fuels) Amendment Regulations 2009 set out the data collection requirements and methods for participants in those sectors to calculate their emissions, including prescribed default emission factors (DEFs).

The Climate Change (Unique Emissions Factors) Regulations 2009 outline requirements for participants in certain sectors to calculate a unique emissions factor (UEF) and apply for approval to use it in place of a DEF to calculate and report on emissions. Sectors that are eligible to apply for a UEF are a class of:

- liquid fossil fuel
- coal
- natural gas – CH_4 and N_2O
- geothermal fluid
- used oil, waste oil, used tyres or waste.

The 2010 year was the first calendar year in which operators could apply for UEFs. MBIE received five applications relating to the use of UEFs of geothermal fluid for that calendar year. These five approved UEFs were then adopted for the inventory after careful assessment of the materiality impact and time-series consistency.

As 2010 was the introduction year, MBIE made a judgement that the UEF would apply only to years for which sufficient data are available, that is, from 2010 onward. This submission continues with this approach. From 1990 to 2009, emissions are calculated using field-specific DEFs. Emissions from 2010 onwards are calculated using UEFs where available and field-specific DEFs otherwise.

When several years of UEF data are available for comparison, the 1990–2009 emission factors for each affected field will be reviewed.

Geothermal methodology for Company A

At Company A, quarterly gas sampling analysis is conducted to measure the amount of CO_2 and CH_4 in the steam. Gas samples are collected at the inlet to the electricity generation station and at the extraction process when gas is dissolved in the condensate (wastewater).

The concentration of CO_2 (e.g., 0.612 per cent) and CH_4 (e.g., 0.0029 per cent) by weight of discharged steam is then calculated by carrying out a mass balance.

'Gas discharged to atmosphere' = 'Gas to electricity generation station' – 'Gas dissolved in condensate'

Company A also collects information on the average steam flow (tonnes of steam per hour) to the electricity generation station. This average steam flow is based on an annual average (e.g., 582.3 tonnes of steam per hour).

Therefore, working out CO_2 emissions discharged to atmosphere involves the following calculations.

Average discharge per hour is calculated as:

$$582.3 \frac{tonnes\ of\ steam}{hour} \times \frac{0.612\ CO_2}{100}\ by\ weight\ of\ steam = 3.565 \frac{tonnes\ of\ CO_2}{hour}$$

And the total discharge per year is:

$$3.565 \frac{tonnes\ of\ CO_2}{hour} \times 8760 \frac{hours}{year} = 31{,}230\ tonnes\ of\ CO_2.$$

Using the same methodology above will yield 149 tonnes of CH_4. The overall emission for Company A is therefore 34,359 tonnes of CO_2-e emissions.

Geothermal methodology for Company B

At Company B, spot measurements of both CO_2 and CH_4 concentrations are taken at the inlet steam when the power stations are operating normally. The net megawatt-hours of electricity generated that day are then used to calculate the emission factor. This implied emission factor is then multiplied by the annual amount of electricity generated to work out the annual emissions for each power station.

Activity data

1.B.2.a.1 Exploration

Activity data are the number of wells drilled in each year as reported by New Zealand Petroleum and Minerals (MBIE, 2017). Data were only available for the years from 2001 onwards, so estimates were made by extrapolation for the years preceding 2001.

1.B.2.a.3 Transport

The activity data are New Zealand's total production of crude oil (MBIE, 2017).

1.B.2.a.4 Refining

Activity data are total intake at New Zealand's sole oil refinery (MBIE, 2017).

1.B.2.a.5 Distribution of oil products

Activity data are New Zealand's total consumption of gasoline (MBIE, 2017).

1.B.2.b.3 Processing

Vector Ltd, operator of the KGTP, supplies estimates of CO_2 released during the processing of the natural gas.

1.B.2.b.4 Transmission and 1.B.2.b.5 Distribution

Carbon dioxide and CH_4 emissions from gas leakage mainly occur from low-pressure distribution pipelines rather than from high-pressure transmission pipelines. Emissions from transmission and distribution are reported separately.

Emissions from the high-pressure transmission system were provided by Vector Ltd, the system and technical operator. Natural gas transmission losses included both direct leakage of CH_4 and CO_2 and gas lost and/or used when starting lines compressors. This information is provided by Vector. Data are provided for GJ of CH_4 and tonnes of CO_2. Gigajoules of CH_4 are converted to tonnes of CH_4 using the Ministry for the Environment's standard conversion factor for CH_4 of 55.6 t/GJ. New Zealand has a high-pressure transmission network nearly 3,500 kilometres in length. It joins most North Island cities (natural gas is only available in New Zealand's North Island). No time series of the total length of the transmission lines is available; however, expert opinion is that it would have been nearly constant since 1990.

New Zealand bases distribution loss emissions on information about gas entering the distribution network, which is administrative data collected at the 'gas gate' by the gas industry regulator (the Gas Industry Company). It does not follow the alternative approach of using survey information collected from gas retailers on the amount of gas sold and metered at the individual customer (household, small business) level.

Of the gas entering the low-pressure distribution system, 1.75 per cent (which is based on consultation between the Government and the Gas Association of New Zealand, an industry group) is assumed to be lost through leakage. Consequently, the amount of natural gas leaked from the low-pressure distribution system is assumed to be 1.75 per cent of the gas entering the distribution system, and CO_2 and CH_4 emissions are calculated based on the natural gas composition data provided by the system operator.

1.B.2.b.5 Natural gas storage

Natural gas storage occurs at the Ahuroa gas storage facility. Ahuroa is a depleted gas field that can hold 5–10 PJ of natural gas at any one point. This gas is used to run Contact Energy's Stratford gas peaking plant, which consists of two 100 MW open cycle gas turbine units.

1.B.2.c Venting and flaring

Data on the amount of natural gas flared or vented are reported directly by the gas field operator.

Emission factors

Unless noted otherwise, default IPCC emission factors have been used.

Uncertainties and time-series consistency

The time series of data from the various geothermal fields varies in completeness. Some fields were not commissioned until after 1990 and hence do not have records back to 1990.

Source-specific QA/QC and verification

In the preparation of this inventory, the *Fugitive emissions* category underwent Tier 1 quality-assurance and quality-control checks as recommended in the 2006 IPCC Guidelines. These include regular control sums throughout systems to verify system integrity, and consistency checks of implied emission factors.

Source-specific planned improvements

As the data set of verified unique emission factors for individual geothermal fields and coal mines obtained from the NZ ETS grows, New Zealand will consider methods of incorporating these data to improve the accuracy of estimates.

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Chapter 4: Industrial Processes and Product Use (IPPU)

4.1 Sector overview

4.1.1 IPPU sector in New Zealand

New Zealand has a relatively small number of industrial processing plants emitting non-energy related greenhouse gases. Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) emissions from eight distinct industrial processes in New Zealand are reported in the IPPU sector. These are:

- calcination of limestone in cement production
- calcination of limestone in burnt and slaked lime production
- production of ammonia, which is further processed into urea
- production of methanol
- production of hydrogen, in oil refining and for making hydrogen peroxide
- production of steel, from iron sand and from scrap steel
- oxidation of anodes in aluminium smelting
- use of soda ash and limestone in glass making.

Hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) are used in a large number of products and in refrigeration and air conditioning equipment. Some recovered HFCs are exported for destruction. Perfluorocarbons are also emitted as a result of anode effects in aluminium smelting. Sulphur hexafluoride (SF_6) is used in the electricity distribution sector and in small-scale medical and scientific applications. Historically, a very small amount of SF_6 has also been used for magnesium casting. There is no production of any fluorinated chemicals in New Zealand; they are all imported.

Small amounts of CO_2 are reported from the use of lubricants and paraffin wax, imported calcium carbide, carbonates in kaolin clay used for ceramics production, and secondary lead production (recycling of lead-acid batteries). No other emission sources for direct greenhouse gases are applicable to New Zealand and no other activity data are available. Some indirect greenhouse gas emissions are reported from fertiliser, formaldehyde, and other industries.

4.1.2 Emissions summary

The IPPU sector in New Zealand produces CO_2 emissions (66.3 per cent), fluorinated gases (29.9 per cent) and smaller amounts of CH_4 and N_2O. Coal and natural gas are also used on a significant scale for energy in the *Mineral industry*, *Chemical industry* and *Metal industry* source categories. Carbon dioxide and any other emissions from combustion of fuels in these industries are reported under the Energy sector.

2016

In 2016, emissions in the IPPU sector contributed 4,853.4 kilotonnes carbon dioxide equivalent (kt CO_2-e) or 6.2 per cent of New Zealand's gross greenhouse gas emissions.

The emissions by source category are shown in table 4.1.1. The largest source category is the *Metal industry* category, with substantial CO_2 emissions from the *Iron and steel production* and *Aluminium production* categories, as well as PFCs from the *Aluminium production* category in earlier years. The *Mineral industry* and *Chemical industry* categories also contribute significant CO_2 emissions, and most of the non-CO_2 emissions come from the *Product uses as substitutes for ODS* category.

1990–2016

IPPU sector emissions in 2016 were 1,268.3 kt CO_2-e (35.4 per cent) higher than emissions in 1990 (3,585.1 kt CO_2-e). This increase was mainly driven by increasing emissions from the *Product uses as substitutes for ODS* category due to the introduction of HFCs to replace ozone-depleting substances (ODS) in refrigeration and air conditioning, and to the increased use of household and commercial air conditioning. Carbon dioxide emissions have also increased due to increased production of cement, metals and ammonia but at a slower rate. There has been a substantial reduction in emissions of PFCs due to improved management of anode effects in the *Aluminium production* category, and some reduction in emissions of N_2O used for medical applications in the *Other product manufacture and use* category. The trends are shown in figures 4.1.1 and 4.1.2.

2015–2016

IPPU sector emissions in 2016 were 461.9 kt CO_2-e (8.7 per cent) lower than emissions in 2015. This change was a result of decreases in emissions from the *Mineral industry* (149.5 kt CO_2-e or 17.1 per cent), *Chemical industry* (72.4 kt CO_2-e or 18.6 per cent), *Metal industry* (66.1 kt CO_2-e or 2.8 per cent) and *Product uses as substitutes for ODS* (173.3 kt CO_2-e or 11.1 per cent) categories. The decreases were due to the closure of a cement plant, consolidation in the steel industry, and a decrease in the import and use of HFCs for refrigeration and air conditioning.

Table 4.1.1 **New Zealand's greenhouse gas emissions for the IPPU sector by source category in 1990 and 2016**

Source category	Emissions (kt CO₂-e)		Difference (kt CO₂-e)	Change (percentage)	Share (percentage)	
	1990	2016	1990–2016	1990–2016	1990	2016
Mineral industry (2.A)	561.9	726.8	164.9	29.4	15.7	15.0
Chemical industry (2.B)	203.0	316.6	113.6	56.0	5.7	6.5
Metal industry (2.C)	2,670.2	2,300.2	–370.0	–13.9	74.5	47.4
Non-energy products from fuels and solvent use (2.D)	30.3	46.5	16.2	53.4	0.8	1.0
Product uses as substitutes for ODS (2.F)	–	1,387.0	1,387.0	–	–	28.6
Other product manufacture and use (2.G)	119.7	76.3	–43.4	–36.3	3.3	1.6
Total	**3,585.1**	**4,853.4**	**1,268.3**	**35.4**	**–**	**–**

Note: Columns may not sum due to rounding. Percentages presented are calculated from unrounded values.

Figure 4.1.1   New Zealand's annual emissions from the IPPU sector from 1990 to 2016
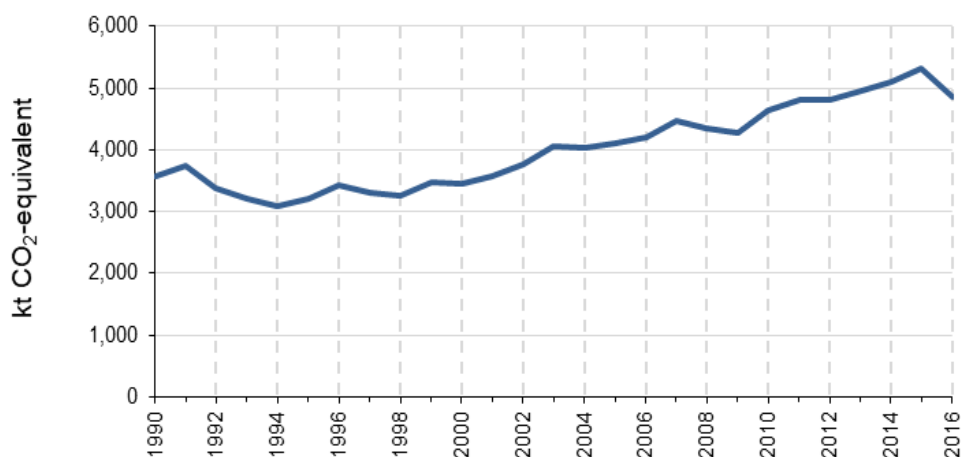
Figure 4.1.2   Change in New Zealand's emissions from the IPPU sector from 1990 to 2016
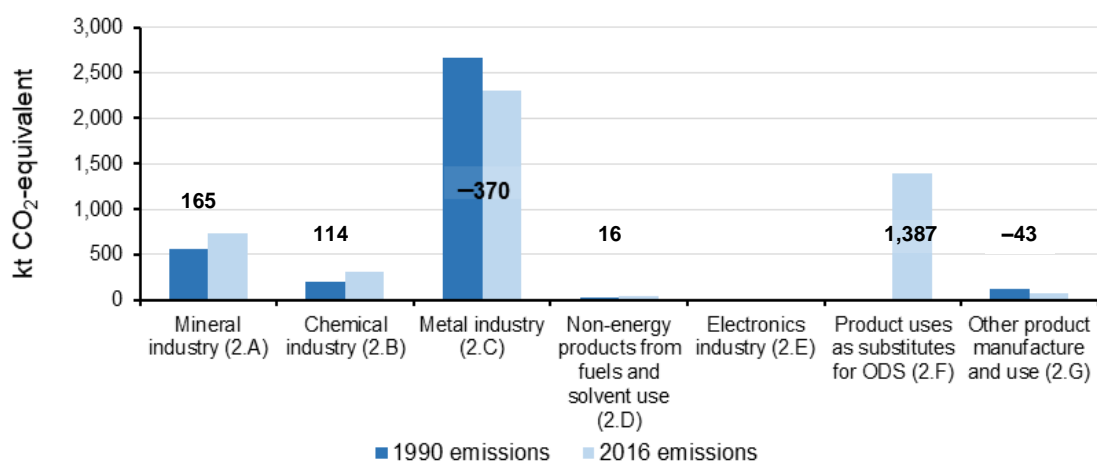
4.1.3   Key categories for IPPU sector emissions

Details of New Zealand's key category analysis are in chapter 1, section 1.5. The key categories in the IPPU sector are listed in table 4.1.2 below.

Table 4.1.2   Key categories in the IPPU sector

CRF category code	IPCC categories	Gas	Criteria for identification
2.A.1	Mineral Industry – Cement Production	CO_2	L1
2.B.8	Chemical Industry – Petrochemical and Carbon Black Production	CH_4	T1
2.C.1	Metal Industry – Iron and Steel Production	CO_2	L1, T1
2.C.3	Metal Industry – Aluminium Production	CO_2	L1
2.C.3	Metal Industry – Aluminium Production	PFCs	T1
2.F.1	Product Uses as Substitutes for ODS – Refrigeration and Air Conditioning	HFCs	L1, T1
2.F.4	Product Uses as Substitutes for ODS – Aerosols	HFCs	T1

Notes: L1 means a key category is identified under the level analysis – approach 1 and T1 is trend analysis – approach 1. Refer to chapter 1 for more information.

4.1.4 Methodological issues for the IPPU sector

Activity data in the IPPU sector have been derived from a variety of sources. In the *Mineral industry* category, the primary data source is emissions data reported under the New Zealand Emissions Trading Scheme (NZ ETS). For the *Chemical industry* and *Metal industry* categories, data (including activity data) are provided to the Ministry of Business, Innovation and Employment (MBIE) in response to an annual survey.

For some large-scale activities in the *Mineral industry*, *Chemical industry* and *Metal industry* categories, which are carried out by only one or two companies in New Zealand, activity data are reported as confidential in the common reporting format (CRF) tables.

Emissions data for glass production (2.A.3) are reported in 2.A.4 to aggregate the data with other sources and preserve confidentiality. Also, data on emissions from hydrogen making at the Marsden Point oil refinery are reported in the *Chemical industry* source category. This allows data from New Zealand's only industrial hydrogen making process, which is smaller in scale than refining, to be aggregated and kept confidential.

For the *Product uses as substitutes for ODS* source category, updated activity data have been obtained by a detailed annual survey covering the electrical, refrigeration and other industry participants (CRL Energy, unpublished(c)) as well as importers of HFCs and other substances in this source category.

New Zealand uses a combination of Tier 1 and Tier 2 methodologies for the IPPU sector. Tier 2 methods are used for all key categories with the exception of CH_4 emissions from methanol production (CRF 2.B.8) for which no Tier 2 method is available.

For small amounts of indirect greenhouse gas emissions reported in the *Chemical industry* category and the *Other product manufacture and use* category, data were obtained by a detailed industry survey and analysis (CRL Energy, unpublished(a)). Emissions and activity data have been extrapolated for the years since 2006.

Country-specific emission factors have been used where available, including for emissions of indirect greenhouse gases.

4.1.5 Uncertainties

The uncertainties are discussed under each category. Intergovernmental Panel on Climate Change (IPCC) default uncertainties have been used in nearly all cases.

Country-specific estimates of uncertainty have been made in the *Product uses as substitutes for ODS* source category, reflecting the variable quality of data provided by a large number of survey respondents, and have been updated for this submission.

4.1.6 Verification

The inventory agency (the Ministry for the Environment) verified information on CO_2 emissions reported in the *Iron and steel production* category against information provided by these industries as participants in the NZ ETS.

For PFCs in the *Aluminium production* category and for CO_2 in the *Mineral industry* category, the NZ ETS is used as a primary data source. Verification will be done over time as ETS returns are verified by the agency that administers the NZ ETS, but no specific verification has been possible for this submission.

All data supplied in response to annual surveys (for the *Chemical industry*, *Metal industry* and *Product uses as substitutes for ODS* categories) were verified against national totals where possible and anomalous data followed up and checked.

4.1.7　Recalculations and improvements

In the *Product uses as substitutes for ODS* source category, activity data and emissions for refrigeration and air conditioning are disaggregated by sub-application. For submissions up to 2015, only mobile air conditioning was reported separately.

For this submission, emissions from refrigeration and air conditioning for all years have been recalculated to better account for changes in the bank of refrigerant in operating equipment, refrigerant stockpiled by importers, and the timing of disposal.

Emissions from SF_6 in electrical equipment, in the *Other product manufacture and use* source category, have been recalculated due to better information on electrical equipment, but this has only a minor impact on the reported emissions.

Expert review team comments

Expert review teams (ERTs) have recommended that New Zealand continue efforts to address the transparency of activity data in the *Mineral industry*, *Chemical industry* and *Metal industry* categories. This relates to activity data that are reported as confidential. Commercial confidentiality remains an issue for this and future submissions.

The ERT recommended that New Zealand improves the documentation of reporting in the *Product uses as substitutes for ODS* and *Other product manufacture and use* categories. The descriptions in these categories in the inventory continue to be updated in each submission, and the source material can be made available for review teams.

4.1.8　Quality assurance and quality control (QA/QC) processes

Tier 1 quality checks were carried out on all data collected for this sector, with minor exceptions where data do not require updating. Figure 4.1.3 describes the quality control process map for the IPPU sector. Verification against independent data sources was possible only in specific cases, such as comparison of NZ ETS returns against data submitted in response to surveys.

Figure 4.1.3   Example of Tier 1 quality checks for the IPPU sector

Legend:

AD – activity data
Al – aluminium
CO₂ – carbon dioxide
CO₂–e – carbon dioxide equivalent
CRF – Common Reporting Format
CRL – Crown Research Laboratory
ETS – Emissions Trading Scheme
GL - Guidelines
HFCs – hydrofluorocarbons
IPCC – Intergovernmental Panel on Climate Change
MBIE – Ministry of Business, Innovation and Employment
MfE – Ministry for the Environment
N₂O – nitrous oxide
PFCs – perfluorocarbons
QC – quality control
SF₆ – sulphur hexafluoride
SL – sector lead
T1 – Tier 1

4.2   Mineral industry (2.A)

4.2.1   Description

Emissions from the *Mineral industry* source category include CO_2 from the calcination of limestone for cement and lime, and from the use of soda ash and limestone in the production of iron and steel, glass, and aluminium. Only CO_2 from calcination is reported here. Any emissions from the combustion of fuel to provide heat for these activities are reported in the Energy sector.

There is now only one cement production facility operating in New Zealand, a dry-process plant operated by Golden Bay Cement Ltd near Whangarei. Holcim New Zealand Ltd has operated a wet-process cement plant at Cape Foulwind, on the west coast of the South Island, but this plant was closed at the end of June 2016 and Holcim is now marketing cement made from imported clinker. Another, smaller cement company (Lee Cement Ltd) operated only from 1995 to 1998. These facilities produce clinker from the calcination of limestone and process it into Portland cement and general purpose cement.

Three companies (McDonald's Lime Ltd, Websters Hydrated Lime Company and Perry Resources Ltd) have a history of making burnt and slaked lime at five different facilities in New Zealand. The industry has been consolidated over time and two companies (Graymont New Zealand and Websters Hydrated Lime Company) now produce all of New Zealand's burnt and slaked lime.

Small amounts of indirect emissions (sulphur dioxide (SO_2) only) from the *Cement production* category are also reported. Some emissions of SO_2 from the *Lime production* category were estimated in 2006 (CRL Energy, unpublished(a)), but there is currently no provision in the CRF to report this. Some additional SO_2 is derived from sulphur in coal or waste oil used as fuel in cement and lime kilns, and this is reported in the Energy sector.

Two companies are making glass in New Zealand, with emissions from the use of soda ash and limestone in the process. O-I New Zealand makes container glass and Tasman Insulation New Zealand Ltd makes smaller amounts of glass for building insulation products.

Limestone and soda ash are also used in the steel and aluminium industries and would normally be reported in the *Metal industry* source category. Emissions from this use of mineral inputs are reported in the *Mineral industry* source category (see 4.2.2 below) to protect the confidentiality of data provided by the two glass companies.

A very small amount of CO_2 is reported from the use of kaolin clays in ceramics production.

The only key category is CO_2 emissions from the *Cement production* category (level assessment). No sources were identified as key categories in the trend assessment.

In 2016, the *Mineral industry* source category accounted for 726.8 kt CO_2-e (15.0 per cent) of emissions from the IPPU sector. This is 164.9 kt (29.4 per cent) above the 1990 emissions, driven by increasing production of cement, lime, and glass containers. However, emissions in 2015 were 876.3 kt CO_2-e. Emissions have decreased in 2016 due to the closure of the Holcim cement plant.

Changes in the national standards for cement, in 1995 and 2010, allowed increasing amounts of other minerals to be added to clinker in formulating cement. Various cement products sold in New Zealand contain limestone and fly ash as mineral additions. This allowed a reduction in emissions per tonne of cement produced (Cement and Concrete Association of New Zealand, 1995).

4.2.2 Methodological issues

Choice of activity data

Use of NZ ETS data

Firms that use limestone or soda ash in the production of clinker (for cement), burnt or slaked lime, or glass have had emission reporting obligations under the NZ ETS since 2010. The emission returns submitted by participants in the NZ ETS are the primary source of data for CO_2 emissions from these categories.

The Environmental Protection Authority (EPA) administers and audits the emission returns submitted by participants. Data submitted by NZ ETS participants are protected by stringent provisions relating to commercial confidentiality. However, under section 149 of the Climate Change Response Act 2002, the inventory agency may request information from the EPA for the purpose of compiling New Zealand's annual national inventory report.

Those NZ ETS participants who apply for an allocation of emission units in any year also report the amount of product that they make in the calendar year. This includes production of clinker, container glass and burnt lime, including any burnt lime that is subsequently made into slaked lime (calcium hydroxide).

Cement production (2.A.1)

In 2016, the *Cement production* category accounted for 486.4 kt CO_2-e (66.9 per cent) of emissions from the *Mineral industry* category. The activity data used are the reported tonnes of clinker produced by the cement plants. Calculation of emissions from clinker production is done on a plant-specific basis by the companies in preparing their ETS returns. Because historically there have been only two companies in the cement sector in New Zealand, and now there is only one, the activity data for the *Cement production* category are not reported and have been shown as confidential in the CRF. For the years up to 2009, activity and emissions data were supplied by the cement companies to MBIE. From 2010, the companies' ETS returns have been used as the data source.

Lime production (2.A.2)

In 2016, the *Lime production* category accounted for 176.0 kt CO_2-e (24.2 per cent) of emissions from the *Mineral industry* category. The activity data used are the amounts of burnt lime or the amounts of pure calcium oxide (CaO) produced, regardless of whether it is subsequently made into calcium hydroxide (Ca(OH)$_2$).

Activity data and emissions data were supplied annually by the lime companies to MBIE until 2009. This included the amount of burnt lime produced each year. From 2010, lime companies have reported CO_2 emissions and the amounts of pure CaO in the lime that they produced in their reporting to the NZ ETS regulator.

Glass production (2.A.3)

Activity and emissions data for the *Glass production* category are provided on a confidential basis by the two companies that produce glass in New Zealand and are not reported in the CRF tables (2.A.3). Emissions from the use of soda ash and limestone in glass making are reported in the *Other process uses of carbonates* (CRF 2.A.4) category and are aggregated with other relatively small amounts of CO_2 emissions that derive from the calcination of limestone and soda ash.

Other process uses of carbonates (2.A.4)

To preserve the confidentiality of data provided by the two glass companies (above), the data reported in the *Glass production* category have been aggregated as follows and reported in the *Other process uses of carbonates* category:

- emissions from a relatively small amount of soda ash used by New Zealand Aluminium Smelters Ltd at the Tiwai Point smelter are reported in CRF 2.A.4.b (*Other uses of soda ash*) and aggregated with the CO_2 emissions from soda ash used in glass making

- emissions from a relatively small amount of limestone used by New Zealand Steel Limited are reported in CRF 2.A.4.d (*Other*) and aggregated with emissions from limestone used in glass making.

The amounts of soda ash and limestone used are reported as activity data in these two tables. Also, because the limestone emissions cannot be fully disaggregated in the data provided by New Zealand Steel, an extremely small amount of CO_2 from coke and electrode use at the steel plant is also included (see section 4.4.2).

Data on glass making for the years up to 2006 were provided by the companies (CRL Energy, unpublished(c)) and updated for the years 2007–09 by survey requests from MBIE. Data on limestone and soda ash use were based on the companies' records where available. In the case of one glass-making facility, some historical emissions data had to be estimated based only on glass production rates, because actual limestone and soda ash use was not recorded before 2006.

For 2010–16, the glass companies' ETS returns are used.

A very small amount of CO_2 is reported from the use of kaolin clays in ceramics production (2.A.4.a). The activity data used are the approximate amount of kaolin clay produced for this purpose (Christie et al., 1999). In the absence of better data, the rate of production is assumed constant for the whole time series. Emissions from ground limestone used in liming agricultural soils are reported in the Agriculture sector.

Choice of methods

For the years up to 2009, cement emissions were calculated using the methodology specified in the *Cement CO₂ Protocol* (World Business Council for Sustainable Development, 2005), which uses plant-specific emission factors based on the CaO and magnesium oxide (MgO) content of clinker produced. This also includes an adjustment for emissions due to cement kiln dust. This calculation is consistent with the IPCC Tier 2 method (IPCC, 2006).

Emissions for lime up to 2009 were calculated using the IPCC Tier 1 method and the default emission factor of 0.75 tonnes CO_2 per tonne of burnt lime produced. For glass making, the IPCC Tier 1 method and default emission factors were also used for the years up to 2009.

For NZ ETS reporting in the *Mineral industry* source category (from 2010), the methodologies used are specified in the Climate Change (Stationary Energy and Industrial Processes) Regulations 2009 (New Zealand Government, 2017). These methods require firms making clinker or burnt lime to report CO_2 emissions calculated from the amount of pure product made from calcination. In calculating their emissions, NZ ETS participants who make clinker or lime are required to determine and report the amounts of pure CaO and MgO in the clinker or burnt lime produced, and in kiln dust if relevant. The emissions are calculated from this chemical composition. The calculation of total emissions can be summarised as:

$$TE = 0.7848 \times A + 1.0919 \times B + 0.7848 \times C$$

Where: A is the amount of CaO produced

B is the amount of MgO produced

C is the amount of kiln dust produced

Similarly, based on NZ ETS regulations (New Zealand Government, 2017), NZ ETS participants who make glass report the amounts of pure limestone, dolomite and soda ash that they use in the process. This is consistent with the Tier 3 methods in the IPCC Guidelines (IPCC, 2006) but is described as country specific in the CRF.

NZ ETS participants in this category are not required to report annually on the specific methods that they have used to determine the amounts of pure CaO, MgO, and other compounds that they report in their NZ ETS returns. They are required to keep this information available and it is verified periodically by the NZ ETS regulator.

All other emissions use Tier 1 methods. This includes the small amount of SO_2 emissions reported for cement production. Emissions of SO_2 from lime production were also estimated in 2006 (CRL Energy, unpublished(a)). These used a country-specific emission factor of 0.5 kilograms SO_2 per tonne of burnt lime produced, derived from plant measurements carried out in earlier years. There is no provision in the CRF to report these emissions, however.

Choice of emission factors

All calculations made for NZ ETS reporting and used in the *Mineral industry* source category are based on plant-specific analysis.

The small amounts of SO_2 emitted in the *Cement production* category are estimated using plant-specific emission factors taken from mass balance data derived for the two cement plants in 2002 and 2005 (CRL Energy, unpublished(a)).

For the very small emissions of CO_2 from the *Ceramics* (2.A.4.a) category, a country-specific emission factor of 0.1 per cent of carbonates (as equivalent calcium carbonate) in local kaolin clay is used.

Other emission factors used are IPCC defaults.

4.2.3　Uncertainties and time-series consistency

Uncertainties

IPCC default uncertainties have been used for all CO_2 emissions from the *Mineral industry* category (see table 4.2.1). For SO_2 emissions in the *Cement production* category, an uncertainty of ±40 per cent was estimated based on the variance between surveys when these emissions were determined (CRL Energy, unpublished(a)).

Table 4.2.1　Uncertainty in emissions from mineral products

Mineral product	Uncertainty in activity data (%)	Uncertainty in emission factors (%)
Cement: CaO content of clinker	±1	±1
Cement: kiln dust	±1	±5
Cement (SO_2)	±1	±40
Lime (CO_2)	±2	±2
Glass (SO_2)	±5	±10
Glass (NMVOC)	±5	±50

Time-series consistency

Because of the change to using NZ ETS data for cement and lime, and the use of slightly different calculation methods for these emissions, the reported activity data for lime production is not fully consistent through the time series. For the years up to 2013, a default emission factor was used, based on the amount of burnt lime produced. For 2014–16, NZ ETS returns are the data source. The companies carry out analysis and report the amount of pure CaO made to the NZ ETS regulator, and consequently the implied emission factor reflects small year-to-year changes in composition.

4.2.4　Source-specific QA/QC and verification

For this submission, data for all CO_2 emissions in the *Mineral industry* source category underwent Tier 1 quality checks in the preparation of this inventory. The only key category is CO_2 emissions from *Cement production*.

Verification of activity data from independent sources is not currently possible. The EPA carries out verification of NZ ETS participants' submitted data on a rotating basis, and, as these verifications occur, the inventory agency will make use of the resulting information to verify the emissions data where possible.

4.2.5　Source-specific recalculations

There are no recalculations affecting emissions for the *Mineral industry* source category.

The reported activity data for lime production in the years 2014 and 2015 have been recalculated to ensure greater consistency. Previously, the amount of pure CaO made was reported for these years.

4.2.6　Source-specific planned improvements

The inventory agency has worked with the companies in the *Mineral industry* source category to improve transparency and confidence in the data provided. However, concerns about the confidentiality of data provided by the two cement companies and two glass companies, including data submitted as part of their compliance with NZ ETS obligations, remain a barrier to further improvements in transparency for this source category.

4.3   Chemical industry (2.B)

4.3.1   Description

The significant chemical processes occurring in New Zealand are the production of urea, methanol, superphosphate fertiliser, hydrogen peroxide, formaldehyde and ethanol. In addition, a substantial amount of hydrogen is made at the Marsden Point oil refinery and CO_2 emissions from this process are reported in the *Chemical industry* category. No other relevant chemical products (such as nitric acid, adipic acid or ethylene) are produced in New Zealand.

Ammonia is made at one site in Taranaki by the catalytic steam reforming of natural gas. The ammonia produced is further processed into urea. Emissions of CO_2 arise from the fraction of process CO_2 that is not recovered for urea production. Essentially all of the urea product is used as a fertiliser in New Zealand. The emissions associated with agricultural use of urea (both manufactured in New Zealand and imported) are reported in the Agriculture sector (CRF 3.H). A small amount of urea is also used for catalytic reduction of diesel exhaust emissions. The emissions of CO_2 from this use of urea are considered to be insignificant.

Methane emissions are reported from the production of methanol, which is made from natural gas feedstock at two sites in Taranaki. From 1990 to 1997, a large proportion of the methanol made in New Zealand was processed into synthetic gasoline for transport use. All emissions associated with the production of gasoline, including the synthetic gasoline produced from 1990 to 1997, are reported in the Energy sector (chapter 3, sections 3.2 and 3.3). From 1998 on, all methanol made in New Zealand has been chemical methanol for export, and process emissions from the methanol plants have been reported in the IPPU sector.

A small amount of CO_2 is reported from the use of imported calcium carbide, which is used to produce acetylene for welding. No carbides are manufactured in New Zealand.

Some indirect emissions (oxides of nitrogen (NO_x), carbon monoxide (CO), non-methane volatile organic compounds (NMVOCs) and SO_2) are reported from methanol, formaldehyde, ethanol, and superphosphate fertiliser production.

Emissions from the *Chemical industry* source category in 2016 were 316.6 kt CO_2-e (6.5 per cent) of emissions from the IPPU sector. This is 113.6 kt CO_2-e (56.0 per cent) above the 1990 level. The increase has been driven by increasing production of ammonia and methanol, and increasing demand for transport fuels, which has increased the demand for hydrogen as an intermediate in oil refining. However, emissions in 2015 were 389.0 kt CO_2-e. Emissions have decreased in 2016 due to lower rates of production for hydrogen and urea.

The only key category in the *Chemical industry* source category is *Methanol* (trend assessment).

4.3.2   Methodological issues

Choice of activity data

Ammonia and urea (2.B.1)

Data on the production of urea are supplied to MBIE by Ballance Agri-Nutrients Limited, which operates the ammonia–urea production plant. The activity data reported are the production of ammonia, which is back-estimated from the amount of urea produced on the basis of a site-specific conversion factor that reflects the actual rate of conversion of ammonia to urea achieved in this plant.

Calcium carbide (2.B.5.b)

A small amount of calcium carbide is imported to New Zealand and used to produce acetylene gas for welding. The approximate amount of calcium carbide imported is used as activity data.

Methanol (2.B.8.a)

Data on methanol production (chemical methanol produced for export) are supplied to MBIE by Methanex, which operates the two methanol plants.

Hydrogen (2.B.10)

Most of the hydrogen produced in New Zealand is made by Refining New Zealand Ltd at the Marsden Point oil refinery. Another company, Degussa Peroxide Ltd, produces a small amount of hydrogen, which is converted to hydrogen peroxide. In both cases, the hydrogen is produced from CH_4 (from refinery gas and natural gas) and steam. Carbon dioxide is a by-product of the reaction and is vented to the atmosphere.

The activity data reported are the amount of hydrogen produced, as reported to MBIE by the plant operators.

Fertiliser, formaldehyde and ethanol (2.B.10)

Some indirect emissions (SO_2 and NMVOCs) are also reported from the production of superphosphate fertiliser, and formaldehyde and from the production of ethanol for purposes other than food and drink.

Choice of methods

Ammonia and urea (2.B.1)

The CO_2 emissions are estimated from a Tier 2 carbon balance, based on the feedstock gas used. The emissions are derived from all carbon in the feedstock gas used, less carbon recovered for urea production and remaining in the urea product (IPCC, 2006). Note that only gas used as feedstock is included in this calculation. Gas used for combustion is reported in the Energy sector under the *Manufacturing industries and construction* source category (CRF 1.A.2).

Calcium carbide (2.B.5.b)

The Tier 1 method is used.

Methanol (2.B.8 and 2.B.8.a)

Data on the natural gas used for methanol production are also supplied to MBIE by the plant operators. However, the available data on gas supplied to the methanol plants do not allow for feedstock to be clearly distinguished from gas used for combustion. Also, close to 100 per cent of the carbon in feedstock gas is converted to methanol. Therefore, no significant CO_2 emissions can be clearly related to the process. The IPCC Guidelines do not provide a method for estimation of any CO_2 emissions from this process (IPCC, 2006). Any small amount of CO_2 emissions from the methanol production process is included in the Energy sector (1.A.2), along with the much larger amount of combustion-related emissions from the methanol plants.

Fugitive CH_4 from the methanol manufacturing process is estimated using the Tier 1 method. Emissions of NO_x, CO and NMVOC are also reported.

Hydrogen (2.B.10)

Emissions of CO_2 from hydrogen production are calculated using the Tier 2 methodology, based on feedstock composition (IPCC, 2006). The required data are supplied directly to MBIE by the two production companies.

Choice of emission factors

Carbon dioxide and methane

For ammonia production, the carbon content of each type of natural gas (up to three types taken from different natural gas fields, and mixed pipeline gas) used as feedstock determines country-specific CO_2 emission factors.

These emission factors are higher on average than Tier 1 default emission factors, due to the use of untreated high-CO_2 gas from the Kapuni field as part of the feedstock at this plant. This gas has a carbon content factor (CCF_i) of approximately 22.5 kilograms per gigajoule in comparison with the default of 15.3 kilograms per gigajoule.

For hydrogen production, site-specific (for refinery gas) and field-specific (for natural gas) emission factors are used to determine the CO_2 emissions from the feedstock gas streams used. In 2016, the implied emission factor was 5.9 tonnes of CO_2 per tonne of hydrogen produced.

IPCC default emission factors are used to estimate emissions of CH_4 from methanol manufacture and CO_2 from calcium carbide use (IPCC, 2006). No other information on these emission sources is available.

Indirect emissions

Indirect emissions of NO_x, CO and NMVOC from methanol production are reported (2.B.8) with emission factors estimated by Methanex (CRL Energy, unpublished(a)). The emission factors for NO_x and CO were derived from site measurements, and the emission factor for NMVOC is based on American Petroleum Institute methods for estimating vapour emissions from storage tanks.

Some indirect greenhouse gas emissions are also reported for superphosphate fertiliser, formaldehyde and ethanol production (2.B.10). The emission factors used are country-specific (CRL Energy unpublished(a)) and are as shown in table 4.3.1.

Table 4.3.1   Country-specific emission factors for indirect emissions

Activity	Emissions of	Emission factor
Superphosphate fertiliser production	SO_2	1.5 kg per tonne of H2SO4
Formaldehyde production	NMVOCs	1.5 kg per tonne of formaldehyde
Ethanol production	NMVOCs	6 g NMVOC per litre of ethanol

4.3.3   Uncertainties and time-series consistency

Uncertainties

The IPCC default uncertainties have been used for CO_2 and most non-CO_2 emissions from this source category, as shown in table 4.3.2.

Table 4.3.2   Uncertainty in emissions from the *Chemical industry* source category

Product	Uncertainty in activity data (%)	Uncertainty in emission factors (%)
Ammonia	±2	±6 (CO_2)
Calcium carbide	±50	±50
Formaldehyde	±2	±50 (NMVOCs)
Hydrogen	±2	±6
Methanol	±2	±50 (NOx and CO) ±30 (NMVOCs) ±80 (CH_4)
Superphosphate	±10	±25–60 (varies by site)
Sulphuric acid	±10	±15

Time-series consistency

The implied emission factor for CO_2 in ammonia production has reduced by about 5.0 per cent through the time series, reflecting higher plant utilisation and some improvements in plant efficiency. Because ammonia is made at a single site in New Zealand, the implied emission factor may also vary from year to year as a result of maintenance shutdowns and other events that affect plant performance.

The implied emission factor for hydrogen production (2.B.10) also varies from year to year due mainly to changes in refinery gas composition.

Other implied emission factors in this source category only reflect the default emission factors used.

4.3.4   Source-specific QA/QC and verification

The *Chemical industry* source category contains one key category *Petrochemical and carbon black* (for CH_4 emissions in methane production). The data for these emissions underwent Tier 1 quality checks in the preparation of this inventory. Submission of data under the NZ ETS allows some verification of activity data.

4.3.5   Source-specific recalculations

There are no recalculations for this source category.

4.3.6   Source-specific planned improvements

There are no planned improvements for this source category.

4.4   Metal industry (2.C)

4.4.1   Description

The main emissions in the *Metal industry* source category in New Zealand are from iron and steel production (from iron sand and from recycled scrap steel) and from aluminium production. New Zealand has no production of coke, sinter or ferroalloys.

There are two steel producing sites in New Zealand. New Zealand Steel Limited produces iron using an 'alternative iron-making process', from titanomagnetite iron sand (Ure, 2000). This

iron-making process involves the direct reduction of iron oxide contained in the sand, with sub-bituminous coal (which forms a reactive char) as the reductant. There is no coke production and no use of blast furnaces. The iron produced is then processed into steel.

Pacific Steel Limited has, until recently, operated an electric arc furnace at a separate site to process recycled scrap steel. The owners of New Zealand Steel Limited bought the Pacific Steel Limited production assets in 2015, and all of New Zealand's steel-making capacity is now in integrated at the New Zealand Steel site. Steel billet production at the Pacific Steel plant, using recycled scrap, stopped in October 2015. As a result, all production in New Zealand is now based on newly produced iron – there is no domestic production using recycled steel scrap.

There is one aluminium smelter in New Zealand, operated by New Zealand Aluminium Smelters Limited (NZAS). The plant produces aluminium by smelting imported bauxite using centre-work prebake technology. Carbon dioxide and PFC emissions from aluminium production are reported.

Very small amounts of emissions are also reported from secondary lead production (from the recycling of lead-acid batteries) up to 2015 and from the historical use of SF_6 in a magnesium foundry.

Key categories in the *Metal industry* source category are CO_2 emissions from *Iron and steel production* and from *Aluminium production*, and PFCs from *Aluminium production*.

Emissions from the *Metal industry* source category in 2016 were 2,300.2 kt CO_2-e (47.4 per cent) of emissions from the IPPU sector. This is 370.0 kt CO_2-e (13.9 per cent) below the 1990 level. The decrease has been driven by a reduction in emissions of PFCs in aluminium smelting, which has been partly offset by increasing CO_2 emissions due to increasing production of steel and aluminium. Emissions in 2015 were 2,366.3 kt CO_2-e. Emissions have decreased in 2016 due to the closure of the Pacific Steel plant and the cessation of lead battery recycling.

4.4.2   Methodological issues

Choice of activity data

Iron and steel production (2.C.1 and 2.C.1.a)

In 2016, the *Iron and steel production* category accounted for 1,712.1 kt CO_2-e (74.4 per cent) of emissions from the *Metal industry* source category. The activity data provided to MBIE by the two steel producers (tonnes of steel produced) are regarded as commercially confidential and are reported as confidential in the CRF.

Most of the CO_2 emissions from the *Iron and steel production* category are produced through the production of iron from titanomagnetite iron sand. Nearly all of the emissions in this process come from the use of sub-bituminous coal as a reducing agent. There is no carbon in the iron sand used by New Zealand Steel Limited (table 4.4.1).

Table 4.4.1   Typical analysis from New Zealand Steel Limited of the primary concentrate (provided by New Zealand Steel Limited)

Element	Result (%)
Fe_3O_4	81.4
TiO_2	7.9
Al_2O_3	3.7
MgO	2.9
SiO_2	2.3
MnO	0.6
CaO	0.5
V_2O_3	0.5
Zn	0.1
Na_2O	0.1
Cr	0.0
P	0.0
K_2O	0.0
Cu	0.0
Sum	100.0

Figure 4.2.1   Simplified schematic of iron and steel production in New Zealand
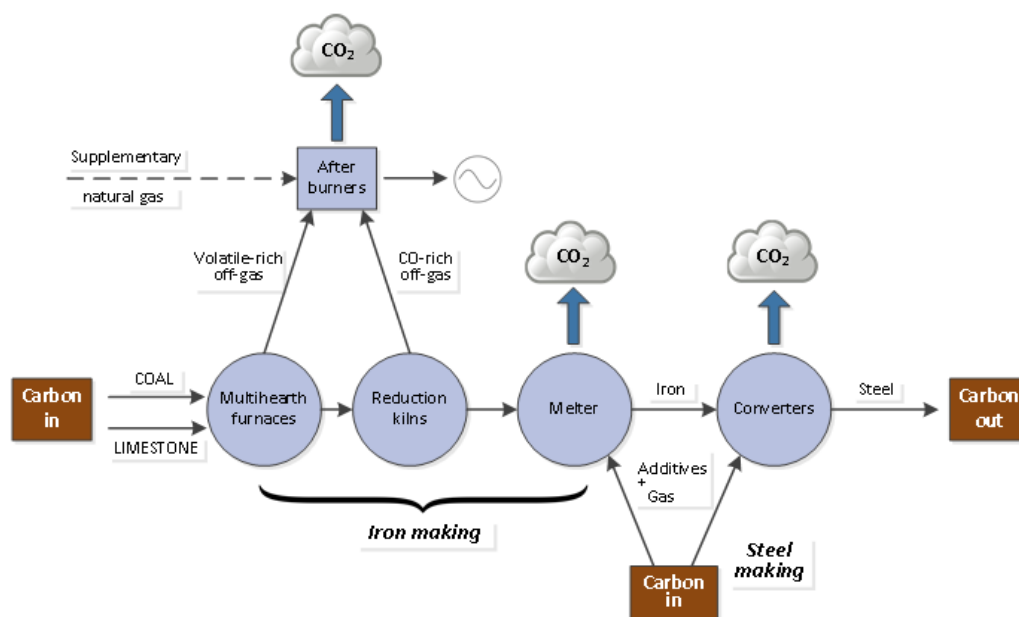
Nearly all of the carbon entering the process is from coal used as a reductant in the iron-making process, and nearly all of this is emitted as CO_2 in two waste gas streams:

- gas generated in multihearth furnaces used to heat and dry concentrated iron sand and coal – this gas contains excess volatiles from the coal

- gas generated in rotary reduction kilns used to convert oxide in the iron sand to iron – this gas is rich in CO.

All of this waste gas is combusted in 'afterburners' and used for electricity production. It would not be acceptable for gas containing coal volatiles or CO to be emitted without this combustion stage. There is no other flaring or disposal mode for the waste gases.

Much smaller amounts of CO_2 derive from limestone added to the multihearth furnaces and from additives and natural gas used in melters and steel making.

Aluminium production (2.C.3)

Carbon dioxide is emitted during the oxidation of carbon anodes. The two PFCs tetrafluoromethane (CF_4) and hexafluoroethane (C_2F_6) are emitted from the reduction cells used for smelting during anode effects. An anode effect occurs when the aluminium oxide concentration in the cell is low. The emissions from combustion of various fuels used in aluminium production (heavy fuel oil, liquefied petroleum gas, petrol and diesel) are reported in the Energy sector.

In 2016, the *Aluminium production* category accounted for 539.4 kt CO_2-e (23.5 per cent) of emissions from the *Metal industry* category. Activity data (production of hot metal aluminium from the smelter) and estimates of CO_2 and PFC emissions were supplied by NZAS to MBIE until 2010. From 2011 to 2016, the CO_2 and PFC emissions data and activity data have been sourced from the company's ETS reporting.

Magnesium and other metal production

From 1990 to 1999 a very small amount of SF_6 was used as a cover gas in a magnesium foundry. Emissions are estimated based on an approximate estimate of the amount of SF_6 that was used (2.C.4). No other activity data are available (CRL Energy, unpublished(b)).

A very small amount of CO_2 emissions was also reported from secondary lead production between 1990 and 2015, with the approximate recycled lead output as the activity data. This production has now stopped. The only other metal production that occurs in New Zealand is gold and silver mining. No emissions are reported from these activities.

Choice of methods

Iron and steel production (2.C.1 and 2.C.1.a)

The IPCC Tier 2 approach is used for calculating CO_2 emissions from the iron and steel plant operated by New Zealand Steel Limited. Emissions from pig iron and steel production are not estimated separately because all of the iron made is processed into steel. This is a mass balance approach in which all carbon in inputs is assumed to be emitted, except the small amount sequestered in the steel produced.

Most of the input carbon comes from the coal used as a reductant. There are also some CO_2 emissions from the use of limestone in iron and steel production. These emissions are reported in the *Mineral industry* source category (2.A.4.d), to preserve the confidentiality of data on limestone use supplied by companies in the *Glass production* category. A very small amount of CO_2 from other carbon-containing inputs (coke and electrodes) is also included.

Emissions from the production of steel by Pacific Steel are also estimated using the Tier 2 mass balance approach. The average carbon content (0.20 per cent by mass) in the finished product is subtracted from the total carbon in inputs to obtain the amount of carbon emitted. Due to limited process data collected and retained by Pacific Steel in the past, emissions for the years 1990 to 1999 were calculated using the average of the implied emission factors for 2000–08 based on production volume.

Aluminium production (2.C.3)

NZAS calculates the process CO_2 emissions using the International Aluminium Institute's Tier 3 method (International Aluminium Institute, 2006, equations 1–3), which is compliant with the IPCC 2006 Tier 2 method. The same method is used in NZ ETS reporting for aluminium smelting. This method breaks the prebake anode process into three stages: baked anode consumption, pitch volatiles consumption and packing coke consumption.

Also, NZAS adds soda ash to the reduction cells to maintain the electrolyte chemical composition. This results in CO_2 emissions as a by-product. These emissions are reported in the *Mineral industry* source category (2.A.4.b), to preserve the confidentiality of data on soda ash use supplied by companies in the *Glass production* category.

Data on the duration of anode effects at the smelter are available for 1993 to 2014. Perfluorocarbon (CF_4 and C_2F_6) emissions from aluminium production are estimated using:

- the IPCC Tier 1 method for the years 1990 and 1991. The data needed to apply a Tier 2 method are not available

- interpolation for 1992; at this time, there was still no recording of anode effect duration

- the IPCC Tier 2 method (using slope coefficients) for 1993 to 2015. This methodology is replicated in the reporting requirements the company now uses in its ETS returns.

There are no current plans to directly measure PFC emissions at the smelter, so it is not likely that site-specific slope coefficients (required for the use of Tier 3) will be available for some time.

Magnesium production (2.C.4)

Emissions are estimated based on an approximate estimate of the amount of SF_6 that was used as cover gas and on the basis that all SF_6 used is emitted. The method is Tier 1.

Lead production (2.C.5)

The Tier 1 methodology is used.

Choice of emission factors

Carbon dioxide

Plant-specific emission factors are applied for the sub-bituminous coal used as a reducing agent in iron and steel production. For the early years, the coal emission factor was 0.0937 tonnes of CO_2 per gigajoule. Plant-specific emission factors are also used for other carbon-containing inputs in both the *Iron and steel production* and *Aluminium production* categories.

For secondary lead production, the IPCC default emission factor (0.2 tonnes of CO_2 per tonne of lead recycled) is used.

Perfluorocarbons and SF_6

Default emission factors (slope coefficients) are used for emissions of CF_4 and C_2F_6 from aluminium production. For the emissions in 1990 to 1992, when data on the duration of anode effects are not available and a Tier 1 method is used, the default emission factors of 0.4 kilograms CF_4 and 0.04 kilograms C_2F_6 per tonne of aluminium are used.

Emissions of SF_6 used in magnesium casting are considered to be immediate.

Indirect emissions

Emissions of indirect greenhouse gases (CO, SO_2 and NO_x) are reported for the *Iron and steel production* and *Aluminium production* categories. These are based on a mass balance calculation (for SO_2) and a mix of plant-specific emission factors and IPCC defaults for other gases (CRL Energy, unpublished(a)).

4.4.3 Uncertainties and time-series consistency

Uncertainties

IPCC default uncertainties have been used for activity data (see table 4.4.2). For the CO_2 emission factors in the *Iron and steel production* category, an uncertainty of ±7 per cent was assessed to reflect some uncertainty in the carbon content of the product. An uncertainty of ±30 per cent was assessed for PFCs reflecting the use of Tier 1 methods for the first three years. The uncertainties for indirect gases were assessed on a site-specific basis at the time the data were collected (CRL Energy, unpublished(a)).

Table 4.4.2   Uncertainty in emissions from the metal industry

Category	Uncertainty in activity data (%)	Uncertainty in emission factors (%)
Iron and steel (CO_2)	±5	±7
Iron and steel (CO)	±5	±30
Iron and steel (NO_x)	±5	±70
Aluminium (CO_2)	±5	±2
Aluminium (PFCs)	±5	±30
Aluminium (SO_2)	±5	±5
Aluminium (CO)	±5	±40
Aluminium (NO_x)	±5	±50
Magnesium (SF_6)	±100	–
Lead (CO_2)	±50	±50

Time-series consistency

The implied emission factors for PFC emissions from aluminium production fluctuated over the time series between 1990 and 1998. The introduction of monitoring at the aluminium smelter in 1993 contributed to process and management improvements that reduced the frequency and duration of anode effects. This improvement process continued. Since 1998, emissions have been lower and relatively stable, due to the much better control of anode effects (see table 4.4.3).

Table 4.4.3   Explanation of variations in New Zealand's aluminium emissions

Variation in emissions	Reason for variation
Increase in CO_2 and PFC emissions in 1996	Commissioning of Line 4 cells
Decrease in CO_2 emissions in 1995	Good anode performance, compared with 1994 and 1996
Decrease in CO_2 emissions in 1998	Good anode performance
Decrease in CO_2 emissions in 2001, 2003 and 2006	Fewer cells operating from reduced aluminium production due to reduced electricity supply
	Good anode performance contributed in 2001
Increase in CO_2 emissions in 1996	All cells operating, including introduction of additional cells
	Increasing aluminium production rate from the cells
Decrease in PFC emissions in 1995	Reduced anode frequencies
	The implementation of the change control strategy to all reduction cells
	Repairs made to cells exerting higher frequencies
PFC emissions remained high in 1997	Instability over the whole plant as the operating parameters were tuned for the material coming from the newly commissioned dry scrubbing equipment (removes the fluoride and particulate from the main stack discharge)
Decrease in PFC emissions in 1998	Cell operating parameter control from the introduction of modified software. This software has improved the detection of an anode-effect onset and will initiate actions to prevent the anode effect from occurring
PFCs remain relatively static in 2001, 2003 and 2006	Increased emissions from restarting the cells

4.4.4 Source-specific QA/QC and verification

The two key categories in the *Metal industry* source category are CO_2 emissions from *Iron and steel production* and *Aluminium production*, and PFCs from *Aluminium production*. The data for all direct emissions in this source category underwent Tier 1 quality checks in the preparation of this inventory.

4.4.5 Source-specific recalculations

Secondary lead production (from recycled lead-acid batteries) was reported for the first time in the 2016 submission. There are no recalculations for this submission.

4.4.6 Source-specific planned improvements

There are no planned improvements for this source category.

4.5 Non-energy products from fuels and solvent use (2.D)

4.5.1 Description

The emissions reported in the *Non-energy products from fuels and solvent use* source category include CO_2 from the use of lubricants and a very small amount from the use of paraffin wax, some of which is likely to be used for candles.

In addition, some emissions of indirect greenhouse gases (mainly NMVOCs) are estimated and reported from:

- the use of asphalt in road paving and roofing applications
- painting
- degreasing and dry cleaning
- use of solvents in printing
- general domestic and commercial use of solvents.

Emissions from the *Non-energy products from fuels and solvent use* source category in 2016 were 46.5 kt CO_2-e (1.0 per cent) of emissions from the IPPU sector.

There are no key categories.

4.5.2 Methodological issues

Choice of activity data

Lubricant use (2.D.1)

Data reported to MBIE by the industry provide estimates of the amount of lubricants imported into New Zealand in each calendar year and the amounts in stock at the start and end of the year. This allows the amount of lubricants used in the year to be estimated.

However, this information is only available for the years 2011 to 2016. For earlier years, the activity data have been estimated by assuming that the amount of lubricant used was proportional to the amount of transport fuel used in New Zealand in the year. Also, because

apparent use fluctuates from year to year and it is very unlikely that such variations are reflected in actual lubricant use and emissions, averaging is used to estimate emissions for 2011–16.

Paraffin wax use (2.D.2)

A very small amount of paraffin wax is imported into New Zealand. There is no reliable data on import volumes, so the activity data have been estimated from an estimate of the value of imports. This is only available for 2005 to 2011, and the activity data for other years have been assumed to be the same.

Asphalt paving and roofing and solvent use (2.D.3)

Three main bitumen production companies are operating in New Zealand that provide materials for road paving. Data on bitumen production and emission rates were provided by these companies (CRL Energy, unpublished(a)). One company is also manufacturing asphalt roofing in New Zealand.

Solvent use was estimated in 2006 (CRL Energy, unpublished(a)) and, for all of these sources, activity data for the years up to 2005 have been extrapolated for 2006–16 in the absence of any updated information.

Choice of methods

Tier 1 methods (IPCC, 2006) are used to estimate all emissions in this category. Only approximate activity data are available, with no country-specific information on the amounts of lubricant and paraffin wax used for specific applications. For this reason, the IPCC Tier 1 approach is used (IPCC, 2006).

Choice of emission factors

Lubricant use (2.D.1) and paraffin wax use (2.D.2)

Default emission factors (carbon content and 'oxidised during use' factor) are used.

Asphalt paving and roofing and solvent use (2.D.3)

The bitumen content of road paving used in New Zealand is about 6.0 per cent, which is lower than commonly used in most countries. The NMVOC emissions from road paving are calculated using a country-specific method based on the fraction of bitumen in asphalt used in road paving material, the fraction of solvent added to bitumen and an assessment that 75.0 per cent of the solvent added will be emitted (see table 4.5.1).

Table 4.5.1   Calculation of NMVOC emissions from road paving

Calculation of NMVOC emissions from road paving
NMVOC emitted = A × B × C × D
Where:
A = road paving material used (kt)
B = fraction by weight of bitumen in asphalt
C = fraction of solvent added to bitumen (0.04)
D = fraction of solvent emitted (0.75)

The fraction of bitumen in asphalt used in road paving materials was reduced over time as methods of laying roading improved (see table 4.5.2).

Table 4.5.2   Fraction of bitumen in road paving material

Reporting years	Fraction of bitumen in asphalt (B above)
1990–2001	0.80
2002–03	0.65
2004–15	0.60

For asphalt used as roofing material, IPCC default emission factors of 0.05 kilograms NMVOC and 0.0095 kilograms CO per tonne of product have been used.

4.5.3   Uncertainties and time-series consistency

Uncertainties

IPCC default uncertainty is estimated for CO_2 from lubricant use. The uncertainties used for indirect emissions in this source category are a mix of defaults and country specific. These uncertainties are shown in table 4.5.3.

Table 4.5.3   Uncertainty in emissions in non-energy products from fuels and solvent use

Category	Uncertainty in activity data (%)	Uncertainty in emission factors (%)
Lubricant use	±20	±50
Paraffin wax use	±20	±100
Asphalt road paving	±40	±40
Asphalt roofing	±50	±40
Paint application	±40	±50
Degreasing and dry cleaning	±40	±60
Printing	±50	±50
Domestic and commercial solvent use	±50	±60

Time-series consistency

For CO_2 emissions in this source category, the activity data have been extrapolated and emission factors are defaults. The implied emissions factors and time-series consistency reflect this.

4.5.4   Source-specific QA/QC and verification

Non-energy products from fuels and solvent use is a non-key category. Verification of the data from independent sources was not feasible.

4.5.5   Source-specific recalculations

Import quantities for lubricants have been averaged over the period that they are available (2011–16) resulting in small changes to the reported emissions for the entire time series. As indicated above, this is because it is unlikely that the observed year-to-year variation in import quantities is reflected in actual emissions.

4.5.6   Source-specific planned improvements

This source category is not a priority for improvement, due to the small scale of emissions. The inventory agency will make use of improved activity data where possible, particularly for lubricants.

4.6　Electronics industry (2.E)

New Zealand has no significant industry engaged in the manufacture of electronic products, and no emissions are reported in this source category.

4.7　Product uses as substitutes for ODS (2.F)

4.7.1　Description

HFCs and small amounts of PFCs are used in a wide range of equipment and products including refrigeration and air conditioning systems and aerosols. No HFCs or PFCs are manufactured in New Zealand; they are all imported. PFCs are also emitted from the aluminium-smelting process and these emissions are reported in the *Metal industry* source category (2.C.3.b).

The use of these gases, almost entirely HFCs, has increased since the mid-1990s when chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) began to be phased out under the Montreal Protocol. In New Zealand, the Ozone Layer Protection Act 1996 sets out a programme for phasing out the use of ODS.

In 2016, emissions in the *Product uses as substitutes for ODS* category were 1,387.0 kt CO_2-e or 28.6 per cent of emissions from the IPPU sector. This was a decrease of 173.3 kt CO_2-e (11.1 per cent) from the 2015 level of 1,560.3 kt CO_2-e. There was no use of HFCs or PFCs in 1990. The first consumption of HFCs in New Zealand was reported in 1992 and the first consumption of PFCs in 1995.

Most of these emissions come from the use of HFCs in the *Refrigeration and air conditioning* category. Emissions from the use of HFCs in *Refrigeration and air conditioning* (level assessment and trend assessment) and HFCs in *Aerosols* (trend assessment) were identified as key categories.

4.7.2　Methodological issues

Choice of activity data

Most of the activity data for the *Product uses as substitutes for ODS* source category are collected using annual surveys of companies that import, distribute and export refrigerants and other synthetic gases, manufacture or import products containing them or use them on a significant scale (CRL Energy, unpublished(c)).

Refrigeration and air conditioning (2.F.1)

New Zealand imports substantial amounts of new refrigerant both in bulk and in factory-charged equipment. Both bulk chemical and equipment charged in New Zealand are exported but on a smaller scale. Data on bulk imports and exports of refrigerant, and factory-charged imported and exported equipment, were obtained using a survey questionnaire and follow up for completeness.

These items of activity data are used to estimate the annual sales of new refrigerant and the total charge of new equipment, for input into the mass balance equation used to estimate emissions of each compound for each sub-application.

Annual sales and the charge in new equipment are calculated as shown in box 7.3 in the IPCC Guidelines (see box 4.1).

Box 4.1

IPCC (2006) first equation in box 7.3

Annual Sales of New Refrigerant

= Domestically Manufactured Chemical

+ Imported Bulk Chemical — Exported Bulk Chemical

+ Chemical Contained in Factory Charged Imported Equipment

– Chemical Contained in Factory Charged Exported Equipment.

Total Charge of New Equipment

= Chemical to Charge Domestically Manufactured Equipment that is not Factory Charged

+ Chemical to Charge Domestically Manufactured Equipment that is Factory Charged

+ Chemical to Charge Imported Equipment that is not Factory Charged

+ Chemical Contained in Factory Charged Imported Equipment

– Chemical Contained in Factory Charged Exported Equipment.

There is no domestically manufactured chemical in New Zealand.

Detailed, but not complete, information on the supplies and banks of chemical in each sub-application was obtained from surveys and follow-up calls to request specific data.

This information has been used to assess the mass balance for each sub-application. However, the attribution of bulk chemical to individual sub-applications is not as accurate as the data on total amounts of each chemical imported. It is consistently difficult to attribute bulk chemical accurately to a specific sub-application. The accurate attribution of bulk chemical to a specific year of use is also challenging, due to stockpiling by importers.

For the *Mobile air conditioning* sub-application, only HFC-134a is used in New Zealand, and has been since 1994. Data on vehicle registrations and fleet numbers were provided by the New Zealand Transport Agency and inform a model of the fleet. Estimates of the annual amount added to the bank, and first-fill emissions, are based on a good understanding of the number of new cars, trucks and buses with air conditioning added to the fleet each year. The results of the survey of bulk importers and distributors were also used to help determine the amount of HFC-134a sold for mobile air conditioning.

In 2009, the average charge of HFC-134a in vehicle air conditioning systems added to the bank at that time was estimated to be as shown in table 4.7.1, based on IPCC defaults and information from the industry.

Table 4.7.1   Average charge of HFC-134a in mobile air conditioners, 2009

Charge for cars and vans (g)	Charge for heavy trucks (g)	Charge for buses (g)
600	800	4,000

These amounts were higher in earlier years, with the charge in a car air conditioner at approximately 700 grams in 2000. New Zealand imports a large variety of vehicles, many of them used cars, and it is not feasible to obtain accurate and up-to-date statistics on the refrigerant charge in these vehicles. Based on this earlier trend, the average charges in vehicles added to the fleet are assessed to reduce by 2.0 per cent per year for 2010–16.

Foam blowing agents (2.F.2)

Only closed-cell foams are produced in New Zealand. Companies importing and using HFCs for foam blowing have provided data on the gas imported and used in response to an annual survey. In addition, some information is available on the quantities of HFCs contained in insulating foam in refrigerators and freezers that are imported from Mexico and the United States of America.

Fire protection (2.F.3)

Three companies in New Zealand import and supply fire protection equipment that contains HFC-227a. This gas has been used since 1994 as a substitute for ODS. No other HFCs or PFCs are used. The companies provide data on the amount imported in equipment in response to an annual survey.

Aerosols (2.F.4)

Most of the HFC use and emissions in this category are for medical use in metered dose inhalers (MDIs). MDIs that use HFC-134a were introduced in 1995, and all MDIs sold in New Zealand from 2012 have used HFCs as the propellant. Nearly all of the propellant in MDIs is HFC-134a, but a small amount of HFC-227ea is also used. Also, 12.0 per cent of MDIs now sold do not use a propellant at all.

All MDIs used in New Zealand are imported. The government pharmaceutical purchasing agency (Pharmac) supplies annual data on the sales of MDIs.

Most of the MDIs imported and sold in New Zealand contain either 200 or 120 doses and either 15 grams or 9.5 grams of HFC-134a propellant per inhaler. An approximate weighted average is used to estimate emissions for each propellant, per dose:

- 81.4 milligrams of HFC-134a; or
- 66.9 milligrams of HFC-227ea.

HFC-134a is the only HFC propellant used in non-medical aerosols in New Zealand.

All non-MDI aerosols used in New Zealand now are imported, with the propellant charge already in place. Up until 2014, one company loaded specialised aerosols in New Zealand with HFC-134a as the propellant. This activity is no longer carried out.

Nearly all of the aerosol cans that are imported and sold in New Zealand use hydrocarbon propellants, with only a few specialised applications using HFCs.

Information on the imports, manufacture and use of non-MDI aerosol products has been sourced from the Aerosol Association of Australia/New Zealand, from survey data supplied by importers and by the one New Zealand aerosol manufacturer that previously used HFC-134a.

Import data – regardless of the source – are not complete or reliable, because the aerosol market is diffuse and the available data do not clearly distinguish aerosols that contain HFCs from the much greater number containing hydrocarbons.

Survey data have provided some incomplete estimates of imports containing HFCs, accounting, for example, for 6.6 tonnes of HFC-134a in 2006. By combining this information with data from the New Zealand manufacturer, an assessment has been made of the proportion of HFC-134a in aerosol products sold in New Zealand:

- zero from 1990 to 1995, when HFC propellant had not yet been introduced
- phased in from 1996 to 2000 reaching 1.0 per cent in 2000
- 1.0 per cent (approximately 17.0 tonnes of HFC-134a annually) for all later years.

For all non-MDI aerosol products using HFC propellant, the average propellant charge is assessed to be 84 grams of HFC-134a.

Choice of methods

Refrigeration and air conditioning (2.F.1)

The Tier 2b mass balance approach is used to estimate emissions from the *Refrigeration and air conditioning* source category. This method is used because quite complete and accurate data are available on bulk imports of the refrigerants used for these applications. The alternative Tier 2a approach would require bottom-up data on the charges, leakage rates and population of a great variety of equipment items. This information is not available.

The mass balance approach uses equation 7.9 in the IPCC Guidelines (box 4.2).

Box 4.2

IPCC (2006) equation 7.9

Emissions = Annual Sales of New Refrigerant — Total Charge of New Equipment + Original Total Charge of Retiring Equipment — Amount of Intentional Destruction

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Spreadsheet models have been used to represent the refrigerant consumption and banks. Estimates have been made for the six sub-applications: household refrigeration, commercial refrigeration, industrial refrigeration, transport refrigeration, stationary air conditioning and mobile air conditioning.

There is no facility for the intentional destruction of HFCs or PFCs from this application in New Zealand. Some HFCs are exported for destruction in Australia, and the amounts recovered for destruction are reported in this submission.

Other (2.F.2, 2.F.3 and 2.F.4)

The IPCC Tier 1a method is used for foam blowing agents and fire protection equipment.

Aerosol emissions are calculated using the IPCC Tier 1a/2a method (IPCC, 2006, equation 7.6). Tier 2a requires subdividing these emissions by sub-application. In this submission, emissions from MDIs are reported separately as a sub-application (2.F.4.a) but insufficient data are available to further subdivide aerosol products by sub-application. All other aerosol products are reported together (2.F.4.b).

Choice of emission factors

Refrigeration and air conditioning (2.F.1)

The emission factors used in each sub-application (other than mobile air conditioning) were assessed using a combination of IPCC defaults, information from the New Zealand industry and expert judgement.

In addition, the annual leakage rates were adjusted in some cases, to ensure that the total results for all sub-applications were consistent with the much more complete and accurate data available to estimate the total mass balance (for all five sub-applications) for each chemical (CRL Energy, unpublished(c)). For each chemical, this has meant that one of the sub-applications is treated as a residual and is, consequently, subject to greater year-to-year variation.

These emission factors are detailed in the report by CRL Energy (unpublished(c)).

For mobile air conditioning, the emission factors used are shown in table 4.7.2.

Table 4.7.2   Emission factors for mobile air conditioning

First fill (%)	Operation (%)	End of life (%)
0.5	10.0	50.0

Foam blowing agents (2.F.2)

The IPCC default emission factors for closed-cell foam are used, that is, assuming 10.0 per cent loss in the first year of use and 4.5 per cent in each of the following 20 years.

Fire protection (2.F.3)

For fire protection equipment, a country-specific emission factor of 0.015 (1.5 per cent of the charge lost in leakage each year) is used. This estimate is based on information from one major supplier of these systems, which was able to supply records of the amount of HFC-227ea it used to replace leakage and accidental discharges.

Aerosols (2.F.4)

Aerosol emissions are considered to be prompt (emitted in the first year or two after manufacture or import) and so the default emission factor of 50.0 per cent of the initial charge emitted per year is applied.

4.7.3   Uncertainties and time-series consistency

Uncertainties

Data on bulk imports of refrigerant gases in the *Refrigeration and air conditioning* category are complete and accurate with uncertainty of ±5 per cent. Data on the amount imported in factory-charged equipment, and the amount in retired equipment, are much less accurate.

Uncertainties in this source category have been estimated for each sub-application, and table 4.7.3 summarises the uncertainties for each category. For the *Refrigeration and air conditioning* category, uncertainty is attributed only to the activity data.

Table 4.7.3   New Zealand's uncertainties in product uses as substitutes for ODS

Source category	Uncertainty in activity data (%)	Uncertainty in emission factors (%)
Refrigeration and air conditioning	±47	NA
Foam blowing agents	±12	±49
Aerosols	±25	±10
Fire protection	±10	±30

Note: NA = not applicable.

Time-series consistency

Significant stockpiling of refrigerant gases occurred in anticipation of NZ ETS obligations in 2013, and some stockpiling appears to have occurred in other years in response to low NZ ETS unit prices. This has meant that stockpiling needed to be taken into account in applying the mass balance approach to calculate emissions. Some year-to-year variation in the emissions from

refrigeration and air conditioning may indicate that there are also random changes in stocks from year to year that cannot be accurately assessed from available data.

4.7.4 Source-specific quality assurance and quality control and verification

Refrigeration and air conditioning (2.F.1)

Use of HFCs in *Refrigeration and air conditioning* was a key category. In the preparation of this inventory, the data on HFCs underwent Tier 1 quality checks. During data collection and calculation, activity data provided by industry were verified against national totals, where possible, and unreturned questionnaires and anomalous data were followed up and verified to ensure a complete and accurate record of activity data.

For the years up to 2001, the survey data supplied by importers on bulk HFC imports were verified by comparison with import data supplied by Statistics New Zealand. The Ministry of Economic Development compiled a detailed breakdown of bulk HFCs using this data and information from import licences for a range of mixtures such as HFCs and HCFCs. This analysis has not been carried out since 2001, due to restricted access to commercially sensitive import data. Consequently, this independent check on the total imports reported by bulk chemical suppliers is no longer available.

Survey data provided by Fisher and Paykel Limited (the largest importer and manufacturer) were used to compare with total import data where possible. In addition, bulk importers now submit NZ ETS returns, which are used to verify the information on import volumes where possible.

No other key categories and data underwent Tier 1 quality checks.

4.7.5 Source-specific recalculations

In the 2017 submission, some HFC emissions for 2011–14 in the *Refrigeration and air conditioning* source category were recalculated because two suppliers of bulk HFCs revealed in their survey responses that they sold significant amounts of previously stockpiled HFCs in 2015. This gas had therefore not been available for use in the previous four years.

Emissions from MDIs, in the *Aerosols* category, were also reassessed in the 2017 submission because of revised import data for 2013 and 2014, and because of improved information on the propellants used.

In this inventory submission, emissions from the *Refrigeration and air conditioning* source category have been recalculated as a result of further small changes to the amounts of chemical in banks following stockpiling by importers.

The impact of recalculation is to increase the 2015 emissions by 36.8 kt CO_2-e. All recalculations of this type are changes to the timing of emissions, attributing them to a different year, and would not affect total emissions if they are averaged over a longer period.

In addition, in this submission, HFCs exported for destruction are reported as the 'amount of intentional destruction' term in IPCC equation 7.9. In previous submissions, this was excluded from the CRF tables because the destruction does not take place in New Zealand.

4.7.6 Source-specific planned improvements

There are no specific planned improvements for this source category. Improved information on the charge in mobile air conditioners is expected to become available over time. Also, there are still significant year-to-year variations in emissions from the *Refrigeration and air conditioning* source category, which are an indication that improvements can be made by better accounting for stockpiling of bulk chemical. This will be investigated for future submissions.

4.8 Other product manufacture and use (2.G)

4.8.1 Description

This source category in New Zealand comprises emissions from:

- use of SF_6 as an insulant and as an arc-extinguishing agent in electrical switchgear
- use of SF_6 in eye surgery
- use of PFCs (C_2F_6 and perfluoropropane (C_3F_8)) in eye surgery
- use of SF_6 as a tracer gas in scientific experiments
- possible other uses of SF_6, such as in vehicle tyres and industrial equipment
- medical uses of N_2O.

There are no emissions of nitrogen trifluoride (NF_3) in New Zealand. Small amounts of indirect emissions (NMVOC and SO_2) are reported from the manufacture of food and drink, pulp and paper, and board products (fibreboard and particleboard).

There are no key categories in this source category.

In 2016, net emissions of SF_6 and N_2O from the *Other product manufacture and use* category totalled 76.3 kt CO_2-e or 1.6 per cent of emissions from the IPPU sector. This is a decrease of 43.4 kt (36.3 per cent) from the emissions in 1990, driven by a reduction in the importation and use of N_2O over time.

4.8.2 Methodological issues

Choice of activity data

Companies importing or using SF_6 and N_2O provided data on their imports and holdings in response to an annual survey. In addition, companies that use SF_6 in electrical equipment, and have more than 1.0 tonne of the gas in operating equipment, report their holdings and emissions in ETS returns.

Electrical equipment (2.G.1)

Data on bulk imports of SF_6 and the charge in installed equipment were supplied by New Zealand's only manufacturer of relevant electrical equipment (ABB Limited) and by the electricity transmission and generation companies. The transmission and generation companies import SF_6 for their own use.

Sulphur hexafluoride and PFCs from other product use (2.G.2)

One company (BOC Limited) imported SF_6 into New Zealand (for uses other than electrical switchgear) until 2012. There is no other known importer, and some users appear to have been

using previously imported supplies since that time. The current usage rate is assessed (from earlier importation rates) to be approximately 120 kilograms per year. This is made up of 30 kilograms for medical use, 50 kilograms for scientific use and 40 kilograms for other uses.

Extremely small amounts of C_2F_6 and C_3F_8 are imported into New Zealand for use in a specialised type of eye surgery. The importer provided information on the amount imported: between 0.1 kilogram and 0.3 kilograms per year.

Nitrous oxide from product uses (2.G.3)

Data on the import quantities of N_2O were available from the New Zealand Customs Service and Statistics New Zealand from 2005, but some of these are considered unreliable due to classification errors by importers. Survey responses from companies that sell N_2O and import data have been assessed together to estimate the total imports, which vary between 181 tonnes and 205 tonnes per year (CRL Energy, unpublished(c)).

Choice of methods

Electrical equipment (2.G.1)

The national grid company, Transpower, and several of the larger electricity generation companies have supplied stocks and usage data that are detailed enough to allow the use of a Tier 3 approach for the years 2003 to 2016. This uses a mass-balance calculation for closed pressure equipment and an emission factor calculation for sealed pressure equipment.

For all data prior to 2003, and for the other distribution companies that do not have ETS reporting obligations and have not provided detailed data, a Tier 1 approach is used.

Both approaches account for emissions from the operation and disposal of equipment.

Other

Because the quantities are small and the emissions are all considered to be prompt, Tier 1 methods are used for all other emissions in this source category. All SF_6 or N_2O that is imported is assumed to be sold and emitted.

Choice of emission factors

Electrical equipment (2.G.1)

Default emission factors (loss rates and disposal emissions) have been used, where an emission factor is required, for sealed pressure equipment and where a Tier 1 method has had to be used. Factors based on Europe have been used, because these are based on a study that distinguished between sealed and closed equipment types (IPCC, 2006).

Improved information from surveys allowed the use of these two different equipment types in New Zealand to be better disaggregated in the 2017 submission, and the choice of emission factors is now more accurate (CRL Energy, unpublished(c)). However, this distinction is not always clear and remains a source of some uncertainty. Units that are described as sealed can sometimes be topped up with SF_6 in service.

Other

Emissions of SF_6 and other gases for all other applications are assumed to be prompt, and an emission factor of 50.0 per cent or 100 per cent is used, as appropriate.

4.8.3 Uncertainties and time-series consistency

Uncertainties

A mix of expert judgement and IPCC default uncertainties has been used for emissions in this source category (see table 4.8.1). IPCC (2006) recommends the use of expert judgement for sources such as N_2O from product uses, because the uncertainties vary from country to country. For categories other than *Electrical equipment*, there is no uncertainty in emission factors because emissions are considered to be immediate.

Table 4.8.1   Uncertainty in emissions from other product manufacture and use

Category	Uncertainty in activity data (%)	Uncertainty in emission factors (%)
Electrical equipment	±36	±30–60
Medical and other product use (SF_6)	±60 (2005–14)	–
	±80 (2000–04)	
Medical and other product use (PFCs)	±80	–
N_2O from other product uses	±30 (2002–12)	–
	±5 (2013–14)	

Time-series consistency

The implied emissions factors for the *Electrical equipment* category have declined, due to improvements both in data quality and the actual management of SF_6 emissions by Transpower over time.

4.8.4 Source-specific quality assurance and quality control and verification

Other product manufacture and use was a non-key category.

4.8.5 Source-specific recalculations

For the 2017 submission, emissions of SF_6 for the *Electrical equipment* category were recalculated to reflect the availability of better information from surveys on the use of sealed versus closed pressure equipment. This resulted in significant reallocation of emissions between firms and between use and disposal, with a small net effect in increasing 2014 emissions.

For this submission, one of the respondents indicated that the prevalence of closed pressure equipment is higher than previously estimated. This has resulted in a further small recalculation. The effect has been to reduce 2015 emissions by 1.2 kt CO_2-e.

4.8.6 Source-specific planned improvements

For the *Electrical equipment* category, it is expected that further improved activity data and more detailed reporting on stocks of SF_6 will become available over time from NZ ETS reporting and from surveys, as SF_6 handling practices in the industry improve. Better information should enable the consistent use of Tier 2 or Tier 3 methods for this category in future.

Chapter 4: References

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Chapter 5: Agriculture

5.1 Sector overview

In 2016, the Agriculture sector contributed 38,727.3 kilotonnes carbon dioxide equivalent (kt CO_2-e) emissions, representing 49.2 per cent of New Zealand's gross emissions. Emissions have increased by 4,145.5 kt CO_2-e (12.0 per cent) from the 1990 level of 34,581.9 kt CO_2-e (see figure 5.1.1).

The increase since 1990 is primarily due to a 1,895.8 kt CO_2-e (28.3 per cent) increase in nitrous oxide (N_2O) emissions from the *Agricultural soils* category and a 1,064.7 kt CO_2-e (4.0 per cent) increase in methane (CH_4) emissions from the *Enteric fermentation* category (see figure 5.1.2). The main drivers for this change in emissions are an increase in the application of synthetic nitrogen fertiliser of over 600 per cent since 1990 and a 92.4 per cent increase in the dairy herd population. A decrease of 52.3 per cent in the sheep population and a decrease of 23.1 per cent in the non-dairy cattle population since 1990 have partially offset these increases.

In 2016, 71.7 per cent (27,782.9 kt CO_2-e) of the total emissions from the Agriculture sector were from *Enteric fermentation*, followed by 22.2 per cent (8,593.3 kt CO_2-e) from *Agricultural soils*, 3.2 per cent from *Manure management*, 1.5 per cent from *Urea application*, 1.3 per cent from *Liming* and 0.1 per cent from *Field burning of agricultural residues* (see table 5.1.1). Methane emissions from *Enteric fermentation* were 35.0 per cent of New Zealand's gross emissions, and N_2O emissions from the *Agricultural soils* category were 9.9 per cent of New Zealand's gross emissions.

Figure 5.1.1   New Zealand's Agriculture sector emissions from 1990 to 2016
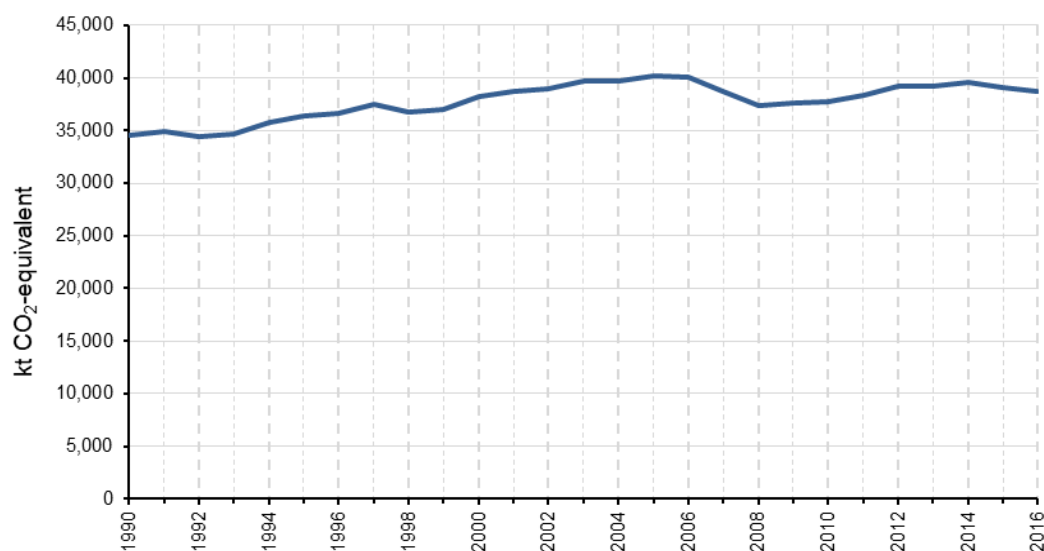
Figure 5.1.2   Change in New Zealand's emissions from the Agriculture sector from 1990 to 2016
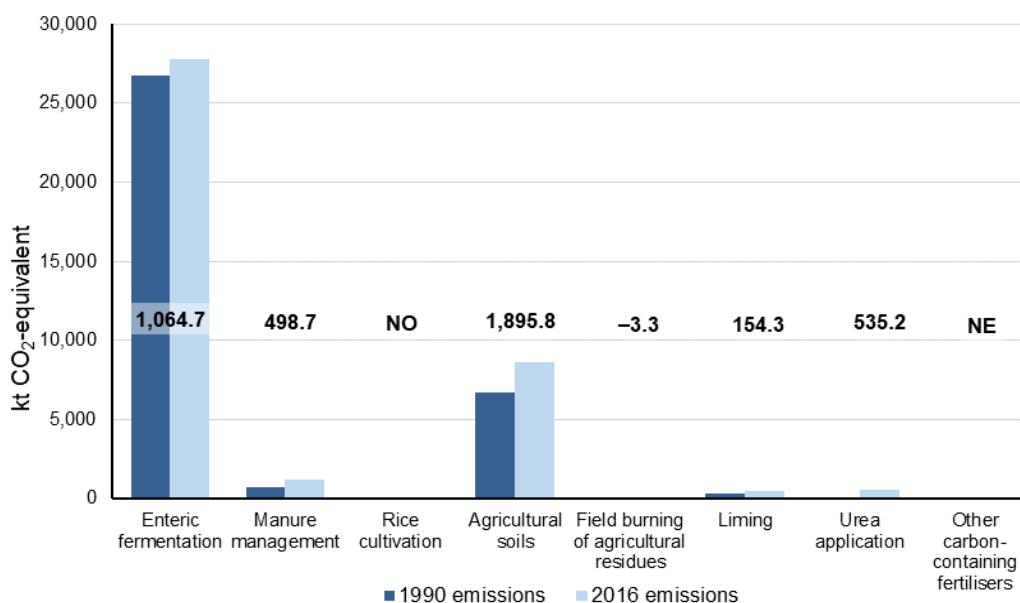
Note: Rice cultivation does not occur (NO) in New Zealand. Emissions from other carbon-containing fertilisers are not estimated (NE).

Table 5.1.1   Trends and relative contribution of New Zealand's agricultural greenhouse gas emissions by category between 1990 and 2016

Category	Emissions (kt CO_2-e)		Change (percentage)	Difference (kt CO_2-e)	Share (percentage) of sector	
	1990	2016	1990–2016	1990–2016	1990	2016
Enteric fermentation (CRF 3.A)	26,718.2	27,782.9	4.0	1,064.7	77.3	71.7
Manure management (CRF 3.B)	739.6	1,238.3	67.4	498.7	2.1	3.2
Rice cultivation (CRF 3.C)	NO	NO	–	–	–	–
Agricultural soils (CRF 3.D)	6,697.5	8,593.3	28.3	1,895.8	19.4	22.2
Field burning of agricultural residues (CRF 3.F)	27.4	24.0	–12.2	–3.3	0.1	0.1
Liming CO_2 emissions (CRF 3.G)	360.1	514.4	42.9	154.3	1.0	1.3
Urea application CO_2 emissions (CRF 3.H)	39.2	574.4	1,365.5	535.2	0.1	1.5
Other carbon-containing fertilisers (CRF 3.I)	NE	NE	–	–	–	–

Note: NO = not occurring. Percentages presented are calculated from unrounded values.

Agriculture is a major component of the New Zealand economy, and exports from agricultural products (excluding fisheries and forestry) comprise 60.8 per cent of the total value of merchandise exports (Statistics New Zealand, 2017a). The production of land-based agricultural products in New Zealand is helped by the favourable temperate climate and the pastoral farming practices used in New Zealand. These practices include the use of year-round extensive outdoor pastoral grazing systems, nitrogen fixation by legumes and synthetic nitrogen fertiliser.

Dairy cattle, non-dairy cattle (beef), sheep and deer are grazed outside all year round, and intensive housing of major ruminant livestock species is not practised to any significant extent in New Zealand. As part of normal day-to-day management, dairy farmers may temporarily take animals off regular grazing areas in an effort to prevent damage to soils and any subsequent loss in pasture growth, although these sites are also mainly outside. This means that New Zealand has a much lower proportion of agricultural emissions from manure management, compared

with other Annex I Parties. For further information about New Zealand's agricultural growing conditions, see section 2.9 (National circumstances, Agriculture) of New Zealand's Seventh National Communication.[26]

5.1.1   Trends in the Agriculture sector

The *Enteric fermentation* and *Agricultural soils* categories contribute significantly to New Zealand's total agricultural emissions (see table 5.1.1). In 1990 and 2016 respectively, 96.0 per cent and 91.7 per cent of agricultural emissions originated from dairy cattle, non-dairy cattle, sheep and deer, so trends in Agriculture sector emissions are largely driven by the populations of these ruminant livestock categories.

Since 1990, there have been changes in the proportions of the main livestock categories farmed in New Zealand (see figures 5.1.3a and 5.1.3b). The number of dairy cattle has increased while the population of sheep and beef cattle has decreased, reflecting increases in the relative profitability of dairy farming (compared with sheep and beef farming). Since 1990, there has also been a trend for new planted forests to be established in grassland areas (see chapter 6).

Figure 5.1.3a   Populations of New Zealand's dairy cattle, non-dairy cattle and deer from 1990 to 2016 (June year ending)
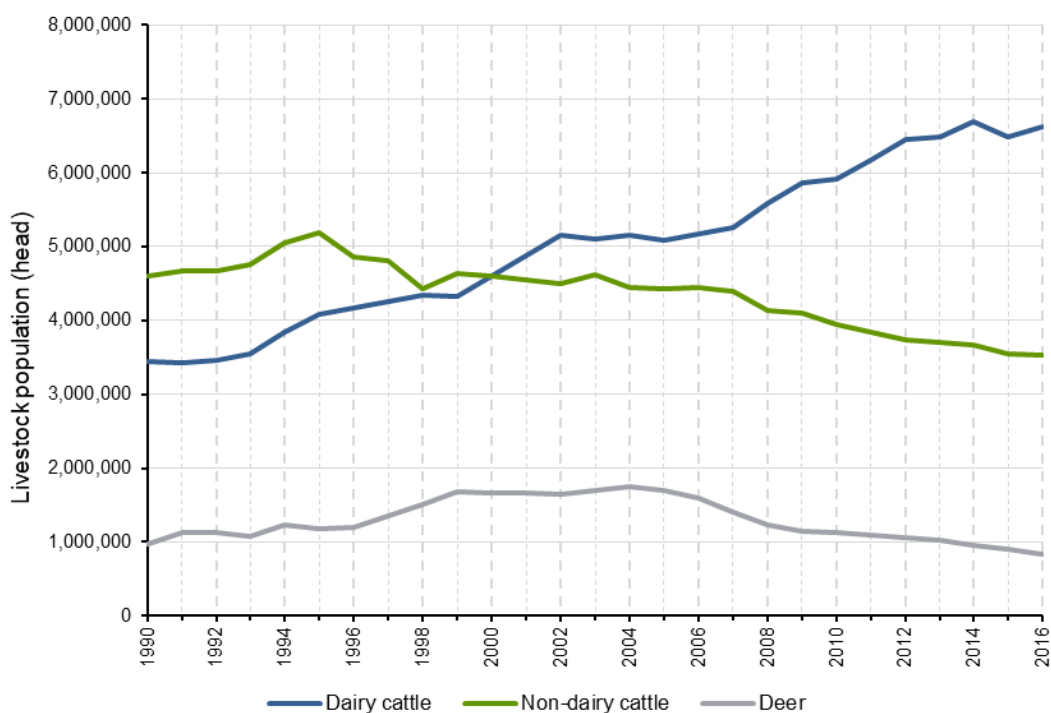
Source: Statistics New Zealand

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[26] Ministry for the Environment. 2017. *New Zealand's Seventh National Communication – Fulfilling reporting requirements under the United Nations Framework Convention on Climate Change and the Kyoto Protocol.* Wellington: Ministry for the Environment. Retrieved from www.mfe.govt.nz/sites/default/files/media/Climate%20Change/21-12-17%20Web%20FINAL%20-%20 Seventh%20National%20Communication%202017.pdf (19 February 2018).

Figure 5.1.3b   Population of New Zealand's sheep from 1990 to 2016 (June year ending)
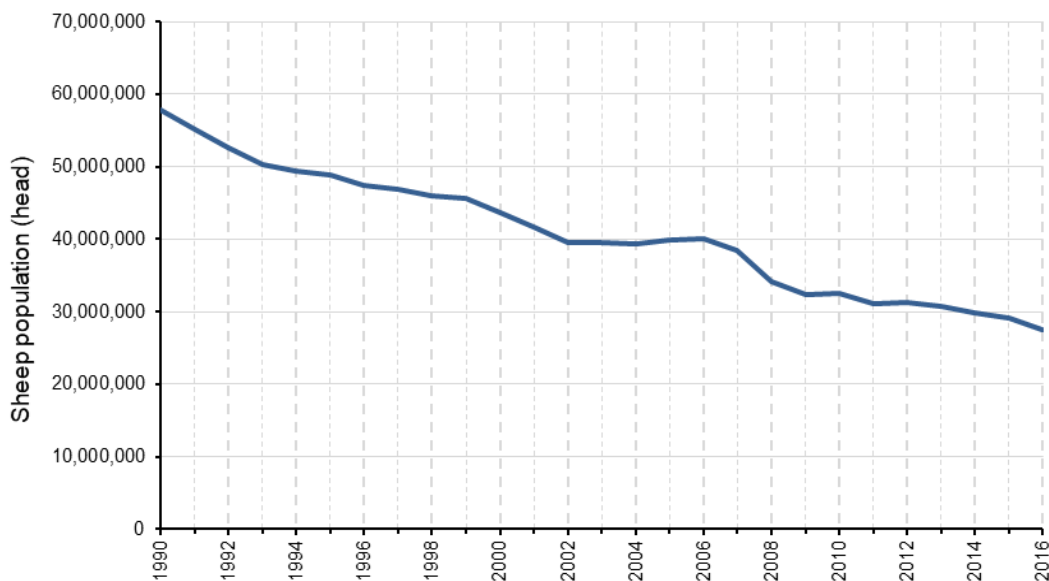
Source: Statistics New Zealand

Effect of productivity improvements, climatic events and commodity prices on implied emission factors

For the major livestock species farmed in New Zealand, there has been a gradual increase in the implied CH_4 and N_2O emission factors[27] per head. This trend reflects the increased levels of productivity (milk and meat yield per head) achieved by New Zealand farmers between 1990 and 2016. Increases in animal liveweight and milk yield per animal require increased feed intake per animal to meet higher energy demands, which results in higher CH_4 and N_2O emissions per animal (i.e., higher implied emission factors (IEFs)).

The amount of feed intake is strongly influenced by weather and climatic events, such as droughts and floods, and by changes in commodity prices. These factors can cause large changes in IEFs in adjacent years. In 2008, a nationwide drought affected both livestock numbers and animal performance, resulting in lower livestock emissions, which are reflected in overall agricultural emissions (see figure 5.1.1). The livestock population and IEFs started to increase after the drought, once seasonal growing conditions improved.

Figure 5.1.4 overlays milk production per dairy cow with the implied enteric fermentation emission factors for dairy cattle for each year from 1990 to 2016. This graph shows that, while per cow productivity has trended upward, there is a significant amount of inter-annual variability, which is influenced by climatic conditions and milk prices. It also shows that the IEFs are affected by these changes in productivity and there is a strong correlation between productivity and IEFs for dairy cattle.

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[27]   Implied emission factors (IEFs) are calculated by dividing the total emissions of a particular animal and sector (e.g., enteric fermentation from sheep) by the number of animals.

Figure 5.1.4   Dairy milk productivity and implied emission factors for dairy cows from 1990 to 2016
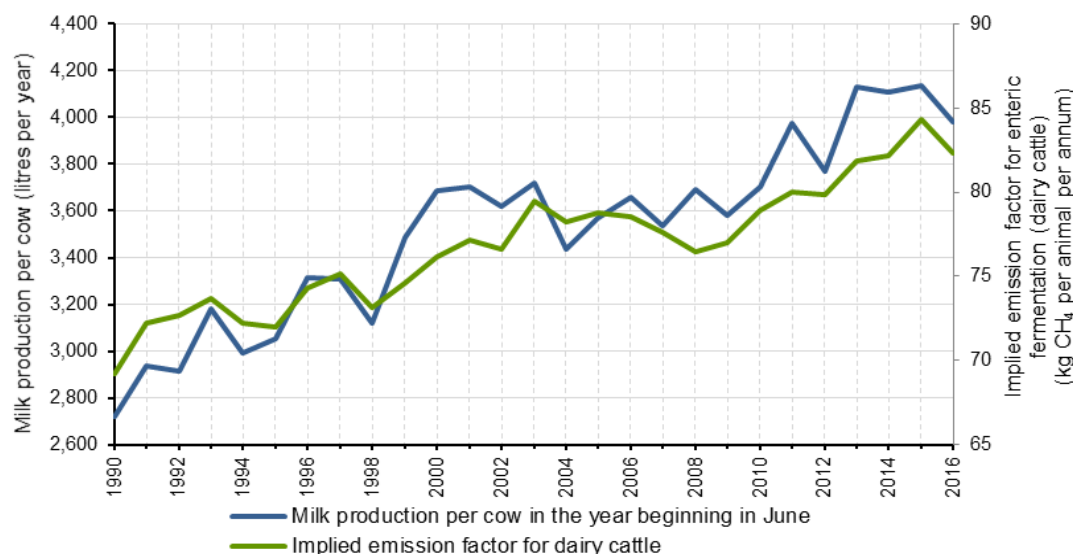
Note: Milk production per cow calculated by dividing total milk production by total dairy cattle population (including replacements and breeding bulls).

Figure 5.1.5 overlays data on the average heifer carcass weight with the implied enteric fermentation emission factors for beef cattle for each year from 1990 to 2016. This graph shows that changes in carcass weights are correlated with changes in the enteric fermentation implied emissions factor.

Figure 5.1.5   Heifer carcass weights and implied emission factors for beef cattle from 1990 to 2016
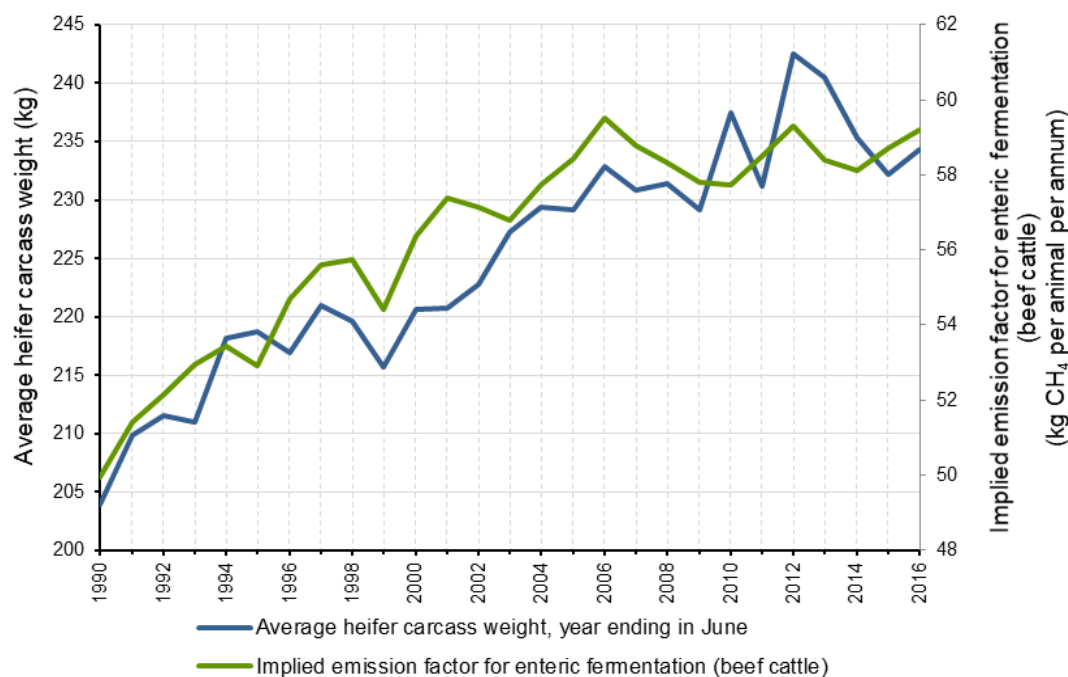
Figure 5.1.6 overlays data on the average adult ewe carcass weight (excluding hoggets and rams) with the implied enteric fermentation emission factors for sheep for each year from 1990 to 2016. This graph shows that there is a large amount of inter-annual variability in IEF values and carcass weights, reflecting variability in climate and market conditions. Changes in carcass weights are correlated with changes in the enteric fermentation implied emissions factor.

Figure 5.1.6   Sheep carcass weights and implied emission factors for sheep from 1990 to 2016

Average adult sheep carcass weight (excluding hoggets and rams), year beginning in June

Implied emission factor for enteric fermentation (sheep)
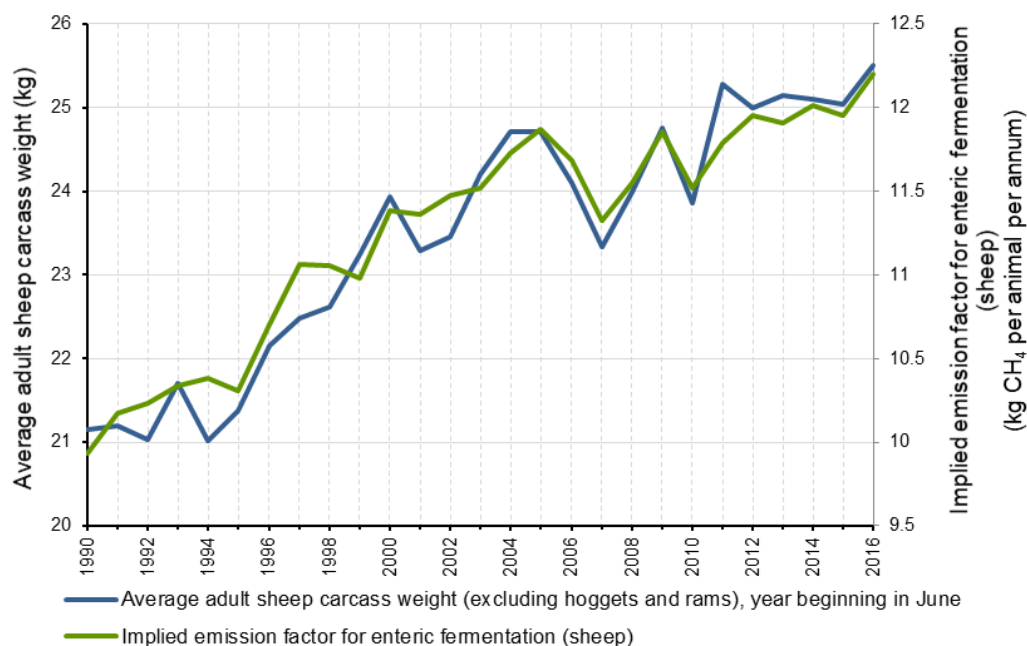
Land used for agriculture

Agriculture (excluding forestry) uses 46.1 per cent of New Zealand's land area, mostly for grazing. Since 1990, the area used for sheep, beef and deer grazing has decreased by 31.6 per cent while the area used for dairy grazing has increased by 71.7 per cent (Statistics New Zealand, 2017b).

Nitrogen fertiliser use

Synthetic nitrogen fertiliser applied to agricultural land has increased markedly since 1990. In 1990 and 2016 respectively, 0.8 per cent and 4.2 per cent of agricultural emissions originated from N_2O from synthetic nitrogen fertiliser, and 0.1 per cent and 1.5 per cent came from carbon dioxide (CO_2) from synthetic urea fertiliser. Total emissions from synthetic nitrogen fertiliser (including urea) have increased from 0.9 per cent to 5.7 per cent of agricultural emissions.

Changes in emissions between 2015 and 2016

Total agricultural emissions in 2016 were 409.3 kt CO_2-e (1.0 per cent) less than those from 2015, which was mostly due to a decrease in sheep emissions.

There was a decrease in emissions of 359.6 kt CO_2-e (3.3 per cent) from sheep, and the sheep population decreased by 5.3 per cent between 2015 and 2016 (see figure 5.1.3b). Emissions from sheep fell from 10,831.5 kt CO_2-e in 2015 to 10,471.9 kt CO_2-e in 2016.

Emissions from dairy cattle fell by 58.1 kt CO_2-e (0.3 per cent) in 2016, compared with emissions in 2015 (from 18,075.8 kt CO_2-e in 2015 to 18,017.7 kt CO_2-e in 2016). The size of the national dairy herd increased between 2015 and 2016 by 133,265 animals (2.1 per cent), although total milk production decreased by 1.0 per cent (LIC and DairyNZ, 2017).

Emissions from deer were 34.0 kt CO_2-e (5.6 per cent) lower in 2016, compared with 2015, because the deer population fell by 7.3 per cent in this period.

There was a 24.7 kt CO_2-e (0.4 per cent) increase in emissions from non-dairy (beef) cattle in 2016, despite a slight decrease in the non-dairy cattle population of 0.4 per cent. The carcass weights of beef animals increased between 2015 and 2016.

In 2016 there was an increase in N_2O emissions from synthetic nitrogen fertiliser of 52.7 kt CO_2-e (3.4 per cent), compared with 2015. Emissions from agricultural liming and urea use fell by 21.9 kt CO_2-e (4.1 per cent) and 33.8 kt CO_2-e (5.6 per cent) respectively.

5.1.2   Key categories for Agriculture sector emissions

Details of New Zealand's key category analysis are in chapter 1, section 1.5. The key categories in the Agriculture sector are listed in table 5.1.2 below.

Table 5.1.2   Key categories in the Agriculture sector

CRF category code	IPCC categories	Gas	Criteria for identification
3.A.1	Option A – Dairy Cattle	CH_4	L1, T1
3.A.1	Option A – Non-Dairy Cattle	CH_4	L1, T1
3.A.2	Other (please specify) – Sheep	CH_4	L1, T1
3.A.4	Other livestock – Deer	CH_4	L1
3.A.4	Other livestock – Goats	CH_4	T1
3.B.1.1	Option A – Dairy Cattle	CH_4	L1, T1
3.D.1.1	Direct N_2O Emissions from Managed Soils – Inorganic N Fertilisers	N_2O	L1, T1
3.D.1.3	Direct N_2O Emissions from Managed Soils – Urine and Dung Deposited by Grazing Animals	N_2O	L1, T1
3.D.1.4	Direct N_2O Emissions from Managed Soils – Crop Residues	N_2O	L1
3.D.2.1	Indirect N_2O Emissions from Managed Soils – Atmospheric Deposition	N_2O	L1
3.D.2.2	Indirect N_2O Emissions from Managed Soils – Nitrogen Leaching and Run-off	N_2O	L1
3.G	Agriculture – Liming	CO_2	L1
3.H	Agriculture – Urea Application	CO_2	L1, T1

5.1.3   Methodological issues for the Agriculture sector

New Zealand uses a range of models and tiers appropriate to the size of the different emission categories.

In 2016, 91.7 per cent of New Zealand's agriculture emissions were due to four grazed ruminant livestock categories: *Dairy cattle*, *Non-dairy cattle*, *Sheep* and *Deer* (referred to in this chapter as the 'major' livestock categories). New Zealand uses a detailed livestock population characterisation (see annex 3, table A3.1.2) and a complex ruminant animal nutrition and energy model to support the calculation of emissions from these livestock.

Other livestock species (*Swine*, *Goats*, *Horses*, *Llamas and Alpacas*, *Mules and asses,* and *Poultry* – referred to as 'minor' livestock categories) account for only 0.5 per cent of New Zealand's agriculture emissions. These are estimated using Tier 1 methods. Where information is available, New Zealand has used country-specific emission methods and factors to estimate emissions for these minor livestock species.

Direct and indirect N_2O emissions from synthetic nitrogen fertiliser accounted for 4.2 per cent of New Zealand's agricultural emissions and are calculated using country-specific emission factors. Carbon dioxide emissions from liming and urea contributed a combined 2.8 per cent towards 2016 total agricultural emissions. The remaining 0.8 per cent of New Zealand's agriculture emissions is due to organic fertiliser, crop residue returned to the soil, cropland cultivation (histosols and nitrogen mineralisation) and cropland burning. Emissions from crop residues and the burning of some agriculture residues are calculated using a Tier 2 method.

Further technical detail is provided in the inventory methodology document on the Ministry for Primary Industries website (www.mpi.govt.nz/news-and-resources/open-data-and-forecasting/greenhouse-gas-reporting/agricultural-greenhouse-gas-inventory-reports/#model) and in the methodological issues section for each category. The approach for determining livestock nutritional and energy requirements is described in the following paragraphs.

Description of the Tier 2 model for determining emissions from energy requirements for major ruminant livestock categories

A Tier 2 inventory model has been developed to calculate emissions from the major ruminant livestock categories (Clark et al., 2003), in line with good practice guidelines (IPCC, 2000, 2006). The model is constantly being improved through new research. New Zealand's modelling for the major livestock categories is considered to be close to a Tier 3 methodology, because country-specific data and monthly data intervals for livestock populations, animal productivity and pasture quality are used. Figure 5.1.7 outlines the methodology used to estimate emissions for the major livestock categories.

Data on production (meat, milk and wool) and animal populations are combined with information on the energy content of the diet and energy requirements of the animals to meet the productivity levels of the livestock categories. This is used to determine the level of feed intake, which is then multiplied by a CH_4 emission factor (or a suitable alternative methodology) to calculate CH_4 emissions from enteric fermentation. Information on the nitrogen content of feed is used with dry-matter intake (DMI) to calculate nitrogen intake and hence nitrogen excretion, and finally N_2O emissions.

Figure 5.1.7   **Simplified methodology for calculating emissions for major ruminant livestock categories**
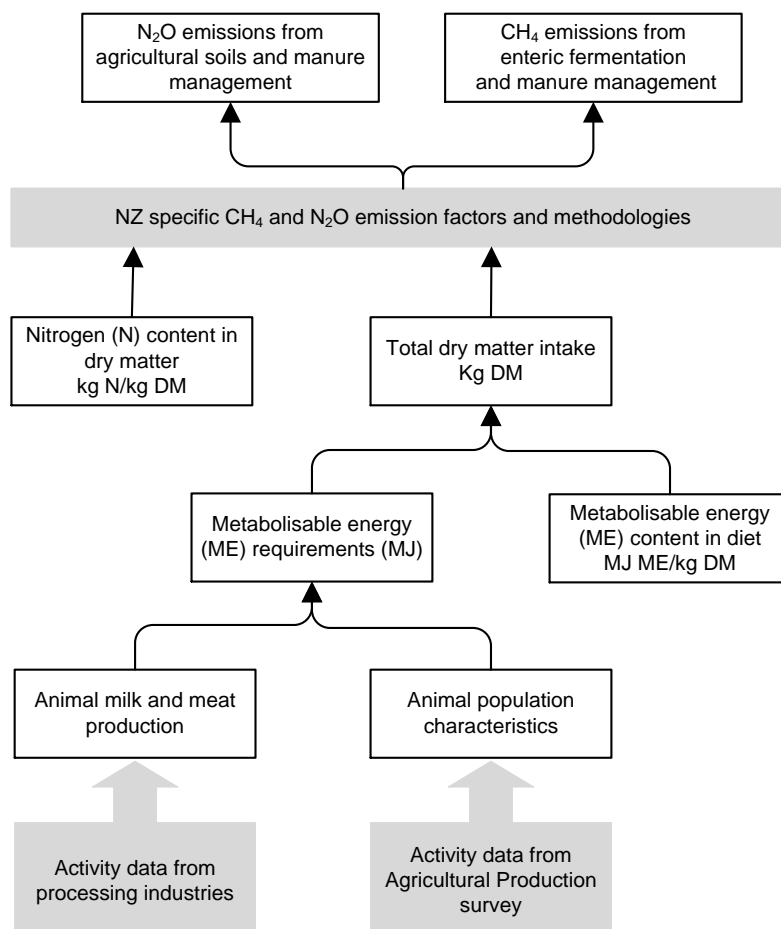
Note: CH_4 = methane; DM = dry matter; kg = kilogram; N_2O = nitrous oxide.

The main emissions from ruminant livestock are CH_4 from enteric fermentation and N_2O from manure (urine and dung). The level of these emissions is a function of livestock energy requirements and the energy concentration of the feed, which determine the level of required feed intake (DMI):

$$DMI = \frac{ME_{TOTAL}}{E}$$

Where: DMI is the dry-matter intake (kg)

ME$_{TOTAL}$ is the total metabolisable energy requirement of the animal (kJ), and

E is the energy concentration in the feed (kJ/kg dry matter).

Calculating metabolisable energy requirements (ME$_{TOTAL}$)

For dairy cattle, non-dairy cattle and sheep, the approach for calculating the total metabolisable energy (ME) requirement was developed in Australia by the Commonwealth Scientific and Industrial Research Organisation (CSIRO, 1990). These algorithms have been chosen because they specifically include methods to estimate the energy requirements of grazing animals, which is the predominant feeding method used in New Zealand. All calculations are performed on a monthly basis. The equation below is derived from the general equation used in the Australian feeding standards and adjusted to suit New Zealand conditions.

The total energy required is made up of:

- energy required to maintain animal weight, which is a function of the animal's liveweight and stage of maturity (ME$_{BASAL}$)

- energy required for a given level of productivity (milk yield and liveweight gain), and physiological state (e.g., pregnant or lactating), and

- the additional amount of energy expended on the grazing process, compared with similar housed animals (ME$_{GRAZE}$).

$$ME_{TOTAL} = ME_{BASAL} + 1.1 ME_P + ME_{GRAZE}$$

Where: ME$_{BASAL}$ is the energy requirement for maintenance

ME$_P$ is the energy used directly for production (meat, milk, wool, gestation and so on), and

ME$_{GRAZE}$ is the additional energy required by grazing livestock.

And:

$$ME_{TOTAL} = \frac{KSM(0.28W^{0.75}\exp(-0.03A))}{k_m} + 1.1ME_P + \frac{E_{GRAZE}}{k_m}$$

Where: K, S and M are constants defined elsewhere (CSIRO, 1990); K = 1.0 for sheep and 1.4 for cattle, S = 1.0 for females and castrates and 1.15 for entire males, M = 1 for all animals except milk-fed animals. M has been removed from the New Zealand calculations and an adjustment for milk-fed animals is carried out through a milk adjustment factor detailed later.

W is the liveweight (kg)

A is the age in years, up to a maximum value of 6

k_m is the net efficiency of use of ME for maintenance, and

E$_{GRAZE}$ is the additional energy expenditure of livestock in cold stress.

The CSIRO algorithms take into account animal liveweight and production requirements based on the rate of liveweight gain, sex, milk yield and physiological state (CSIRO, 1990). For further details, see the inventory methodology document on the Ministry for Primary Industries website (http://mpi.govt.nz/news-and-resources/statistics-and-forecasting/greenhouse-gas-reporting).

Monthly diet energy (E) concentration

Dairy cattle, non-dairy cattle, sheep and deer are predominantly fed on pasture all year round. Data sets of estimated monthly energy concentrations of pasture consumed by different livestock are used. These data are reported in the inventory methodology document (Pickering and Fick, 2015, appendices 3, 9 and 19, http://mpi.govt.nz/news-and-resources/statistics-and-forecasting/greenhouse-gas-reporting), and are derived from published and unpublished research trial data and supplemented with additional data from farm surveys on commercial cattle and sheep farms.

To ensure consistency, a single livestock population characterisation and feed-intake estimate is produced by the Tier 2 model. It is used in different parts of the Agriculture sector inventory to estimate CH_4 emissions for the *Enteric fermentation* category, CH_4 and N_2O emissions for the *Manure management* category and N_2O emissions for *Urine and dung deposited by grazing animals* onto pasture.

5.1.4   Activity data

Major livestock categories

The Tier 2 methodology developed by New Zealand uses detailed data on livestock population and productivity to calculate livestock energy requirements. Animal population census data are collected by Statistics New Zealand every five years (the Agricultural Production census) and survey statistics are collected annually between censuses (the Agricultural Production survey). Productivity data are available from the Livestock Improvement Corporation (LIC) (dairy statistics) and industry organisations such as Beef + Lamb New Zealand Ltd and Deer Industry New Zealand, which regularly collect animal sector statistics. Statistics on animal carcass weights are collected by the Ministry for Primary Industries and are used to derive liveweights.

Most of these data are collected on a June year-end basis but the inventory is calculated on a calendar year. New Zealand uses a June year for animal statistics because this reflects the natural biological cycle for animals in the southern hemisphere. New Zealand's Tier 2 model has been developed to estimate livestock emissions on a monthly time step, beginning on 1 July of one year and ending on 30 June of the next year. To calculate emissions for a single calendar year (January–December), the calculated emission data from the last six months of a July–June year are combined with the first six months' emissions of the next July–June year. This approach enables comparisons with the inventories of other countries.

Animal population data

Statistics New Zealand collects animal population data on a territorial authority basis. Territorial authorities are the second level of local government in New Zealand, beneath regional councils. Further details about the scope and accuracy of Statistics New Zealand Agricultural Production data collection are provided in annex 3.1.

The New Zealand inventory uses a different population characterisation for pasture-based livestock, compared with that recommended by the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2000, 2006). The full list of categories for the major livestock populations can be found in annex 3.1 and in the inventory methodology document on the Ministry for Primary Industries website (http://mpi.govt.nz/news-and-resources/statistics-and-forecasting/greenhouse-gas-reporting).

Dairy cattle encompass all cattle that are required to support the milking dairy herd. This includes calves, young growing non-lactating heifers, dry cows and dairy bulls. All other cattle in New Zealand tend to be used for the breeding of animals that are slaughtered for meat consumption. These animals are characterised as non-dairy cattle. These include non-dairy breeding lactating cows used for producing slaughter animals, such as calves, dry cows, bulls and all slaughter classes. A proportion of female calves not required for dairy replacements, and dairy bull calves, also go into the non-dairy herd and are slaughtered for meat consumption.

A detailed livestock population model is used to calculate monthly populations for dairy cattle, non-dairy cattle, sheep and deer (see annex 3, table A3.1.2 for the full list of categories).

This monthly population delineation has been developed by using industry knowledge and assumptions as detailed in Clark (2008b), Thomson et al., (2010, unpublished) and Suttie (2012). The populations within a year are adjusted on a monthly basis to account for births, deaths and transfers between age groups. This is necessary because the livestock population numbers present and recorded at one point in time may not accurately reflect the numbers present at other times of the year. For example, the majority of lambs are born and slaughtered between August and May so do not appear in the June census or survey data. Additionally, male and female dairy calves not wanted as replacements are usually slaughtered at four days of age or transferred to the non-dairy herd. The monthly population model ensures that the calculated feed demand accurately reflects the status of each livestock category at a particular time of the year.

Dairy livestock emissions are calculated on a regional council area basis by using regional dairy data from Statistics New Zealand, Dairy NZ and LIC. This allows the inventory to take into account regional differences in productivity (Clark, 2008a).

Animal productivity data

Productivity data are obtained from LIC and DairyNZ (2017), Beef + Lamb New Zealand Ltd (2017) and Deer Industry New Zealand. These are non-governmental, industry organisations providing services to the dairy cattle, non-dairy cattle, sheep and deer industries.

Slaughter statistics are collected by the Ministry for Primary Industries (http://mpi.govt.nz/news-and-resources/open-data-and-forecasting/agriculture) and are used as a proxy to establish changes in animal liveweight over time. Animal liveweight is derived from published slaughter-weight statistics and general nationally derived killing-out percentages (Clark et al., 2003; Muir et al., 2008; Muir and Thomson, 2010).

To ensure consistency, the same data sources are used each year. Other information, such as the liveweight of non-dairy cattle and breeding bulls, is collected at irregular intervals from small survey populations. For years when data is not available, expert opinion and extrapolation from existing data are used.

Dairy cattle – milk production: Regional data on milk production, proportions of dairy cattle breeds and animal weights are provided by LIC and published annually. These data are collectively compiled by LIC and DairyNZ.

Data on New Zealand's total milk production originate from the amount of milk processed through New Zealand dairy factories for both the export and domestic markets. Data on individual animal production are sourced from the Dairy Core Database, the regulated portion of LIC's database that holds core production data from cow herds tested in New Zealand. Dairy farmers are paid on the basis of milk solids collected (and not on a volume basis). Tankers that collect the milk also meter the milk collected from individual farms, and these meters are regularly calibrated and audited. Milk samples from individual farms are also independently tested for milk solids, milk fat and protein content.

LIC provides annual milk production data (milk yield and composition), but the Tier 2 livestock model operates on a monthly time step. Monthly milk production is determined by multiplying the assumed proportion of annual milk production for each month by the total annual milk production (see annex 3, table A3.1.3). Milk production commences from mid-July to early August every year, peaking around October–November and declines during autumn (April–May in the southern hemisphere); milk production is low to non-existent in June and July in most herds (see figure 5.1.8).

From 2004, annual milk yields per animal have been obtained and reported as additional data in the common reporting format (CRF) tables by dividing the total milk produced by the total number of milking dairy cows and heifers. New Zealand assumes an additional 107 litres of milk is added to the first half of the annual lactation of each cow to allow for the milk fed to calves; this assumption was based on a review of the animal energy model and a survey of farmers by Thomson et al. (2010).

Figure 5.1.8   National monthly milk production in New Zealand from 2014 to 2016
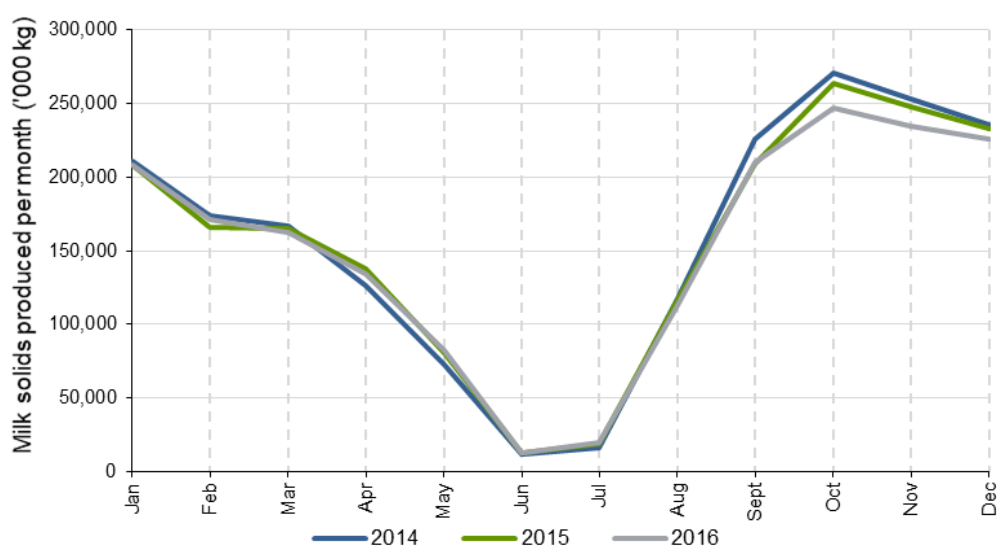
Before 1993, no productivity data was collected at a territorial authority level, so pre-1993 data has been estimated by extrapolating from the trends observed in existing data from 1994 to 2008.

Before 2004, not all productivity data required could be collected from LIC at a territorial authority level. From 1993–2003, annual milk yield per cow was determined by the following equation:

$$Litres\ per\ cow = \frac{Mean\ milk\ fat\ (kg/cow) \cdot 100}{per\ cent\ milk\ fat}$$

From 2004 onwards, productivity data has been collected by LIC at a similar territorial authority level as the livestock population data collected by Statistics New Zealand. Ministry for Primary Industries officials aggregate these territorial data up into the regional council boundaries used for the population data.

Approximately 65.9 per cent of all dairy cattle were tested by LIC for liveweight and milk production, along with the milk tested for milk fat and protein levels in 2016 (LIC and DairyNZ, 2017). LIC also does genetic testing to identify key breeding stock and their genetic background. Genetic improvement has contributed significantly to the per-animal productivity improvements in the New Zealand dairy cattle herd (LIC, 2009).

New Zealand's dairy production per animal is lower, compared with other developed countries. This is because New Zealand has predominantly pasture-based dairy systems rather than the intensively housed grain-fed systems used in Europe and North America.

Dairy cattle – liveweight: Average liveweight data for dairy cows are obtained by taking into account the proportion of each breed in the national herd and its age structure based on LIC data. Dairy cow liveweight data are only available from LIC from 1996 onwards and have been disaggregated into eight regions, with some of these comprising several regional council regions. Data from the nine livestock improvement regions were appropriately apportioned to regional council areas. Liveweights prior to 1996 were estimated using the trend in liveweights from 1996 to 2008, together with data on the breed composition of the national herd (LIC, 2009).

In the model, replacement dairy animals (calves) are assumed to be approximately 9 per cent of the weight of the average cow at birth and to reach 90 per cent of the weight of the average adult cow at calving (at two years of age) (Clark et al., 2003). Growth between birth and calving is divided into two periods: birth to weaning and weaning to calving. Higher growth rates are applied in the model between birth and weaning, when animals receive milk as part of their diet. Within each period, the same daily growth rate is applied for the entire length of the period.

No data are available on the liveweights and performance of most breeding dairy bulls, which can range from the small Jersey breeds through to larger European beef breeds. It is assumed, based on expert opinion and taking into account industry data (Clark et al., 2003), that the average mature weight at 1 January is 500 kilograms and that they grow at 0.5 kilograms per day. This gives an average weight (at the mid-point of the year) of 592 kilograms. This is almost 25 per cent higher than the average weight of a breeding dairy cow but is supported by expert opinion given that some of the bulls will be of a heavier breed (e.g., Friesian and some beef breeds). Total emissions are not highly sensitive to these assumed liveweight values because breeding bulls in the dairy herd are low in number and contribute less than 0.1 per cent of emissions to the dairy sector.

In 2016, the New Zealand dairy herd comprised a number of breeds including the Holstein–Friesian/Jersey crossbreed (48.0 per cent of the national cow population in 2016), Holstein–Friesian (33.0 per cent), Jersey (9.3 per cent), Ayrshire (0.6 per cent) and other breeds (9.1 per cent) (LIC and DairyNZ, 2017).

The Holstein–Friesian/Jersey crossbreed has been developed specifically for New Zealand's pasture-based systems. This breed is approximately 5 per cent lighter than a Holstein–Friesian (LIC and DairyNZ, 2017) and has less maintenance feed requirements. It does less damage to pasture during wet periods due to its lower liveweight, compared with larger cattle breeds. It also has higher milk volumes than the Jersey breed while maintaining a high percentage of milk solids.

Non-dairy cattle: The principal source of information for estimating productivity for non-dairy (beef) cattle is livestock slaughter statistics provided by the Ministry for Primary Industries. All growing beef animals are assumed to be slaughtered at two years of age, and the average weight at slaughter for the three categories (*Heifers*, *Steers* and *Bulls*) is estimated from the carcass weight at slaughter. Liveweights at birth are assumed to be approximately 9 per cent of an adult cow weight for heifers and 10 per cent for steers and bulls (Clark et al., 2003). As with dairy cattle, growth rates of all growing animals are divided into two periods in the model: birth to weaning and weaning to slaughter. Higher growth rates are applied before weaning when animals receive milk as part of their diet. Within each period, the same daily growth rate is applied for the entire length of the period.

The Ministry for Primary Industries slaughter statistics do not separate carcass weights of adult dairy cows and adult beef cows. Therefore, a number of assumptions[28] are made to estimate the liveweights of breeding beef cows. A total milk yield of 800 litres is assumed to be produced per breeding beef cow, which is then consumed by beef calves (Clark et al., 2003).

Sheep: Livestock slaughter statistics from the Ministry for Primary Industries are used to estimate the liveweights of adult sheep and lambs at slaughter, assuming killing-out percentages[29] of approximately 40 per cent for ewes and 45 per cent for lambs (Thomson et al., 2010). Lamb liveweights at birth are assumed to be 9 per cent of the adult ewe weight, with all lambs assumed to be born on 11 September (Thomson et al., 2010). Growing breeding and non-breeding ewe hoggets are assumed to reach full adult size when subsequently mated at age 20 months. Adult wethers are assumed to be the same weight as adult breeding females. No within-year pattern of liveweight change is assumed for either adult wethers or adult ewes. All ewes rearing a lamb are assumed to have a total milk yield of 100 litres. Breeding rams are assumed to weigh 40 per cent more than adult ewes (Clark et al., 2003). Wool growth (greasy fleece growth) is assumed to be 5 kilograms per annum in mature sheep (ewes, rams and wethers) and 2.5 kilograms per annum in growing sheep and lambs. Beef + Lamb New Zealand Ltd, the industry organisation representing the non-dairy cattle and sheep industries, provides estimates of the total wool production from 1990 to 2016 from which the individual fleece weight is estimated (Beef + Lamb New Zealand Ltd, 2017).

Deer: Liveweights of growing hinds and stags are estimated from Deer Industry New Zealand statistics, assuming a killing-out percentage of 55 per cent. A fawn birth weight of 9 per cent of the adult female weight and a common birth date of mid-November are assumed. Liveweights of breeding stags and hinds are based on a report by Suttie (2012). It is assumed there is no pattern of liveweight change within any given year. The lactation assumptions are 204 litres over 120 days, an average daily lactation yield of 1.7 litres per day (Suttie, 2012).

Minor livestock categories

A Tier 1 methodology is used for goats, horses, mules and asses, swine, poultry and alpacas (IPCC, 2006), using a combination of country-specific and IPCC default emission factors (annex A3.1.2, table A3.1.4).

The populations of goats, horses and swine are reported using data from the Statistics New Zealand Agricultural Production census and survey. Data on the population of alpacas prior to 2010 are provided by Henderson and Cameron (unpublished) based on data from the Alpaca Association New Zealand. Alpaca population data from 2010 onwards are provided by Statistics New Zealand.

There are small herds of buffalo and donkeys in New Zealand. Statistics New Zealand advised that, in 2011, there were 192 buffalo and 141 donkeys. As the buffalo livestock are used for producing milk (which is then used to produce mozzarella cheese in the restaurant industry), they are reported within the dairy herd, so the notation key IE (included elsewhere) is used for buffalo.

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[28] The number of beef cows slaughtered is assumed to be 17per cent of the total beef cow herd, with other adult cows slaughtered assumed to be dairy cows. The carcass weight of dairy cattle slaughtered was estimated using the adult dairy cow liveweights and a killing-out percentage of 42 per cent (Thomson et al., 2010). The total weight of dairy cattle slaughtered was calculated (carcass weight × number slaughtered) and then deducted from the national total carcass weight of slaughtered adult cows. This figure was then divided by the number of beef cows slaughtered to obtain an estimate of the carcass weight of adult beef cows. Liveweights were calculated assuming a killing-out percentage of 42.6 per cent (Thomson et al., 2010).

[29] Percentage of carcass weight in relation to liveweight.

Mules and asses are not farmed commercially or used as working animals in New Zealand. A constant population of 141 donkeys has been included in the inventory under mules and asses. The emissions from these small populations of animals are extremely small relative to the major livestock categories.

Statistics New Zealand provides estimates of average annual broiler chicken flock sizes using industry data on the numbers of broilers processed every year since 1990, mortality rates and days alive as suggested by Fick (2010). Statistics New Zealand also obtains estimates of the number of layer hens and other poultry (e.g., ducks, turkeys, emus and ostriches) from the Agricultural Production census and survey.

The average annual flock size of chickens is determined by the following equation:

$$Average\ annual\ flock\ size = \frac{days\ alive}{365} \times annual\ number\ of\ birds\ processed(1 - rate\ of\ mortality)$$

Farming of rabbits or other fur-breeding animals does not occur in New Zealand.

5.1.5 Recalculations

Agriculture emissions research

New Zealand has set up a number of research organisations and reference groups that have the aim of understanding and reducing biological greenhouse emissions.

The New Zealand Agricultural Greenhouse Gas Research Centre was set up in 2009. This group comprises New Zealand research providers, including the Pastoral Greenhouse Gas Research Consortium. The aims of the Centre are to contribute to the agricultural greenhouse gas mitigation strategy through research programmes and international collaboration, and to enhance New Zealand's research capability and infrastructure in this area. Its research focuses on ruminant CH_4, N_2O, soil carbon and emissions from farming systems. Funding is made available through the Ministry for Primary Industries' Primary Growth Partnership. Relevant research results by the Centre feed into improving the inventory. In most cases, the research is published in national and international peer reviewed science publications.

The Pastoral Greenhouse Gas Research Consortium was established by New Zealand in 2003 by agricultural sector organisations and private companies. It funds research, primarily into mitigation technologies and management practices for ruminants but also to provide information to improve on-farm inventories. The Consortium is funded in partnership between the Government and the Agriculture sector.

New Zealand is also a founding member of the Global Research Alliance on Agricultural Greenhouse Gases (GRA). The GRA is an international alliance of countries with an aim of meeting the world's growing demand for food without increasing greenhouse gas emissions. The GRA now has 49 member countries. Research in the area of greenhouse gas emissions mitigation and adaptation, and in capacity and capability building, is supported by this alliance. The GRA has also recently developed flagship programmes to help focus research areas and encourage funding. One of these flagship programmes is dedicated to improving agricultural inventories, and New Zealand is one of the leads for this. New Zealand is also a co-leader of the GRA Inventory network and has committed $65 million to New Zealand activities under the GRA from 2009 to 2020.

In 2016, the Biological Emissions Reference Group (BERG) was established (and is currently co-chaired) by the Ministry for Primary Industries and DairyNZ as a collaboration between the agricultural sector and government departments. BERG was established to build a robust and

agreed evidence base on what the sector can do on farm to reduce emissions, and to assess the costs and opportunities of doing so. The evidence produced by BERG will provide a foundation for any future policy to reduce biological emissions.

The Ministry for Primary Industries also has a research fund that aims to improve the accuracy of emissions reporting and forecasting. This fund is part of a wider process focused on improving the Agriculture inventory. Further details on this process are provided below.

Recalculation and improvement approval process in the Agriculture inventory

The process for developing improvements and agreeing methodological changes in the Agriculture inventory is shown in figure 5.1.9.

Two national science and industry expert groups, Methanet and NzOnet, have been running for over 16 years. The groups were formed to identify the key strategic directions of research into the CH_4 and N_2O inventory and mitigation, to develop a collaborative approach to improve the quality of CH_4 and N_2O emission data, and build and maintain inventory research capability. These expert groups are supported through the Ministry for Primary Industries. The implementation of the Tier 2 approach for livestock, development of country-specific emission factors and parameters, improved activity data and uncertainty analyses are all examples of research identified, conducted and peer reviewed by these expert groups.

The New Zealand Methanet and NzOnet networks meet annually to present their research findings. New inventory research ideas raised by the two networks provide the basis for determining future research. Final decisions on research priorities are made by the Ministry for Primary Industries following discussions between the network leaders and Ministry for the Environment staff. Research is contracted to address specific questions related to gaps in New Zealand's knowledge and to review, test and improve current parameters used. Draft research reports are reviewed by at least one external independent expert with knowledge in the field and are assessed for their scientific robustness and suitability to be included in the inventory.

A briefing and the final report are sent to the Agriculture Inventory Advisory Panel (the Panel), which meets annually to review proposed changes to the inventory. The Panel, formed in 2009, comprises expert representatives from the Ministry for Primary Industries and Ministry for the Environment, science representatives from the Royal Society of New Zealand and the Methanet and NzOnet expert advisory groups. The Panel is independent of policy and industry influences and has been formed to give advice on whether changes to New Zealand's agriculture section of the National Inventory Report are scientifically robust and justified. The Panel assesses if the proposed changes have been appropriately researched, using recognised scientific principles, and if there is sufficient scientific evidence to support the recommended changes.

Changes recommended by the Panel are sent to the Deputy Director-General (Policy and Trade) of the Ministry for Primary Industries. The Deputy Director-General approves the changes that will be presented to the Ministry for the Environment for implementation into the annual inventory. During the course of the year, recalculations being considered by all sectors are proposed to the Reporting Governance Group. This group is chaired by the Ministry for the Environment and leads the reporting, modelling and projections of greenhouse gas emissions and removals across government. Further details of the Reporting Governance Group are provided in chapter 1, section 1.2.2.

Figure 5.1.9   Agriculture sectoral approval process for inventory recalculations and improvements
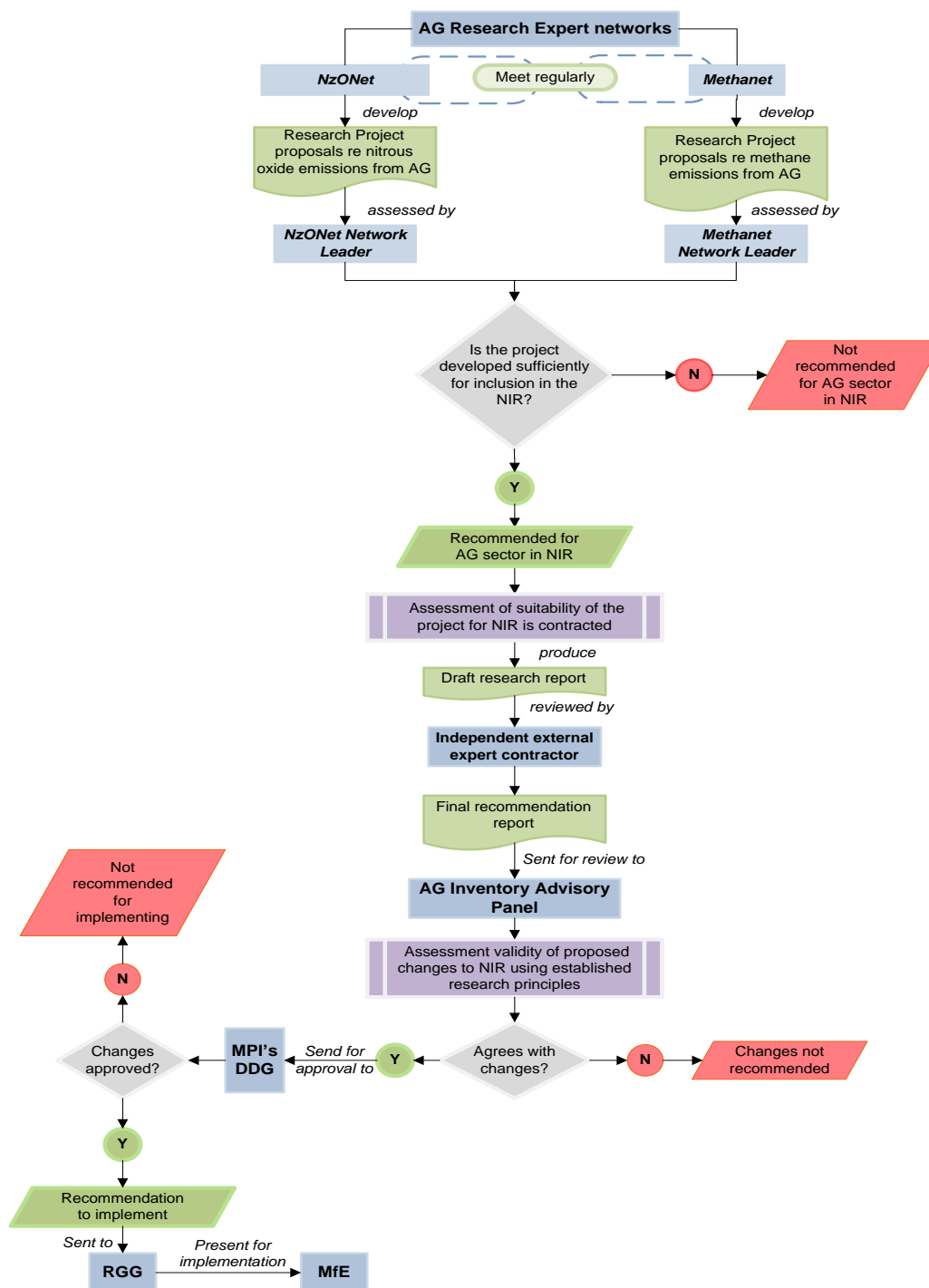
Note: AG = agriculture; DDG = Deputy Director-General; MfE = Ministry for the Environment; MPI = Ministry for Primary Industries; NIR = National Inventory Report; RGG = Reporting Governance Group (for the NIR).

Agriculture Inventory Advisory Panel meeting – 2017

The 2017 meeting of the Panel was held on 8 November and considered the methodology used to estimate burning areas for barley, oats and wheat crops. This change was recommended for inclusion in the inventory.

The Panel also discussed errors in the previous inventory submission relating to the calculation of nitrogen retained in wool by sheep and the population models for sheep and deer. Further details on these changes are outlined in the relevant recalculation and methodology sections of the National Inventory Report.

The briefs, reports and minutes of the 2017 Panel meeting (as well as panel meetings for previous years) are all publicly available on the Ministry for Primary Industries website (http://mpi.govt.nz/news-and-resources/statistics-and-forecasting/greenhouse-gas-reporting/agricultural-inventory-advisory-panel).

Recalculations approved for the 2018 National Inventory Report submission in the Agriculture sector

New Zealand has made one improvement for the Agriculture sector in its 2018 annual submission relating to the methodology used to estimate burning areas for barley, oats and wheat crops. This change was recommended by the Agriculture Inventory Advisory Panel, and further details on this improvement can be found in section 5.5.6 and chapter 10 (section 10.1.3).

New Zealand has also corrected two errors for the Agriculture sector for the 2018 (1990–2016) submission relating to the:

- amount of nitrogen retained in the production of wool by sheep
- estimated population of deer in June.

The implementation of these corrections and improvements has caused the estimate of Agriculture sector emissions in 2015 to be 1.9 per cent higher than the estimate for 2015 Agriculture sector emissions in the 2017 (1990–2015) submission. Further details of these corrections are provided in section 5.5.5 (nitrogen retained in wool) and chapter 10 (section 10.1.3).

5.1.6   Quality assurance and quality control (QA/QC)

The team responsible for the Agriculture inventory preparation within the Ministry for Primary Industries maintains close contact with the teams responsible for the collation of primary industries (agriculture, horticulture, forestry and fishing) data. These teams liaise with Statistics New Zealand and provide analysis and forecasts of primary industries activity and performance. This arrangement ensures that the inventory preparation team has a good understanding of activity data and agriculture performance.

The connection with Statistics New Zealand ensures that the statistical collection work keeps pace with the changes in the primary industries sector and provides for the tracking of possible new activities and management practices in the primary industries sector. The team responsible for the Agriculture inventory preparation also maintains relationships with organisations that provide additional data, such as Beef + Lamb New Zealand Ltd, LIC, Deer Industry New Zealand, the Poultry Industry Association New Zealand and the Fertiliser Association of New Zealand.

The draft inventory is reviewed by Ministry for Primary Industries personnel with expertise in climate change policy, climate change science and livestock farming policy. This ensures that the inventory submission is accurate. The review also ensures that the inventory clearly explains the main causes of agricultural emissions in New Zealand as well as the drivers of changes in emissions from year to year. The results from the inventory are also used to inform domestic and international climate change policy.

The Agriculture inventory experts meet regularly with the team at the Ministry for the Environment that is responsible for coordinating the annual national inventory submission. The Ministry for the Environment monitors the Ministry for Primary Industries' progress in

implementing recommendations from previous expert review reports and on meeting timelines during the year.

The Ministry for the Environment also manages an internal guidance document 'New Zealand's National Inventory System Guidelines for compiling New Zealand's Greenhouse Gas Inventory'. This document provides domestic guidelines for sector leaders to follow, including the decisions under the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol, and the application of these decisions within the Kyoto Protocol. The document also includes New Zealand's quality-assurance and quality-control plan followed by all sector leads.

The Ministry for Primary Industries participates in the annual inventory debrief coordinated by the Ministry for the Environment, to ensure the National Inventory Compiler and each sector lead understand what is working well and where improvements could be made.

In 2016, an external audit firm (Deloitte), with specialist skills in quality-assurance and quality-control management, was engaged to evaluate and improve quality-assurance and quality-control processes for the Agriculture inventory. New Zealand has used this feedback to update and improve the quality-assurance and quality-control methodology.

A process of quality-control checks is mandated in the internal compilation process and is provided below.

Activity data

- Data inputs and checks are recorded in a data check table, which is signed by the individual staff members performing the data input and the checks.

- A comprehensive list of all external data to be collected annually from internal and external sources is included as a part of the data check sheet.

- New activity data are cross checked for accuracy and completeness by someone not involved in the data input and primary compilation.

- New data on activity and year-to-year time variance are reviewed by commodity analysts and economic modellers, to ensure the data are consistent and reflect the domestic situation.

- Where practical, key historical data are rechecked concurrently with updating the latest data.

- The data check table is included with the managerial sign-off materials before delivery to Ministry for the Environment.

Emissions

- Implied emission factors are checked over time (1990 to most recent year) and against previous submissions. Any anomalies are investigated.

- Key category emissions are compared against Tier 1 default methodologies and against similar Parties, particularly Australia. A challenge for New Zealand is the lack of countries with similar agricultural circumstances and management practices. For example, New Zealand's major livestock are almost all kept outdoors on pasture in all seasons.

- Total emissions and key activity data from the CRF are checked for accuracy against total emissions and activity in the workbooks. Category totals are also checked.

Recalculations

- Recalculations are agreed with the Ministry for the Environment and the Reporting Governance Group every year, before the Agriculture inventory compilation commences.

- Recalculations are compared with previous submissions and, as far as possible, explained and confirmed by the changes in method or activity data.

- Anomalous results from recalculations are checked and corrected, if necessary.

- The Agriculture inventory compiler completes recalculation forms, signs the forms and forwards them to the Ministry for the Environment.

Periodic reviews

Periodic reviews are completed on different aspects of the Agriculture inventory.

- In recent years, the livestock population models and productivity parameters have been reviewed (e.g., Thomson et al., 2010). These reviews have also been used to update and improve the Tier 2 model.

- During the 2012 submission, new crops were included in the National Inventory Report and a new complex methodology was implemented. For the 2013 submission, Plant and Food Research, a New Zealand-based scientific research company that has expertise in this area, was hired to review the workbooks, check the formulae and model parameters.

- During the 2015 submission, a mutual bilateral greenhouse gas inventory review was held between Australia and New Zealand, which included the Agriculture sector (Australian Government, unpublished).

Error checking and reporting

- Errors confirmed during the year are recorded and the National Inventory Compiler is notified. The factors contributing to the error are assessed.

- An issues, risks and enhancements register is kept up to date and used to prioritise the resolution of key sources of risk to the Agriculture inventory compilation and results.

- A checklist of quality control activities is followed during data collection and entry into the model, data upload to the CRF reporting tool and National Inventory Report chapter preparation.

- The Agriculture chapter of the National Inventory Report and the data exported to the CRF reporter are signed off by the chapter compiler, people involved in data checking and the responsible manager.

Documentation

- Internal working instructions are maintained to allow for staff movements.

- Workbooks and calculations are kept on an electronic archiving and management system, enabling wider team access to all workbooks.

- Hyperlinks between check sheets, sign-off documents and workbooks are used to link relevant files on the document management system.

5.1.7 Planned improvements

The Ministry for Primary Industries is undertaking a number of research projects aimed at improving New Zealand's Agriculture inventory.

Short-term studies in relation to these include:

- research looking at the amount and types of supplemental feed used in the sheep and beef industries

- a review of the methodology used to estimate liveweight for dairy cattle, beef cattle, sheep and deer

- research assessing how nitrogen excretion is apportioned into urine and dung components.

Long-term studies focused on improving the Agriculture inventory include:

- improving the relationship between DMI and CH_4 emissions from dairy cattle

- investigating the effect of land slope on N_2O emissions from dairy cattle, non-dairy cattle, sheep and/or deer in hill-country pasture

- reviewing the ME equations used in the Agriculture inventory model for the major livestock categories

- updating national estimates of pasture quality especially for ME, nitrogen and dry matter digestibility

- research to gain a better understanding of the factors causing variability in N_2O emissions from livestock excreta on pasture.

These specific planned improvements are discussed in further detail in the relevant sector recalculation sections 5.2.6 (*Enteric fermentation* (CRF 3.A)), 5.3.6 (*Manure management* (CRF 3.B)) and 5.5.6 (*Agricultural soils* (CRF 3.D)).

5.2 Enteric fermentation (CRF 3.A)

5.2.1 Description

Methane is a by-product of digestion in ruminants, for example, in cattle and sheep, and in some non-ruminant animals, such as swine and horses. Within the Agriculture sector, ruminants are the largest source of CH_4. The amount of CH_4 released depends on the quantity of feed consumed, which is determined by the type, age and weight of the animal, animal production, feed quality and the energy expenditure of the animal.

In 2016, enteric fermentation contributed 27,782.9 kt CO_2-e to New Zealand's gross emissions. This represented 35.0 per cent of New Zealand's gross CO_2-e emissions and 71.7 per cent of agricultural emissions. Dairy and non-dairy cattle contributed 13,623.6 kt CO_2-e (49 per cent) and 5,228.7 kt CO_2-e (18.8 per cent), respectively, to emissions from the *Enteric fermentation* category. Sheep contributed 8,412.6 kt CO_2-e (30.3 per cent) to emissions from this category. Emissions from the *Enteric fermentation* category in 2016 were 1,064.7 kt CO_2-e (4.0 per cent) above the 1990 level of 26,718.2 kt CO_2-e.

Methane emissions from the *Enteric fermentation* category from dairy cattle, non-dairy cattle and sheep were identified among the largest key category for New Zealand in the 2016 level assessment, and were also assessed as key categories in the trend assessment (excluding Land Use, Land-Use Change and Forestry (LULUCF)). The methodology used by New Zealand for calculating CH_4 emissions from enteric fermentation in domestic livestock is a Tier 2 modelling approach.

Since 1990, there have been changes in the relative sources of emissions within the *Enteric fermentation* category (see table 5.2.1). The largest increase came from emissions from dairy cattle. In 2016, dairy cattle were responsible for 13,623.6 kt CO_2-e, an increase of 7,672.0 kt CO_2-e (128.9 per cent) from the 1990 level of 5,951.6 kt CO_2-e. Meanwhile, there have been decreases in emissions from non-dairy cattle, sheep and minor livestock species, such as goats, horses and swine.

Table 5.2.1   Trends and relative contribution of enteric fermentation from livestock categories between 1990 and 2016

Livestock category	Emissions (kt CO$_2$-e) 1990	Emissions (kt CO$_2$-e) 2016	Change from 1990 %	Change from 1990 kt CO$_2$-e	Share of Enteric fermentation category (%) 1990	Share of Enteric fermentation category (%) 2016	Share of total Agriculture sector (%) 1990	Share of total Agriculture sector (%) 2016
Dairy cattle	5,951.6	13,623.6	128.9	7,672.0	22.3	49.0	17.2	35.2
Non-dairy cattle	5,737.5	5,228.7	−8.9	−508.8	21.5	18.8	16.6	13.5
Sheep	14,361.3	8,412.6	−41.4	−5,948.7	53.8	30.3	41.5	21.7
Deer	418.3	465.0	11.2	46.7	1.6	1.7	1.2	1.2
Minor livestock	249.5	53.1	−78.7	−196.5	0.9	0.2	0.7	0.1

Note: Percentages presented are calculated from unrounded values.

5.2.2   Methodological issues

Emissions from cattle and deer

Using the population characterisation and DMI per head calculated by New Zealand's Tier 2 inventory model (see section 5.1.3), the total amount of CH$_4$ emitted for cattle and deer is calculated using a CH$_4$ conversion rate for emissions per unit of feed intake per livestock category (see figure 5.2.1). A more complex algorithm has been used to calculate enteric CH$_4$ emissions from sheep, which was included for the first time in the 2017 National Inventory Report submission. Enteric CH$_4$ emissions from sheep are discussed in the next section.

Figure 5.2.1   Schematic diagram showing how New Zealand's emissions from enteric fermentation for cattle and deer are calculated
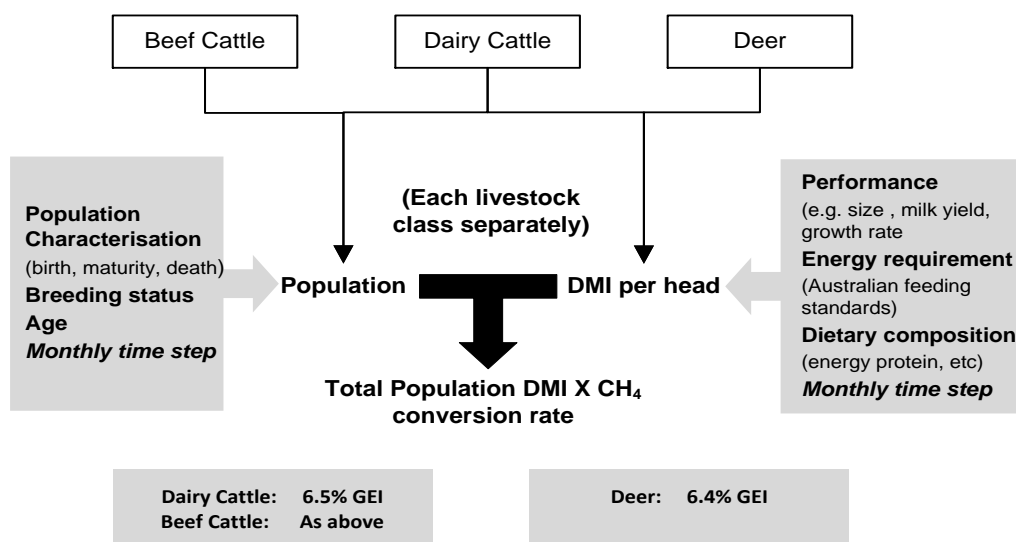
Note: CH$_4$ = methane; DMI = dry-matter intake; GEI = gross energy intake.

The equation for the total production of enteric CH$_4$ for cattle and deer is:

$$CH_{4-enteric} = \sum_{\substack{livestock \\ type}} \frac{n.DMI \cdot CH_4\,conversion\,rate}{1000}$$

Where: $CH_{4\text{-enteric}}$ is the methane from enteric fermentation (kg CH_4/year)

Livestock type is cattle or deer

n is the population of each livestock category (head)

DMI is the dry-matter intake (kg dry matter/head/year), and

CH_4 conversion rate is the CH_4 emissions per unit of feed intake (g CH_4/kg DMI) (see table 5.2.2).

Emissions from sheep

Enteric methane emissions from sheep are calculated using a methodology outlined in a peer reviewed paper published by Swainson et al. (2016). This paper analysed a set of recent experiments where CH_4 emissions from sheep, fed pasture of varying amounts and quality, were measured and analysed. The study confirmed that DMI has the largest influence on CH_4 emissions and that pasture quality (as measured by metabolisable energy content) had a small but statistically significant effect on emissions from sheep less than one year of age.

The paper concluded that two log-transformed equations (one for sheep less than one year of age and one for sheep greater than one year of age) provided the best fit for the data and recommended that these equations be used in the National Inventory Report.

The equation for the total production of enteric CH_4 for sheep less than one year of age is:[30]

$$CH_{4-enteric} = \sum_{class} \sum_{month} d_m n_{cm} \frac{11.705}{1000} e^{0.05 \times ME} DMI^{0.734}$$

The equation for the total production of enteric CH_4 for sheep greater than one year of age is:[31]

$$CH_{4-enteric} = \sum_{class} \sum_{month} d_m n_{cm} \frac{21.977}{1000} DMI^{0.765}$$

Where: $CH_{4\text{-enteric}}$ is the total CH_4 from enteric fermentation (kg CH_4/year)

d_m is the number of days in month m

n_{cm} is the population of sheep in class c during month m (head), greater than one year old

ME is the metabolisible energy concentration of pasture during month m (megajoules of metabolisible energy per kg of dry matter)

DMI is the daily dry-matter intake of an individual sheep of class c in month m (kg dry matter per head per day), greater than one year old

class refers to the different categories of sheep greater than one year old (e.g., dry ewes, wethers, rams) used in the Agriculture inventory, and

month refers to the 12 months of the calendar year.

Dry-matter intake per sheep per day is calculated by New Zealand's Tier 2 inventory model (see section 5.1.3). Monthly values of ME concentration for pasture are provided by Bown et al. (2013).

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[30]   The equation displayed here is a rearranged form of the equation displayed in Swainson et al. (2016): Ln(CH_4) = 0.734 × ln(DMI) + 0.05 × ME + 2.46.

[31]   The equation displayed here is a rearranged form of the equation displayed in Swainson et al. (2016): Ln(CH_4) = 0.765 × ln(DMI) + 3.09.

Prior to the 2017 (1990–2015) National Inventory Report submission, New Zealand used fixed emission factor values to estimate enteric CH_4 emissions from sheep (Swainson et al., 2016):

- 20.9 grams of CH_4 per kilogram of DMI, for sheep greater than one year old

- 16.8 grams of CH_4 per kilogram of DMI, for sheep less than one year old.

The equation used to calculate enteric CH_4 emissions from sheep was identical to that currently used to calculate enteric CH_4 emissions for dairy cattle, non-dairy cattle and deer.

Methane measurement and modelling

New Zealand uses its own country-specific methodology and emission factors for estimating CH_4 emissions per unit of feed intake, despite the relatively large number of published algorithms and models of ruminant digestion.[32] This is because:

- the data requirements of the digestion models make them difficult to use in New Zealand's National Inventory Report

- none of these methods have high predictive power when compared against empirical experimental data (Clark et al., 2003)

- the relationships in these models have been mainly derived from animals fed indoors on diets unlike those consumed by New Zealand's grazing ruminants.

Since 1996, New Zealand scientists have been measuring CH_4 emissions from grazing cattle and sheep initially using the sulphur hexafluoride (SF_6) tracer technique (Lassey et al., 1997; Ulyatt et al., 1999). Research has now moved to using respiration chambers, which are considered the gold standard for assessing emissions from livestock.

To obtain New Zealand-specific values (or algorithms for sheep emissions), published and unpublished data on CH_4 emissions from New Zealand were collated and average values (and algorithms) for CH_4 emissions from different categories of livestock were obtained (Clark et al., 2003; Swainson et al., 2016). Sufficient data were available to obtain values for cattle and to generate a suitable set of algorithms for sheep. The associated data is presented in table 5.2.2 together with the IPCC (2006, tables 10.12 and 10.13) default values for per cent gross energy intake (GEI) used to calculate CH_4. The New Zealand values for cattle fall within the IPCC range and are applied in this submission.

Table 5.2.2   **Methane (CH_4) emissions and gross energy intake (GEI) from New Zealand measurements and IPCC (2006) default values**

	Adult cattle	Adult sheep (> 1 year)	Young sheep (< 1 year)
New Zealand CH_4 emission rates from Clark et al. (2003) and Swainson et al. (2016) (g CH_4/kg DM)	$21.6 \times DM$	$21.977 \times DM^{0.765}$	$11.705 \times e^{0.5ME} \times DM^{0.734}$
New Zealand data (GEI, %)	6.5	–	–
IPCC (2006) default Y_m values (GEI, %)	6.5 ± 1.0	6.5 ± 1.0	4.5 ± 1.0

Note: DM = dry matter; Y_m = methane yield, ME = metabolisable energy.

The adult dairy cattle value is applied to all dairy and non-dairy cattle, irrespective of age. The average of the adult cow and the (now defunct) CH_4 emission rate for adult ewes, used in prior versions of the National Inventory Report (21.25 g CH_4/kg DMI), is assumed to apply to all deer (Clark et al., 2003). In very young animals receiving a milk diet, no CH_4 emissions are assumed to arise from the milk portion of the diet.

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[32]   For example, Blaxter and Clapperton (1965); Moe and Tyrrel (1975); Baldwin et al. (1988); Djikstra et al. (1992) and Benchaar et al. (2001) – all cited in Clark et al. (2003).

Table 5.2.3 shows a time series of CH_4 IEFs (total emissions produced per animal type divided by the population of animals) for dairy cattle, non-dairy cattle, sheep and deer. New Zealand experiences significant inter-annual variability in these IEFs, which is explained further in section 5.1.1.

Table 5.2.3   New Zealand's implied emission factors for enteric fermentation from 1990 to 2016

Year	Dairy cattle (kg CH_4 per animal per annum)	Non-dairy cattle (kg CH_4 per animal per annum)	Sheep, all (kg CH_4 per animal per annum)	Deer (kg CH_4 per animal per annum)
1990	69.2	50.0	9.9	17.0
1991	72.2	51.4	10.2	17.6
1992	72.7	52.1	10.2	18.4
1993	73.7	53.0	10.3	18.8
1994	72.3	53.4	10.4	18.3
1995	72.0	52.9	10.3	19.2
1996	74.3	54.7	10.7	19.6
1997	75.2	55.6	11.1	19.8
1998	73.1	55.7	11.1	19.8
1999	74.6	54.4	11.0	19.9
2000	76.2	56.4	11.4	20.2
2001	77.1	57.4	11.4	20.2
2002	76.6	57.1	11.5	20.3
2003	79.4	56.8	11.5	20.1
2004	78.3	57.7	11.7	20.6
2005	78.8	58.4	11.9	20.9
2006	78.6	59.5	11.7	21.2
2007	77.6	58.0	11.3	21.2
2008	76.5	57.4	11.5	21.4
2009	77.0	57.8	11.9	21.6
2010	78.9	57.6	11.5	21.6
2011	80.0	58.4	11.8	21.7
2012	79.9	59.3	12.0	21.8
2013	81.8	58.3	11.9	21.6
2014	82.1	58.2	12.0	21.7
2015	84.3	58.6	11.9	21.7
2016	82.3	59.2	12.2	22.3

Emissions from minor livestock categories

A Tier 1 approach is adopted for the minor livestock categories of *Goats*, *Horses*, *Swine*, *Llamas and Alpacas*, and *Mules and Asses*, using either IPCC (2006) default emission factors (horses, alpacas, and mules and asses) or New Zealand country-specific emission factors (goats and swine). These minor livestock species comprised 0.2 per cent of the total enteric CH_4 emissions in 2016. The populations of goats, horses, pigs, alpacas, and mules and asses are reported using the statistics and assumptions described in section 5.1.4.

Goats: From 1990 to 2015, the population of goats declined from 1,062,900 to 74,718. In 2016, the population experienced a significant increase to 112,385. New Zealand uses a country-specific emission factor for enteric fermentation of 7.4 kg CH_4/head for 1990 and 8.5 kg CH_4/head for 2009 based on the differing population characteristics for those two years (Lassey, 2011). For the intermediate years between 1990 and 2009 and for 2010 to 2016, the emission factor was calculated based on the goat population, with the assumption that the dairy goat

population has remained at a near constant number over time while the rest of the goat population has declined. The emission factor in 2016 was calculated to be 8.1 kg CH_4/head/year.

Swine: New Zealand uses a Tier 1 approach with country-specific emission factors to determine enteric fermentation emissions from swine and emissions from swine manure management. A country-specific emission factor was developed from research performed by Hill (2012) in which data on the composition of swine diets and industry practices in place to manage waste from production systems were obtained from a survey of 56 swine farms. The information obtained on swine diets and waste management practices was representative of practices from 59 per cent and over 67 per cent of New Zealand pork production respectively. Nutritional information was available for different age classes and categories. Additionally, the average value of GEI was adjusted for population and further verified against national animal welfare standards. The country-specific emission factor for enteric fermentation (1.06 kg/CH_4/head/year) was developed from industry data on GEI (Hill, 2012). Gross energy data from swine diets were used in the Tier 2 IPCC equation (equation 10.21 from the IPCC 2006 Guidelines) to determine the country-specific enteric fermentation emission factor. This factor is then multiplied by population data to obtain the total CH_4 emissions produced by swine from enteric fermentation for a given inventory year.

The New Zealand emission factor for swine is lower than the IPCC (2006) default for developed countries,[33] which is based on average values derived from 1980s Western German swine production and population statistics. The IPCC (2006) default value for swine is not representative of New Zealand swine systems and does not reflect changes in production due to: improvements in genetic selection, reproductive cycle performance, housing and feed, animal husbandry and herd management. Further information on these factors is provided in the report by Hill (2012).

Horses: The IPCC (2006) default value (18 kg CH_4/head/year) is used to estimate emissions from enteric fermentation from horses.

Llamas and Alpacas: The IPCC (2006) default value (8 kg CH_4/head/year) is used to estimate emissions from this category.

Mules and Asses: The IPCC default value from the IPCC (2006) Guidelines is used (10 kg CH_4/head/year) to estimate emissions from this category.

5.2.3 Uncertainties and time-series consistency

To ensure consistency, a single livestock population characterisation and feed-intake estimate is produced by the Tier 2 model (see annex 3, table A3.1.2). It is used in different parts of the calculations for the National Inventory Report to estimate: CH_4 emissions for the *Enteric fermentation* category, CH_4 and N_2O emissions for the *Manure management* category and N_2O emissions for the *Pasture, range and paddock manure* category.

Livestock numbers

The calculations for total enteric fermentation require livestock population numbers. Information on uncertainties and time-series consistency for the livestock population data is included in section 5.1.4 and in annex 3.1.

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[33] The IPCC (2006) default emission factor for swine is identical to the IPCC (1996) emission factor.

Methane emissions from enteric fermentation

In 2009, the Ministry for Primary Industries (then the Ministry of Agriculture and Forestry) commissioned a report that recalculated the uncertainty of the enteric fermentation CH_4 emissions for sheep and cattle (Kelliher et al., 2009) using a Monte Carlo approach. This work superseded a previous analysis undertaken in 2003 (Clark et al., 2003). The analysis expressed the coefficient of variation according to the standard deviation of the CH_4 yield. The report (Kelliher et al., 2009) calculated the uncertainty by expressing the coefficient of variation according to the standard deviation of the CH_4 yield with the larger sample of measurements available by 2009. The analysis was restricted to one diet type: grass–legume pasture, the predominant diet of sheep and cattle in New Zealand. The resulting overall uncertainty of the enteric CH_4 emissions inventory, expressed as a 95 per cent confidence interval, is ±16.0 per cent (Kelliher et al., 2009); see table 5.2.4.

Table 5.2.4   **New Zealand's uncertainty in the annual estimate of enteric fermentation emissions for 1990 and 2016, estimated using the 95 per cent confidence interval (±16 per cent)**

Year	Enteric CH_4 emissions (kt CH_4/annum)	95% confidence interval minimum (kt CH_4/annum)	95% confidence interval maximum (kt CH_4/annum)
1990	1,068.7	897.7	1,239.7
2016	1,111,3	933.5	1,289.1

Note: The CH_4 emissions used in the Monte Carlo analysis exclude those from swine, horses, goats, mules and asses, and llamas and alpacas, which represent a small proportion of total CH_4 emissions.

Uncertainty in the annual CH_4 estimate is dominated by variance in the measurements of the 'methane per unit of intake' factor. This uncertainty is predominantly due to natural variation from one animal to the next. Uncertainties in the estimates of livestock energy requirements, herbage quality and population data are much smaller (0.005–0.05) (Clark et al., 2003).

5.2.4   Source-specific QA/QC control and verification

Methane from *Enteric fermentation* from dairy cattle, sheep, and non-dairy cattle were identified as key categories (level and trend assessment). Methane from *Enteric fermentation* from Deer is a key category in the 2016 level assessment and *Enteric* fermentation from goats is a key category in the trend assessment. In the preparation for this inventory, the data for this category underwent Tier 1 and Tier 2 quality checks.

Methane emission rates have been corroborated using micrometeorological techniques. Laubach and Kelliher (2004) used the integrated horizontal flux technique and the flux gradient technique to measure CH_4 flux above a dairy herd. Both techniques are comparable, within estimated errors, to scaled-up animal emissions. The emissions from the cows measured by integrated horizontal flux (averaged over three trials) were 329 (±153) g CH_4/day/cow, compared with 365 (±61) g CH_4/day/cow for the scaled-up measurements reported by Waghorn et al. (unpublished(a), unpublished(b)) using the SF_6 technique.

Methane emissions from lactating dairy cows have also been measured using the New Zealand SF_6 tracer method and respiration chamber techniques (Grainger et al., 2007). Total CH_4 emissions were similar when measured using respiration chambers (322 g CH_4/day/cow) or the SF_6 tracer technique (331 g CH_4/day/cow).

The calculations in New Zealand's model for cattle, sheep and deer are Tier 2 and are based on the IPCC (2006) Guidelines. Table 5.2.5 shows a comparison of the New Zealand-specific 2016 IEFs for enteric fermentation with the IPCC Tier 1 Oceania default value, the IPCC Tier 2 net energy-based value and the Australian-specific 2015 IEF for dairy cattle, non-dairy cattle and sheep.

The IPCC Tier 2 net energy-based values are determined from the net energy algorithms in the 2006 IPCC Guidelines (equation 10.16) for dairy cattle, non-dairy (beef) cattle and sheep. New Zealand's inventory model calculates emissions for sheep (one year of age and older) and lambs (less than one year old) separately. Therefore, in order to provide an appropriate comparison between the New Zealand-specific IEF and the IPCC Tier 2 net energy-based values for sheep, the gross energy values determined using the IPCC Tier 2 energy equations were obtained for both sheep and lambs.

Table 5.2.5   **Comparison of the IPCC (2006) default emission factor and country-specific implied emission factors (IEFs) for methane (CH_4) from enteric fermentation for dairy cattle, non-dairy cattle and sheep**

	Dairy cattle (kg CH_4/head/year)	Non-dairy cattle (pasture) (kg CH_4/head/year)	Sheep (kg CH_4/head/year)
IPCC (2006) Tier 1 Oceania default value	90.0	60.0	8.0
IPCC (2006) Tier 2 net energy-based value	72.5	51.6	8.9
Australian-specific IEF 2015 value[34]	93.2	51.3 (pasture)	6.8
		67.8 (feedlot)	
New Zealand-specific IEF 2016 value	82.3	59.2	12.2

Note: The IPCC (2006) value for sheep is for developed countries.

Dairy cattle: New Zealand's IEF for dairy cattle is lower than the IPCC Tier 1 Oceania default value and the Australian-specific IEF. Although the predominantly pasture-based system in New Zealand is similar to Australian dairy cattle management, this lower IEF value may be due to the higher proportion of lighter cattle breeds in New Zealand. The Australian dairy herd comprises 80 per cent Holstein–Friesian, 11 per cent Jersey breeds and 9 per cent other, including the Brown Swiss.[35] In 2016, 48.0 per cent of New Zealand's cow population comprised a Holstein–Friesian/Jersey crossbreed, which is, on average, 94.9 per cent of the liveweight of New Zealand's Holstein–Friesian cows (LIC and DairyNZ, 2017).

Also, in New Zealand's Tier 2 inventory model, dairy cattle encompass all cattle that are required to support the milking dairy herd. This includes calves, young growing non-lactating heifers, dry cows and bulls. Because the emissions from these animals are included in the IEF calculations, the IEF will be lower than if only mature milking cows had been taken into account.

However, New Zealand's dairy IEF is higher than the IPCC Tier 2 net energy-based value. This is because the feeding algorithms within New Zealand's national inventory use New Zealand-specific activity data and methodology that better reflect the pastoral-based farming systems in New Zealand.

Non-dairy cattle: The New Zealand-specific IEF for non-dairy cattle is similar to the IPCC Tier 1 Oceania default value but greater than the IPCC Tier 2 net energy-based value. Differences such as feed type and quality, breed and which animals are characterised as non-dairy will, however, influence the IEFs. As explained for dairy cattle above, the main difference between the IPCC Tier 2 value and the New Zealand-specific value (apart from the different equations determining them) is that the feeding algorithms within New Zealand's national inventory use New Zealand-specific activity data and methodology that better reflect the pastoral-based farming systems in New Zealand.

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[34]   As reported in Australia's *National Inventory Report 2015 Volume 1* on Greenhouse Gas Accounts (Commonwealth of Australia, 2017). Note that the Australian-specific non-dairy cattle IEF value is calculated from a population-based weighted average of pasture and feedlot IEF values from non-dairy cattle.

[35]   Australian Rural Exports. 2018. *Dairy Cattle*. Retrieved from www.austrex.com.au/dairy-cattle (3 January 2018).

Sheep: New Zealand's IEF for sheep is higher than the IPCC Tier 1 default value and higher than the Australian-specific IEF. This is because the annual sheep population figure used to calculate the IEF is based on the June population, in winter. This count will exclude the majority of the lamb population, which is born in spring (August–September) and raised and slaughtered during summer and early autumn (February, March and April). New Zealand does take lambs into account when determining actual CH_4 emissions over the course of a year because emissions are calculated on a monthly basis, but it does not include the lamb population when estimating the IEF. This is why the calculated sheep IEF is higher than the IPCC default. The IPCC Tier 2 net energy-based value is lower than the New Zealand-specific IEF. This difference can be explained by the same rationale as put forward for cattle.

5.2.5   Source-specific recalculations

All activity data were updated with the latest available data: Statistics New Zealand table builder and Infoshare database (Statistics New Zealand, 2017b) and LIC statistics (LIC and DairyNZ, 2017). No specific recalculations have been performed in New Zealand's Agriculture inventory for this year's submission.

5.2.6   Source-specific planned improvements

Improvements to the pasture quality dataset

New Zealand is continuing research to improve its data on national pasture quality. Pasture quality is one of the main factors affecting levels of greenhouse gas emissions from grazing livestock animals, and improving the dataset will improve the accuracy of emissions estimates. New Zealand is looking to develop a framework for the collection of detailed pasture quality data (for both metabolisable energy and nitrogen content) that will be more representative of farming systems in New Zealand. This will build on research that assessed the robustness of New Zealand's current pasture quality dataset (Bown et al., 2013; Upsdell et al., unpublished). It will also take into account work by Giltrap et al. (unpublished) that considered the number of samples required to represent the seasonal and spatial variability in pasture within specific uncertainty levels.

Clarification of cattle methane yields

New Zealand is continuing research to improve its understanding of CH_4 emissions from enteric fermentation of cattle. In order to develop a more robust relationship between CH_4 yields and DMI, research looking at CH_4 yields at low and high DMI levels is under way to ensure the CH_4 yield relationship holds at the extremes of DMI. The research is being carried out at the New Zealand Agricultural Greenhouse Gas Research Centre ruminant CH_4 measurement facility in purpose-built calorimeter chambers. The results of the study will be added to past research to help develop a robust equation describing the relationship between DMI and CH_4 yields in New Zealand. This is a three-year project that started in early 2017.

Review of liveweight calculation

New Zealand is looking to improve the accuracy of the calculations and parameters used to estimate liveweight for cattle, sheep and deer, which influences pasture intake and emissions. The current liveweight calculation methodology is being reviewed, and the recommendations from this review will be used to improve the accuracy and transparency of the inventory. It is anticipated that this project will be completed in late 2018.

5.3 Manure management (CRF 3.B)

5.3.1 Description

In 2016, emissions from the *Manure management* category contributed 1,238.3 kt CO_2-e (3.2 per cent of emissions from the Agriculture sector). Emissions from *Manure management* have increased by 498.7 kt CO_2-e (67.4 per cent) from the 1990 level of 739.6 kt CO_2-e. Methane from *Manure management* from dairy cattle was identified as a key category for New Zealand in the 2016 level and 1990–2016 trend assessment.

The majority of the emissions from the *Manure management* category are from CH_4 produced during the storage and treatment of manure, and from CH_4 from manure deposited on pasture. The category also includes N_2O emissions produced during the storage and treatment of manure. It does not include N_2O emissions from the spreading of animal manure and from manure deposited directly onto pasture by grazing livestock. Instead, emissions from these sources are included under the *Agricultural soils* category (under *Organic nitrogen fertilisers* and *Urine and dung deposited by grazing animals* respectively).

Methane is produced when manure decomposes in the absence of oxygen. The main factors affecting CH_4 emissions are the amount of manure produced and the portion of the manure that decomposes anaerobically. When manure is stored or treated as a liquid (e.g., in lagoons or ponds), it decomposes anaerobically and can produce a significant quantity of CH_4. The temperature and the length of time spent in storage also affect the amount of CH_4 produced. When manure is handled as a solid or when it is deposited on pastures, it tends to decompose under more aerobic conditions and less CH_4 is produced. In 2016, CH_4 emissions contributed 1,147.4 kt CO_2-e (92.7 per cent of the *Manure management* category) (see table 5.3.1).

Nitrous oxide emissions occur directly through the processes of nitrification and denitrification of nitrogen contained in the manure. They are also emitted indirectly through diffusion of oxides of nitrogen (NO_x) into the surrounding air (volatilisation) or via leaching and runoff. As with CH_4, the amount of N_2O emissions produced depends on the system of waste management and the duration of storage of the manure. Because most manure falls on pasture, with little going into manure management systems, this is only a very small source of emissions in New Zealand. In 2016, N_2O emissions were 90.8 kt CO_2-e (0.2 per cent of emissions from the Agriculture sector) (see table 5.3.1). In comparison, the combined N_2O emissions from organic fertilisers (spreading of animal manure) and manure deposited directly by grazing livestock reported under the *Agricultural soils* category totalled 5,566.5 kt CO_2-e in 2016 (14.4 per cent of emissions from the Agriculture sector).

Table 5.3.1   Trends and relative contribution of methane and nitrous oxide emissions under the Manure management category between 1990 and 2016

Manure management category	Emissions (kt CO_2-e)		Change from 1990		Share of Manure management category (%)		Share of total Agriculture sector (%)	
	1990	2016	%	Difference (kt CO_2-e)	1990 %	2016 %	1990 %	2016 %
Methane (CRF 3.B.1)	686.1	1,147.4	67.2	461.4	92.8	92.7	2.0	3.0
Nitrous oxide (CRF 3.B.2)	53.5	90.8	69.8	37.3	7.2	7.3	0.2	0.2

Note: Percentages presented are calculated from unrounded values.

Table 5.3.2 shows the distribution of livestock waste across animal waste management systems in New Zealand. All non-dairy cattle, sheep and deer manure is deposited directly onto pasture. Dairy cattle have a small amount of excreta (5 per cent) stored in anaerobic lagoon waste systems (Ledgard and Brier, unpublished). This relates to the proportion of time dairy cattle spend on pasture compared with the time they spend in the milking shed.

The minor livestock categories of *Goats*, *Horses*, *Mules and Asses*, and *Llamas and Alpacas* are assumed to graze outdoors all year and deposit all of their manure directly onto pastures. Estimates of the proportions of different waste management systems for swine and poultry in the manure management systems in New Zealand have been provided by Hill (2012) and Fick et al. (2011) respectively.

Table 5.3.2   Distribution of livestock waste across animal waste management systems in New Zealand

Livestock category	Anaerobic lagoon (%)	Daily spread[36] (%)	Pasture, range and paddock[37] (%)	Solid storage and dry lot (%)	Other (%)
Dairy cattle	5.0	–	95.0	–	–
Non-dairy cattle	–	–	100.0	–	–
Sheep	–	–	100.0	–	–
Deer	–	–	100.0	–	–
Goats	–	–	100.0	–	–
Horses	–	–	100.0	–	–
Swine[38]	20.5	25.7	8.9	42.5	2.4
Poultry – broilers[39]	–	–	4.9	–	95.1
Poultry – layers[40]	–	–	5.8	–	94.2
Poultry – other[41]	–	–	3.0	–	97.0
Alpacas	–	–	100.0	–	–
Mules and asses	–	–	100.0	–	–

5.3.2   Methodological issues

Methane from manure management systems (CRF 3.B.1)

New Zealand uses a Tier 2 approach to calculate CH_4 emissions from ruminant animal wastes from the major livestock categories in New Zealand (*Dairy cattle*, *Non-dairy cattle*, *Sheep* and *Deer*). This approach is based on the methods recommended by Saggar et al. (unpublished) and is consistent with the IPCC 2006 Guidelines.

Because New Zealand has detailed information on the dairy population and their characteristics (such as feed intake), the IPCC (2006) Tier 2 methodology for dairy anaerobic lagoons is used. The Tier 1 methodology for the minor livestock categories uses country-specific and IPCC (2006) default emission factors.

Manure methane from the major livestock categories

The approach for calculating CH_4 emissions from the major livestock categories relies on:

(1)   an estimation of the total quantity of faecal material produced, split into dung and urine

(2)   allocating the faecal material to the appropriate manure management system, either onto pastures or anaerobic lagoons (based on the distributions in table 5.3.2)

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[36]   Reported under *Agricultural soils*, under *Organic nitrogen fertilisers* (CRF 3.D.1.2).

[37]   Reported under *Agricultural soils*, under *Urine and dung deposited by grazing animals* (CRF 3.D.1.3).

[38]   Hill (2012).

[39]   Fick et al. (2011) and pers. comm. (2010).

[40]   Fick et al. (2011) and pers. comm. (2010).

[41]   IPCC (1996) default waste management proportions for Oceania.

(3) New Zealand-specific emission factors for the quantity of CH_4 produced per unit of faecal dry-matter (FDM) output.

The following equation is used to determine the monthly FDM output for each livestock category (*Dairy cattle*, *Non-dairy cattle*, *Sheep* and *Deer*):

$$FDM = DMI \times (1 - DMD)$$

Where: FDM is faecal dry matter (kg/head/month)

DMI is dry-matter intake (kg/head/month), and

DMD is dry-matter digestibility (decimal proportion).

The DMI and DMD estimates in this calculation are the same as those used to calculate the enteric fermentation CH_4 and nitrogen in excreta. These Tier 2 model calculations are based on livestock performance statistics (see section 5.1.4).

Methane from dairy effluent anaerobic lagoons

It is estimated that 5 per cent of manure from dairy cows is stored in anaerobic lagoons (Ledgard and Brier, unpublished). A Tier 2 methodology derived from the IPCC (2006, equations 10.23 and 10.24) linking volatile solids to FDM is used for calculating CH_4 emissions from this activity.

The following equation is used to determine CH_4 emissions ($CH_{4\text{-MM}}$) from dairy cattle manure in anaerobic lagoons:

$$CH_{4-MM} = FDM \cdot (1 - ASH) \cdot B_0 \cdot 0.67 \cdot MCF \cdot MS$$

Where: FDM is the faecal dry matter excreted by dairy cows (on pasture and stored in anaerobic lagoons) (kg/head/month)

ASH is the ash content of manure, 0.08 (IPCC, 2006, default value)

B_0 is the maximum methane-producing capacity of manure, 0.24 (IPCC, 2006; Oceania default value, verified by Pratt et al., unpublished)

0.67 is the conversion factor for converting CH_4 from cubic metres to kilograms (IPCC, 2006)

MCF is the methane conversion factor, 0.74 (IPCC, 2006, table 10.17, default for uncovered anaerobic lagoon, average annual temperature 15º, verified by Pratt et al., unpublished)

MS is the fraction of total dairy manure excreted in anaerobic lagoons (6.0 per cent from lactating cattle, which is equivalent to 5 per cent of the total dairy herd (Ledgard and Brier, unpublished)).

Methane emissions from the major livestock categories

The following equation is used to determine CH_4 emissions ($CH_{4\text{-PRP}}$) from beef cattle, sheep and deer manure deposited onto pasture:

$$CH_{4-PRP} = FDM \cdot Y_m$$

Where: FDM is the faecal dry matter (kg/head/month)

Y_m is the methane yield value.

Country-specific CH_4 yield values have been developed from New Zealand studies. Details on the values used for each of the major livestock categories are provided below.

Dairy cattle: The quantity of CH_4 produced per kilogram of FDM is 0.98 g CH_4/kg for manure on pasture. This value is obtained from New Zealand studies on dairy cows and ranges from approximately 0.92 to 1.04 g CH_4/kg (Saggar et al., unpublished; Sherlock et al., unpublished).

Non-dairy cattle: The value of 0.98 g CH_4/kg per unit of FDM is based on New Zealand studies on dairy cattle manure (Saggar et al., unpublished; Sherlock et al., unpublished). No specific studies have been conducted in New Zealand on CH_4 emissions from beef cattle manure.

Sheep: The quantity of CH_4 produced per unit of sheep FDM is 0.69 g CH_4/kg. This value is obtained from a New Zealand study on sheep in which values ranged from 0.340 to 1.288 over six sampling periods (Carran et al., unpublished).

Deer: The quantity of CH_4 produced per unit of FDM is assumed to be 0.91 g CH_4/kg. Deer are not housed in New Zealand, and all faecal material is deposited directly onto pasture. This value is derived from New Zealand studies on sheep (Carran et al., unpublished) and dairy cattle (Saggar et al., unpublished; Sherlock et al., unpublished). There are no New Zealand studies on CH_4 emissions from deer manure.

Methane emissions from minor livestock categories

Manure CH_4 emissions from the minor livestock categories are calculated per head, using country-specific and default emission factors.

Swine: New Zealand uses a country-specific emission factor of 5.94 kg CH_4/head/year (Hill, 2012) for estimating emissions from swine manure management. Industry data on swine diets (to determine digestible energy of the swine feed and volatile solid excretion levels) and the use of waste management systems used by New Zealand swine producers (Hill, 2012) were used (equations 15 and 16 from the IPCC 1996 revised Guidelines, which correspond to equations 10.23 and 10.24 in the 2006 IPCC Guidelines) to determine a country-specific manure management emission factor. Further information on this is provided in the report by Hill (2012).

Poultry: Methane emissions from poultry manure management use New Zealand-specific emission factor values derived from Fick et al. (2011). These are based on New Zealand-specific volatile solids and proportions of poultry faeces in each manure management system for each production category. The poultry population has been disaggregated into three different categories, and the manure management emission factor values for each are: *Broiler birds* 0.022 kg CH_4/head/year; *Layer hens* 0.016 kg CH_4/head/year; and *Other* 0.117 kg CH_4/head/year. The overall IEF for poultry is affected by the change over time in the population proportions of these different categories.

Goats, *Horses*, **and** *Mules and Asses:* New Zealand uses IPCC (2006) default emission factors for CH_4 emissions from manure management for goats, horses, mules and asses (table 10.15). The emission factors are 0.20 kg CH_4/head/year for goats, 2.34 kg CH_4/head/year for horses, and 1.10 kg CH_4/head/year for mules and asses. These are the values for temperate developed countries.

Llamas and Alpacas: There is no IPCC default value available for CH_4 emissions from manure management for alpacas. The emissions are calculated by assuming that the CH_4 emission factor from manure management for alpacas for all years is equal to the CH_4 manure management IEF for sheep in 1990 (i.e., manure management CH_4 sheep emissions per sheep). The alpaca emission factor (0.10 kg CH_4/head/year) is not indexed to sheep over time because

there are no data indicating that alpacas have gained the kind of productivity increases that have been seen in sheep.

Nitrous oxide from manure management systems (CRF 3.B.2)

Nitrous oxide emissions from manure management can be classified as either direct or indirect. Direct N_2O emissions occur from nitrification and denitrification of nitrogen contained in the manure. Indirect N_2O emissions result from volatile nitrogen losses in the forms of ammonia (NH_3) and NO_x and are emitted via diffusion into the surrounding air (volatilisation) or via leaching and runoff.

Nitrous oxide emissions from manure are calculated for each livestock category based on:

(1) livestock population characterisation data (consistent with section 5.1.3)

(2) the average nitrogen excretion rate per head

(3) an estimation of the total quantity of faecal material produced (consistent with the calculations in the previous section for CH_4 from manure management) split into dung and urine

(4) the partitioning of this faecal material between manure management systems (based on the distributions in table 5.3.2)

(5) the total amount of nitrogen managed in each system multiplied by an emission factor (IPCC, 2006).

Nitrogen excretion rates for the major livestock categories

The nitrogen excretion (N_{ex}) rates for the main livestock categories in New Zealand (*Dairy cattle*, *Non-dairy cattle*, *Sheep* and *Deer*) are calculated from the nitrogen intake less the nitrogen retained through digestion and in animal products, such as liveweight gain, milk, wool and velvet. Nitrogen intake is determined from the dry-matter feed intake and the nitrogen content of the feed. Feed intake and animal productivity values are the same as those used in the Tier 3 model for determining DMI (Clark et al., 2003; section 5.1.3). The nitrogen content of feed is estimated from a review of over 6,000 pasture samples from dairy systems and sheep and non-dairy (beef) systems (Ledgard et al., unpublished).

The nitrogen content of animal products is derived from industry data. For lactating dairy cows, the nitrogen content of milk is derived from the protein content of milk, which is published annually by LIC. The nitrogen content of sheep meat, milk and wool, non-dairy meat and milk, and the nitrogen retained in deer velvet, are taken from New Zealand research (Bown et al., 2013; values listed in Pickering and Fick, 2015 – see www.mpi.govt.nz/news-and-resources/open-data-and-forecasting/greenhouse-gas-reporting/agricultural-greenhouse-gas-inventory-reports/#model).

Table 5.3.3 shows the N_{ex} rates for the major livestock categories. These rates have increased over time, reflecting the increases in animal productivity and DMI in New Zealand since 1990. N_{ex} rates are also affected by adverse events and changes in commodity prices which can cause large changes in productivity and N_{ex} rates in adjacent years (see section 5.1.1). For full details of how N_{ex} rates are derived for each livestock category, see the technical detail provided in the inventory methodology document on the Ministry for Primary Industries website (www.mpi.govt.nz/news-and-resources/open-data-and-forecasting/greenhouse-gas-reporting/agricultural-greenhouse-gas-inventory-reports/#model).

Table 5.3.3   **Nitrogen excretion rates (N$_{ex}$) for New Zealand's major livestock categories from 1990 to 2016**

Year	Dairy cattle N$_{ex}$ (kg/head/year)	Non-dairy cattle N$_{ex}$ (kg/head/year)	Sheep N$_{ex}$ (kg/head/year)	Deer N$_{ex}$ (kg/head/year)
1990	104.1	64.26	13.19	25.39
1991	108.1	66.13	13.62	26.08
1992	108.8	67.14	13.66	27.01
1993	110.1	68.26	13.86	27.53
1994	108.0	68.92	13.94	27.08
1995	107.6	68.26	13.81	28.09
1996	110.7	70.78	14.38	28.31
1997	111.7	72.07	14.99	28.62
1998	109.2	72.15	14.91	28.73
1999	111.1	70.31	14.96	29.02
2000	112.7	72.81	15.62	29.43
2001	113.8	74.06	15.52	29.37
2002	113.1	73.64	15.72	29.40
2003	117.2	73.20	15.79	29.24
2004	115.7	74.47	16.14	29.46
2005	116.3	75.38	16.42	29.60
2006	115.5	76.87	16.15	29.70
2007	114.2	75.85	15.61	29.54
2008	112.5	75.19	15.89	29.41
2009	113.3	74.54	16.40	29.50
2010	115.9	74.47	15.82	29.48
2011	116.9	75.47	16.27	29.80
2012	116.9	76.58	16.62	29.82
2013	119.4	75.30	16.54	29.56
2014	119.4	74.98	16.73	29.75
2015	122.3	75.83	16.68	29.89
2016	119.5	76.37	17.03	30.41

Nitrogen excretion rates for the minor livestock categories

Swine: A New Zealand-specific N$_{ex}$ rate for swine is calculated for each year (see table 5.3.4) based on the 2009 value of 10.8 kg N/head/year (Hill, 2012). This 2009 value is based on the weighted average of the distribution of animal weights by swine category. Estimates of N$_{ex}$ rates for all other years are indexed relative to 2009 for the average pig kill weights for each year. Average pig weights have increased since 1990 due to improvements in productivity. Data on swine weights are collected by the Ministry for Primary Industries.

Goats: New Zealand uses country-specific N$_{ex}$ rates for goats to estimate N$_2$O emissions of 10.6 kg N/head/year for 1990 and 12.1 kg N/head/year for 2009 based on the differing population characteristics for those two years (Lassey, 2011). As explained in section 5.2.2 for *Enteric fermentation*, for the intermediate years between 1990 and 2009 and for later years, the excretion rate was interpolated based on assumptions that the dairy goat population has remained in a near constant state over time while the rest of the goat population has declined (see table 5.3.4).

Poultry: New Zealand-specific and IPCC default N_{ex} rates are used for poultry (Fick et al., 2011). These are the country-specific values of 0.39 kg N/head/year for broiler birds and 0.42 kg N/head/year for layer hens. Ducks and turkeys make up approximately 1.1 per cent of New Zealand's poultry population, and flock sizes are unclear because they are reported by Statistics New Zealand under 'other poultry'. Therefore, the value of 0.60 kg N/head/year for ducks and turkeys recommended by Fick et al. (2011) is retained. These values are used for all years from 1990. The overall N_{ex} rate for poultry is affected by the change over time in the population proportions of these different categories.

*Horses***,** and *Mules and Asses:* New Zealand-specific N_{ex} rates are not available for horses, mules and asses, and the default N_{ex} rate for Oceania of 0.3 kg nitrogen per 1,000 kg of animal mass per day is used, in line with the IPCC Guidelines (2006, table 10.19).

Llamas and Alpacas: Because there is no IPCC default N_{ex} rate for alpacas, this was calculated by assuming a default N_{ex} rate for alpacas for all years that is equal to the per-head value of the average sheep in 1990 (i.e., 13.2 kg/head/year). The alpaca emission factor is not indexed to sheep over time because there are no data to support the kind of productivity increases that have been seen in sheep. Sheep were used, rather than the IPCC default value for 'other animals', because the literature indicates that alpacas have a nitrogen intake close to that of sheep and no significant difference in the partitioning of nitrogen (Pinares-Patino et al., 2003). Using the much higher default value for 'other animals' would result in the overestimation of N_{ex} for alpacas.

Table 5.3.4   Nitrogen excretion (N_{ex}) rates for New Zealand's swine and goats from 1990 to 2016

Year	Swine N_{ex} (kg/head/year)	Goat N_{ex} (kg/head/year)	Year	Swine N_{ex} (kg/head/year)	Goat N_{ex} (kg/head/year)
1990	10.6	9.0	2004	11.5	10.5
1991	10.7	9.2	2005	11.5	10.6
1992	10.8	9.3	2006	11.5	10.7
1993	10.9	9.5	2007	11.7	10.8
1994	11.0	9.5	2008	11.9	10.8
1995	10.9	9.6	2009	12.1	10.8
1996	11.2	9.8	2010	11.8	10.8
1997	11.1	9.9	2011	12.0	11.0
1998	11.1	9.9	2012	11.9	11.0
1999	11.3	9.9	2013	12.0	11.1
2000	11.3	10.2	2014	11.7	11.3
2001	11.4	10.5	2015	12.1	11.4
2002	11.4	10.2	2016	11.5	11.3
2003	11.3	10.1			

Direct nitrous oxide emissions from manure management

Major livestock categories: For the major livestock categories (*Dairy cattle*, *Non-dairy cattle*, *Sheep* and *Deer*), most manure is deposited directly onto pasture by grazing animals (see table 5.3.2). Direct and indirect N_2O emissions from the manure deposited by grazing animals are reported under the *Agricultural soils* category (*Urine and dung deposited by grazing animals* (CRF 3.D.1.3)).

The remainder of dairy manure is managed in anaerobic lagoons. The IPCC (2006) Guidelines note that the production of emissions of direct N_2O from managed manure requires aerobic conditions for the formation of oxidised forms of nitrogen, but assumes that negligible direct N_2O emissions occur during storage in anaerobic lagoons (IPCC, 2006, table 10.21). Direct N_2O emissions from dairy effluent anaerobic lagoons are reported under the *Agricultural soils*

category (*Organic nitrogen fertilisers* (CRF 3.D.1.2)) when the stored effluent is spread onto agricultural land.

Swine: Swine manure is managed under various types of waste management system (see table 5.3.2). The IPCC (2006) Guidelines (table 10.21) assume that negligible direct N_2O emissions occur in anaerobic lagoons and daily spread. Nitrous oxide emissions from manure from these systems occur once the stored effluent is spread onto agricultural land and are reported under the *Agricultural soils* category (*Organic nitrogen fertilisers* (CRF 3.D.1.2)). Nitrous oxide emissions from manure management of swine for the solid storage, dry lot and other manure management systems are estimated using the IPCC (2006) default emission factors for direct N_2O emissions from manure management (EF_3) of 0.02 and 0.005 kg N_2O-N/kg N respectively.

Poultry: Direct N_2O emissions from poultry manure deposited directly on pasture are reported under the *Agricultural soils* category (*Urine and dung deposited by grazing animals* (CRF 3.D.1.3)). For other manure management systems, the IPCC (2006, table 0.21) default emission factor for EF_3 of 0.001 kg N_2O-N/kg N for poultry manure with and without litter is assumed.

Goats, *Horses*, *Llamas and Alpacas*, **and** *Mules and Asses*: All faecal material from these livestock is deposited directly onto pasture, and direct N_2O emissions from grazing animals are reported under the *Agricultural soils* category (*Urine and dung deposited by grazing animals* (CRF 3.D.1.3)).

Indirect nitrous oxide emissions from manure management

Indirect N_2O emissions from manure management result from diffusion into the surrounding air (volatilisation) and from leaching and runoff. All indirect N_2O emissions for the pasture, range and paddock manure management systems are reported under the *Agricultural soils* category.

The IPCC (2006) Tier 1 methodology is used for calculating N_2O emissions resulting from volatilisation:

$$N_2O_{MM-volatilisation} = \frac{44}{28}(N_{volatilisation -MMS} \cdot EF_4)$$

And:

$$N_{vol-MMS} = \sum_S \left[\sum_T \left[(N_T \cdot Nex_T \cdot MS_{T,S}) \cdot \left(\frac{Frac_{GasMS}}{100} \right)_{T,S} \right] \right]$$

Where: $N_{vol-MMS}$ is the amount of manure nitrogen that is lost due to volatilisation (kg/year)

EF_4 is the emission factor for N_2O emissions from volatilisation; the IPCC (2006) default value of 0.01 kg N_2O-N/(kg NH_3-N + NO_x-N volatilised) is used

N_T is the number of livestock per category (head), detailed in section 5.1.4

Nex_T is the average nitrogen excretion for each livestock category, T, detailed above

$MS_{T,S}$ is the fraction of total nitrogen excretion per livestock category, T, per manure management system, S, derived from table 5.3.2, and

$Frac_{GasMS}$ is the per cent of managed manure nitrogen for each livestock category, T, which volatilises as NH_3 and NO_x per manure management system, S. New Zealand uses default values for $Frac_{GasMS}$ detailed in table 5.3.5.

The IPCC (2006) Tier 1 guidelines do not provide a methodology for determining indirect N_2O emissions from leaching and runoff. There have been no country-specific emission factors derived for leaching and runoff from manure management systems in New Zealand (e.g., Hill, 2012), and there are extremely limited measurement data available generally (IPCC, 2006). Leaching and runoff from dairy anaerobic lagoons is likely to be an insignificant activity in

New Zealand (T Wilson, pers. comm., 2014). All indirect N_2O emissions from leaching and runoff are reported under the *Agricultural soils* category.

Table 5.3.5   IPCC default values for the fraction of managed manure nitrogen that volatilises as ammonia and oxides of nitrogen (Frac$_{GasMS}$/100) for livestock categories per manure management system in New Zealand

Manure management system	Livestock category	Value
Anaerobic lagoons	Dairy	0.35
	Swine	0.4
Daily spread	Swine	0.07
Solid storage and dry lot	Swine	0.3
Other (deep bedding)	Swine	0.25
	Poultry – broilers	0.25
	Poultry – layers	0.25
	Poultry – other	0.25

Source: IPCC (2006) table 10.22 and Hill (2012)

5.3.3   Uncertainties and time-series consistency

To ensure consistency, a single livestock population characterisation and feed-intake estimate is produced by the Tier 2 model for the major livestock categories. It is used in different parts of the calculations for the inventory to estimate: CH_4 emissions for the *Enteric fermentation* category, CH_4 and N_2O emissions for the *Manure management* category and N_2O emissions for the *Agricultural soils* category.

Methane emissions

The major sources of uncertainty in CH_4 emissions from manure management are the accuracy of emission factors for manure management system distribution, the activity data on the livestock population and the use of the various manure management systems (IPCC, 2006). The ranges for measured emissions for the major livestock categories have been stated where available.

The IPCC (2006) states that emission factor estimates are likely to have uncertainties of ±30.0 per cent for Tier 1 methodologies and ±20.0 per cent for Tier 2 methodologies. New Zealand does not currently have country-specific uncertainty values for CH_4 from manure management, and because around 95 per cent of CH_4 from *Manure management* is calculated using Tier 2 methodologies, an uncertainty value of ±20.0 per cent has been used for the *Manure management* CH_4 emission factor uncertainty.

Uncertainties for the livestock characterisation are also discussed in section 5.1.4 and annex A3.1.1.

Nitrous oxide emissions

The main factors causing uncertainty in direct and indirect N_2O emissions from manure management are the N_{ex} rates, the emission factors from manure and manure management systems, activity data on the livestock population and the use of the various manure management systems (IPCC, 2006).

Uncertainty ranges for the default N_{ex} values are estimated at about ±50.0 per cent (IPCC, 2006), and may be substantially smaller for the values for the livestock whose N_{ex} rates were derived from in-country statistics on productivity. New Zealand uses the default values for EF_3 for direct N_2O emissions from the manure management of swine and poultry, which have

uncertainties ranging from –50.0 per cent to +100.0 per cent. An uncertainty value of ±100.0 per cent has been used for the *Manure management* N$_2$O emission factor uncertainty.

As above, uncertainties for the livestock characterisation are discussed in section 5.1.4 and annex A3.1.

5.3.4 Source-specific QA/QC and verification

Methane from *Manure management* from dairy cattle was identified as a key category for New Zealand in the 2016 level and 1990–2016 trend assessment.

In the preparation for this inventory submission, the data for this category underwent Tier 1 and Tier 2 quality checks.

Table 5.3.6 shows a comparison of the New Zealand-specific 2016 IEF for CH$_4$ from *Manure management* with the IPCC (2006) Tier 1 Oceania default, the IPCC Tier 2 net energy-based value and the 2015 Australian-specific IEF for *Dairy cattle*, *Non-dairy cattle* and *Sheep*. The IPCC Tier 2 value was determined from net energy equations to determine gross energy for each of New Zealand's major livestock categories. This information is then used to determine volatile solid excretion and the annual CH$_4$ emission factors for each livestock category as per the equations described in the IPCC 2006 Guidelines (i.e., equations 10.16, 10.24 and 10.23 respectively).

New Zealand has lower IEFs for CH$_4$ from *Manure management* than the IPCC Tier 1 Oceania default and the IPCC Tier 2 net energy-based emission factors. Additionally, New Zealand has lower dairy and non-dairy IEFs for CH$_4$ from *Manure management* than the Australian-specific 2015 IEFs. Differences between New Zealand's IEFs, the IPCC Tier 1 and Tier 2 and the Australian-specific IEFs are due to the reasons outlined under *Enteric fermentation* (see section 5.2.4): that is, size and productivity of the animals, the age classes of livestock included in New Zealand's modelling and the use of different algorithms to determine energy intake.

Table 5.3.6   **Comparison of IPCC (2006) default emission factors and country-specific implied emission factors (IEFs) for methane (CH$_4$) from manure management**

	Dairy cattle (kg CH$_4$/head/year)	Non-dairy cattle (kg CH$_4$/head/year)	Sheep (kg CH$_4$/head/year)
IPCC Tier 1 Oceania default value (average temperature 15⁰C (cattle)/ developed temperate default value (sheep))	27.00	2.00	0.28
IPCC Tier 2 net energy-based value	5.97	0.82	0.18
Australian-specific IEF 2015 value[42]	15.10	0.15	0.002
New Zealand-specific IEF 2016 value	5.62	0.79	0.13

5.3.5 Source-specific recalculations

All activity data were updated with the latest available data: Statistics New Zealand table builder and Infoshare database (Statistics New Zealand, 2017b) and LIC statistics (LIC and DairyNZ, 2017). No specific recalculations have been performed in New Zealand's Agriculture inventory for this year's submission.

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[42] As reported in Australia's *National Inventory Report 2015*. Retrieved from http://unfccc.int/national _reports/annex_i_ghg_inventories/national_inventories_submissions/items/10116.php (23 December 2017). Note that the Australian-specific non-dairy cattle IEF value is calculated from a population-based weighted average of pasture and feedlot IEF values from non-dairy cattle.

5.3.6 Source-specific planned improvements

The following section covers the planned improvements being undertaken for *Manure management*, where these findings may be incorporated in future annual inventory submissions.

Improved manure management disaggregation

New Zealand has reviewed the historical and current data on the use of different types of dairy effluent infrastructure, updating the work carried by (Ledgard and Brier, unpublished). An updated value for the amount of dairy excreta entering anaerobic lagoons is expected to be incorporated into the 2019 inventory submission.

Improvements to the pasture quality dataset

New Zealand is continuing research to improve its knowledge on national pasture quality, including nitrogen content which affects emissions from manure. A programme of pasture sample collection and analysis will begin in 2018. The aim of this work is to provide an up-to-date, detailed and accurate pasture quality dataset that is nationally representative of the range of farming systems. This will build on research that assessed the robustness of New Zealand's current pasture quality dataset (Bown et al., 2013; Upsdell et al., unpublished). It will also take into account work by Giltrap et al. (unpublished) that considered the number of samples required to represent the seasonal and spatial variability in pasture within specific uncertainty levels.

5.4 Rice cultivation (CRF 3.C)

5.4.1 Description

At present, no commercial rice cultivation is carried out in New Zealand. This has been confirmed with experts from Plant and Food Research. The 'NO' (not occurring) notation is reported in the CRF tables.

5.5 Agricultural soils (CRF 3.D)

5.5.1 Description

In 2016, the *Agricultural soils* category contributed 8,593.3 kt CO_2-e (10.1 per cent) to New Zealand's gross emissions and 94.2 per cent of New Zealand's total N_2O emissions. Emissions were 1,895.8 kt CO_2-e (28.3 per cent) above the 1990 level of 6,697.5 kt CO_2-e.

Several categories contribute to N_2O emissions from agricultural soils from both direct and indirect pathways (see figure 5.5.1). Direct N_2O emissions come directly from the soils to which nitrogen has been added or released. Indirect emissions come from the volatilisation (evaporation or sublimation) of nitrogen from the land. A fraction of this volatilised nitrogen returns to the ground during rainfall and is then re-emitted as N_2O. Indirect emissions also arise from leaching and runoff of nitrogen (IPCC, 2006). Figure 5.5.1 shows the key country-specific emission factors and parameters that New Zealand has developed for some of the *Agricultural soils* emission categories.

Figure 5.5.1 Sources of nitrous oxide emissions from agricultural soils, showing the contribution of each source to emissions through both direct and indirect pathways (New Zealand's country-specific emission factors and parameters for each category are also listed)
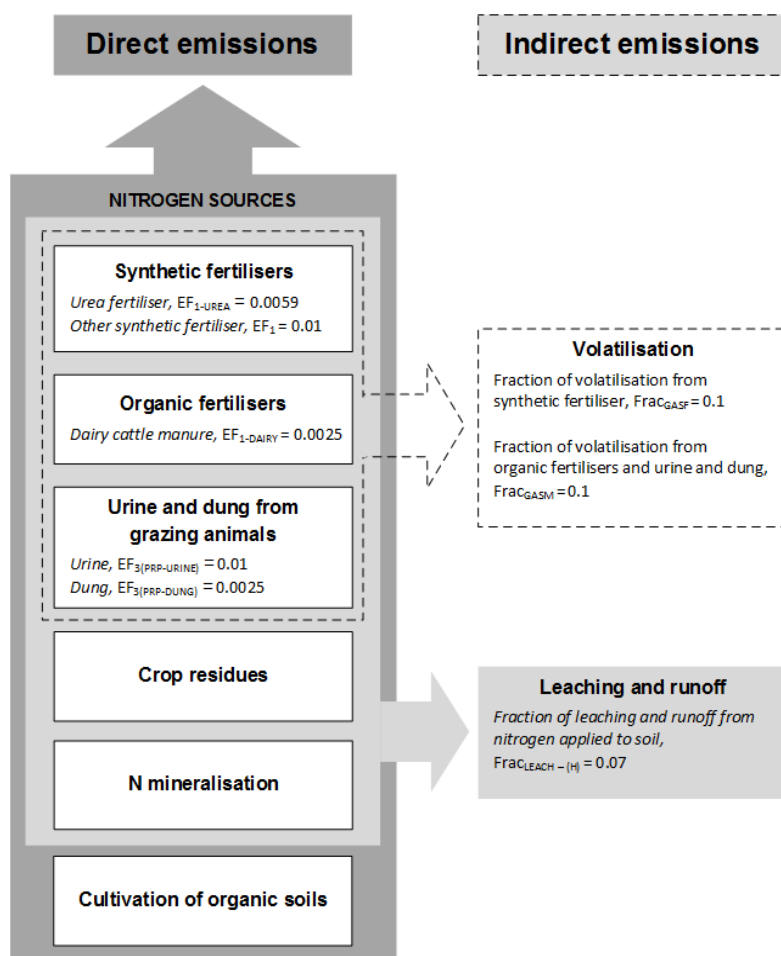
The categories that contribute the most to emissions from agricultural soils and that are identified as key categories are outlined below in order of significance.

- Urine and dung deposited by grazing animals (grazing manure) (level and trend assessment): In 2016, N_2O emissions from this source contributed 5,503.3 kt CO_2-e (64.0 per cent) to emissions from the *Agricultural soils* category and 14.2 per cent of emissions under the total Agriculture sector. This is an increase of 371.4 kt CO_2-e (7.2 per cent) from the 1990 level of 5,131.8 kt CO_2-e.

- Synthetic nitrogen fertiliser (level and trend assessment): In 2016, direct N_2O emissions from synthetic nitrogen fertiliser contributed 1,332.2 kt CO_2-e (15.5 per cent) to emissions from the *Agricultural soils* category. This is an increase of 1,101.8 kt CO_2-e (478.4 per cent) from the 1990 level of 230.3 kt CO_2-e.

- Volatilisation (level assessment): In 2016, this category contributed 910.1 kt CO_2-e (10.6 per cent) to emissions from the *Agricultural soils* category. This was an increase of 200.0 kt CO_2-e (28.2 per cent) from the 1990 level of 710.2 kt CO_2-e.

- Leaching and runoff (level assessment): In 2016, this category contributed 501.6 kt CO_2-e (5.8 per cent) to emissions from the *Agricultural soils* category. This was an increase of 119.6 kt CO_2-e (31.3 per cent) from the 1990 level of 382.0 kt CO_2-e.

- Crop Residues (level assessment): In 2016, this category contributed 252.6 kt CO_2-e (2.9 per cent) to emissions from the *Agricultural soils* category. This was an increase of 77.2 kt CO_2-e (44.0 per cent) from the 1990 level of 175.5 kt CO_2-e

Table 5.5.1 shows the trends and relative contribution of N_2O emissions from these categories between 1990 and 2016.

Table 5.5.1   **Trends and relative contribution of nitrous oxide emissions from Agricultural soils categories between 1990 and 2016**

Agricultural soils category		Emissions (kt CO_2-e)		Change from 1990–2016		Share of Agricultural soils category (%)	Share of total Agriculture sector (%)
		1990	**2016**	**kt CO_2-e**	**%**	**2016**	**2016**
Direct	Synthetic nitrogen fertilisers	230.3	1,332.2	1,101.8	478.4	15.5	3.4
	Organic fertilisers (animal manure spread on pasture)	37.6	63.2	25.7	68.3	0.7	0.2
	Grazing manure	5,131.8	5,503.3	371.4	7.2	64.0	14.2
	Crop residue	175.5	252.6	77.2	44.0	2.9	0.7
	Cropland nitrogen mineralisation from soil organic matter loss	0.0	0.2	0.1	497.2	0.002	Negl.
	Cultivation of organic soils	30.0	30.0	0.0	0.0	0.3	0.1
Indirect	Volatilisation	710.2	910.1	200.0	28.2	10.6	2.4
	Leaching and runoff	382.0	501.6	119.6	31.3	5.8	1.3
Total Agricultural soils		6,697.5	8,593.3	1,895.8	28.3	100.0	22.2

Note: Negl. = negligible. Columns may not add due to rounding. Percentages presented are calculated from unrounded values.

Indirect emissions from livestock waste management systems are reported under section 5.3 (*Manure management*). Carbon dioxide emissions from lime and dolomite fertilisers are reported in section 5.8 (*Liming*).

5.5.2   Methodological issues

New Zealand uses methodologies based on the IPCC Guidelines (IPCC, 2006), as well as the outputs of the Tier 2 livestock population characterisation and modelling of the livestock nutrition and energy requirements, and some country-specific equations to calculate N_2O emissions from *Agricultural soils*. A combination of default and country-specific emission factors and parameters are also used to calculate emissions from this category. Details on these emission factors and parameters are listed in tables 5.5.2 and 5.5.3; tables A3.1.5 and A3.1.6 (annex 3), and in table 5.5.4 for mitigation technologies.

The largest inputs of nitrogen to agricultural soils are manure (urine and dung) from grazing livestock and synthetic nitrogen fertilisers, which together contribute to over three-quarters of emissions from the *Agricultural soils* category. The following paragraphs provide an overview of the country-specific improvements made to the *Agricultural soils* category.

Overview of research and improvements in the Agricultural soils category

Considerable research effort has gone into establishing New Zealand-specific emission factors for emissions from manure on pasture from grazing livestock ($EF_{3(PRP)}$). In New Zealand, most livestock waste is excreted directly onto pasture during grazing (see table 5.3.2). Research to date

has included a disaggregation of emissions from urine and dung for the major livestock categories (*Dairy cattle*, *Non-dairy cattle*, *Sheep* and *Deer* (see table 5.5.2)).

New Zealand also has country-specific emission factors for some other nitrogen inputs to agricultural soils, in particular, for urea fertiliser and dairy cattle manure applied to soils. The IPCC default value of 0.01 is used for other nitrogen inputs such as synthetic nitrogen fertiliser (excluding urea), other animal manure applied to soils, and crop residues. This emissions factor of 0.01 has been verified as suitable for New Zealand conditions by Kelliher and de Klein (unpublished).

The emission factor for indirect N_2O emissions from leaching and runoff (EF_5) for rivers, lakes and estuaries has also been reviewed (Clough and Kelliher, unpublished). The review concluded that further research would be required to develop a country-specific value, but that the IPCC (2006) guideline value of 0.0075 was appropriate for New Zealand in the meantime.

In addition to these emission factors, New Zealand has developed country-specific parameters for volatilisation, leaching, nitrogen input from crop residue burning and pasture renewal (see table 5.5.3). New Zealand has also incorporated emission factors and parameters for the use of the following mitigation technologies (see table 5.5.4):

- urease inhibitor, N-(n-butyl) thiophosphoric triamide (nBTPT, sold as 'Agrotain')

- nitrification inhibitor, dicyandiamide (DCD).

Further detail on the methodologies for each individual category is found in the following sections.

Table 5.5.2   Nitrous oxide (N_2O) emission factors for agricultural soils in New Zealand

Category		Emission factor		Source
3.D.1 Direct N_2O emissions				
Synthetic nitrogen fertiliser (urea)	$EF_{1\text{-UREA}}$	0.0059	kg N_2O-N/kg N	van der Weerden et al. (2016a, b)
Organic fertiliser (dairy cattle manure)	$EF_{1\text{-DAIRY}}$	0.0025	kg N_2O-N/kg N	van der Weerden et al. (2016a, b)
Synthetic nitrogen fertiliser (other), organic fertiliser (swine and poultry manure) crop residue, nitrogen loss due to soil organic matter mineralisation, organic soil mineralisation due to cultivation	EF_1	0.01	kg N_2O-N/kg N	Kelliher and de Klein (unpublished), IPCC (2006, table 11.1)
Cultivation of organic soils	EF_2	8	kg N_2O-N/ha/kg N	IPCC (2006, table 11.1)
Manure (urine) from grazing animals in pasture, range and paddock systems	$EF_{3\text{(PRP- URINE)}}$	0.01	kg N_2O-N/kg N	Carran et al. (1995); Muller et al. (1995); de Klein et al. (2003)
Dung from grazing cattle, sheep and deer in pasture, range and paddock systems	$EF_{3\text{(PRP-DUNG)}}$	0.0025	kg N_2O-N/kg N	Luo et al. (2009)
3.D.2 Indirect N_2O emissions				
Volatilisation	EF_4	0.010	kg N_2O-N/kg N	IPCC (2006, table 11.3)
Leaching and runoff	EF_5	0.0075	kg N_2O-N/kg N	IPCC (2006, table 11.3), confirmed by Clough and Kelliher (unpublished)

Table 5.5.3   Parameters for indirect nitrous oxide (N₂O) emissions from agricultural soils in New Zealand

Category	Parameter			Source
3.D.2 Indirect N₂O emissions				
Fraction of volatilisation from synthetic fertiliser	$Frac_{GASF}$	0.1	kg NH₃-N + NOₓ-N/kg N	IPCC (2006), verified by Sherlock et al. (2008)
Fraction of volatilisation from organic nitrogen additions including pasture manure	$Frac_{GASM}$	0.1	kg NH₃-N + NOₓ-N/kg N	Sherlock et al. (2008)
Fraction of leaching and runoff from all nitrogen applied to soil	$Frac_{LEACH-(H)}$	0.07	kg N/kg N	Thomas et al. (unpublished), Thomas et al. (2005)
Fraction of crop residue burned in the field	$Frac_{BURN}$	Crop-specific	kg N/kg crop-N	Thomas et al. (2008, table 14)
Fraction of legume crop residue burning in the field	$Frac_{BURNL}$	0 (not burned in NZ)	kg N/kg crop-N	Thomas et al. (2008)
Fraction of land undergoing pasture renewal	$Frac_{RENEW}$	Year-specific		Beare et al. (unpublished); Thomas et al. (2014)
Fraction of nitrogen in above-ground residues removed for bedding, feed or construction	$Frac_{REMOVE}$	0	kg N/kg crop-N	Thomas et al. (2014)

Table 5.5.4   Emission factors and parameter values for use of mitigation technologies

Category	Parameter and value (%)		Source
Urine from grazing dairy cattle in pasture, range and paddock systems with application of dicyandiamide (DCD)	$EF_{3(PRP-DCD)}$	0.67	Clough et al. (2008)
Fraction of nitrogen from leaching and runoff with application of DCD	$Frac_{LEACH-(H)-DCD}$	0.53	Clough et al. (2008)
Volatilisation from synthetic nitrogen fertiliser including urease inhibitor (nBTPT)	$Frac_{GASF-UI}$	0.045	Saggar et al. (2013)

Direct nitrous oxide emissions from managed soils (CRF 3.D.1)

Emissions from the *Direct N₂O emissions from managed soils* category arise from:

- synthetic nitrogen fertiliser use (F_{SN})
- organic fertilisers (which in New Zealand are solely the spreading of animal manure, F_{AM})
- manure deposited by grazing livestock in pasture, range and paddock (F_{PRP})
- decomposition of crop residues left on fields (F_{CR})
- nitrogen mineralisation associated with loss of soil organic matter (F_{SOM})
- cultivation of organic soils.

Many of these sources of emissions have N₂O emissions from indirect pathways as well, and these calculations are described in detail in the section on indirect N₂O emissions from *Agricultural soils* (see section 5.5.2).

Emissions from the non-manure components of organic fertilisers (F_{ON}) are not estimated in New Zealand's inventory. These components include sources such as dairy processing wastewater, compost sold to the rural sector, meat processing wastewater sand sludge, grape marc from the wine industry and vegetable processing wastewater applied to land. New Zealand commissioned research to review sources of organic waste but found that they are not significant for New Zealand (van der Weerden et al., 2014).

New Zealand's methodology for determining the values for nitrogen inputs to soils for F_{AM} and F_{PRP} is consistent with other parts of the inventory. The underlying values for N_{ex} and for the

allocation of excreta to animal waste management systems are the same as in the *Manure management* category. These N_{ex} values have been calculated based on the same animal intake and animal productivity values used for calculating CH_4 emissions for the different animal categories and species in the Tier 2 model (see section 5.1.3). This ensures the same base DMI values are used for both the CH_4 and N_2O emission calculations. Further details can be found in the inventory methodology document on the Ministry for Primary Industries website (http://mpi.govt.nz/news-and-resources/statistics-and-forecasting/greenhouse-gas-reporting).

Synthetic nitrogen fertiliser (CRF 3.D.1.1)

Anthropogenic N_2O emissions from synthetic nitrogen fertiliser are a relatively small proportion of total N_2O emissions, but have grown significantly over the past two decades. Most synthetic nitrogen fertiliser used in New Zealand is urea fertiliser applied to dairy pasture land to increase pasture growth during spring and autumn.

In accordance with IPCC Guidelines (IPCC, 2006), the following equation is used to determine direct N_2O emissions from the application of nitrogen-based fertiliser:

$$N_2O \; emissions = \frac{44}{28} \cdot \left[(F_{SN(UREA)} \cdot EF_{1(UREA)}) + (F_{SN(OTHER)} \cdot EF_1) \right]$$

Where: F_{SN} is the total annual amount of synthetic nitrogen fertiliser applied to soils (urea-based and other fertilisers)

$EF_{1(UREA)}$ is the proportion of direct N_2O emissions from nitrogen input to the soil for urea fertilisers (0.0059; table 5.5.2), and

EF_1 is the proportion of direct N_2O emissions from nitrogen input to the soil (0.01; table 5.5.2).

Data on synthetic fertiliser use (including the use of urea) is provided by the Fertiliser Association of New Zealand from sales records for 1990 to 2016.

Since 1990, there has been a large increase in nitrogen applied through synthetic fertiliser, from 59,300 tonnes in 1990 to 432,200 tonnes in 2016 (see figure 5.5.2). At the same time, the proportion of urea fertiliser applied has increased from 41 per cent to around 83 per cent of all synthetic nitrogen fertiliser (see figure 5.5.3).

Figure 5.5.2   Synthetic nitrogen fertiliser use in New Zealand from 1990 to 2016
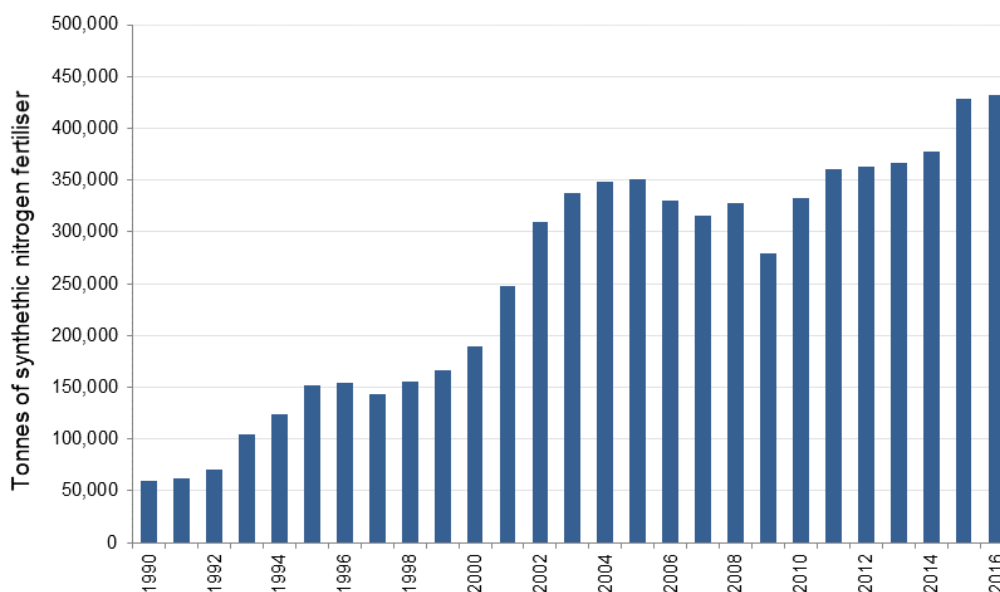
Source: Fertiliser Association of New Zealand

Figure 5.5.3   Percentage of synthetic nitrogen fertiliser derived from urea from 1990 to 2016
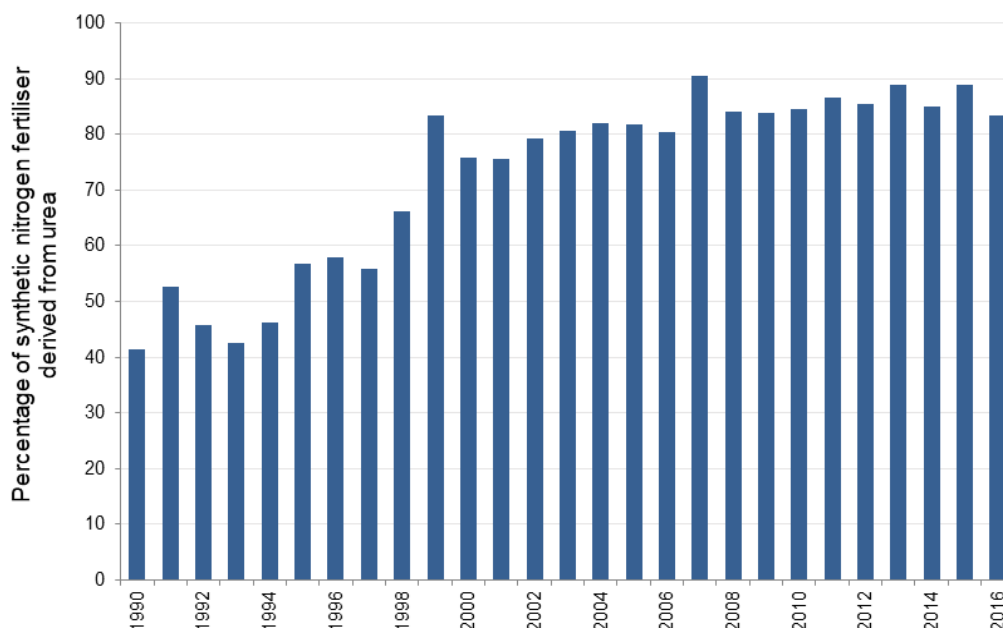
Sources: International Fertiliser Industry Association, Fertiliser Association of New Zealand

The increase in synthetic nitrogen fertiliser use since 1990 has resulted in an increase in emissions from this category, from 230.3 kt CO_2-e in 1990 (0.7 per cent of agricultural emissions) to 1,332.2 kt CO_2-e in 2016 (3.4 per cent of agricultural emissions).

Organic nitrogen fertilisers (CRF 3.D.1.2)

In New Zealand, emissions from organic nitrogen fertilisers are solely from animal manure that is spread on pasture after collection in manure management systems. Most animal manure in New Zealand is excreted directly onto pasture, but some manure from dairy farms is kept in manure management systems and applied to soils as an organic fertiliser (see table 5.3.2). Some manure is also collected but not stored; rather, it is spread directly onto pasture daily (e.g., swine manure and some dairy manure). The calculation for animal waste includes all manure that is spread on agricultural soils, irrespective of the animal waste management system it was initially stored in. This calculation excludes manure deposited directly on pasture by grazing livestock, which is covered in the next section (urine and dung deposited by grazing animals (CRF 3.D.1.3)). Animal manure is not used for feed, fuel or construction in New Zealand.

New Zealand has developed a country-specific emission factor for dairy cattle manure applied to soils of 0.0025 (van der Weerden et al., 2016a, b). This value was based on a meta-analysis of field trials carried out in New Zealand that measured emissions from dairy cattle manure on soil.

Manure from poultry and swine spread onto soil has an emission factor of 0.01, which is consistent with the IPCC default.

The following equation is used to determine direct N_2O emissions from the application of animal manure to soil:

$$N_2O\ emissions = \frac{44}{28} \cdot [(F_{AM} \cdot EF_1) + (F_{AM(DAIRY)} \cdot EF_{1(DAIRY)})]$$

Where: F_{AM} is the total amount of animal manure nitrogen applied to soils from manure management systems (other than pasture, range and paddock), which is derived as a fraction of the nitrogen excretion rates, N_{ex}, described in section 5.3.2

EF$_1$ is the proportion of direct N$_2$O emissions from animal manure (swine and poultry) applied to soils (0.01; table 5.5.2), and

EF$_{1(DAIRY)}$ is the proportion of direct N$_2$O emissions from animal manure (dairy cattle) applied to soils (0.0025; table 5.5.2).

The IPCC (2006) Guidelines recommend that non-manure components of organic nitrogen applied to agricultural soils, such as compost sewage sludge and rendering waste, are included under organic fertilisers. New Zealand commissioned research on sources of organic waste and found that these activities are not significant for New Zealand (van der Weerden et al., 2014). They account for approximately 0.025 per cent of national gross greenhouse gas emissions and therefore this category has been reported as 'not estimated' (NE).

The research assessed a range of potential sources including dairy processing wastewater, compost sold to the rural sector, blood and bone fertiliser, meat processing wastewater and sludge, grape marc from the wine industry, vegetable processing wastewater and sewage sludge applied to land. No brewery waste is applied to soils in New Zealand, because spent yeast is used in the food industry to manufacture a yeast spread, and application of sewage sludge to agricultural land is reported under the Waste sector.

Because most livestock manure in New Zealand is excreted directly onto pasture, emissions from the organic nitrogen fertilisers category are relatively small. In 2016, N$_2$O emissions from this source contributed 63.2 kt CO$_2$-e (0.7 per cent of emissions from *Agricultural soils*, 0.2 per cent of total agricultural emissions). This is an increase of 25.7 kt CO$_2$-e (68.3 per cent) from the 1990 level of 37.6 kt CO$_2$-e.

Urine and dung deposited by grazing animals (CRF 3.D.1.3)

Most livestock in New Zealand are grazed outdoors on pasture, with 95 per cent of dairy cattle excreta and 100 per cent of non-dairy cattle, sheep, deer and other livestock excreta falling on pasture (see table 5.3.2).

The following equations are used to determine direct N2O emissions from grazing livestock manure.

For sheep, cattle and deer urine only, and urine and dung for all other livestock categories:

$$N_2O\ emissions = \frac{44}{28}(N_2O - N) = \frac{44}{28}\left(\sum_T N_T \cdot Nex_T \cdot MS_T\right) \cdot EF_{3(PRP-URINE)}$$

For sheep, cattle and deer dung only:

$$N_2O\ emissions = \frac{44}{28}(N_2O - N) = \frac{44}{28}\left(\sum_T N_T \cdot Nex_T \cdot MS_T\right) \cdot EF_{3(PRP-DUNG)}$$

Where: N_T is the population of livestock category, T (population as calculated in section 5.1.3)

Nex$_T$ is the annual average nitrogen excretion per head by each livestock category (kg N/head/year) (see section 5.3)

MS$_T$ is the proportion of manure excreted directly onto pasture, range and paddock by each livestock category (see table 5.3.2), and

EF$_{3(PRP-URINE)}$ and EF$_{3(PRP-DUNG)}$ are the emission factors for manure from grazing animals in pasture, range and paddock (see table 5.5.2).

New Zealand uses a country-specific emission factor for EF$_{3(PRP-URINE)}$ of 0.01 for the urine of cattle, sheep and deer and for the manure from all other livestock categories. For the dung of cattle, sheep and deer, a country-specific emission factor for EF$_{3(PRP-DUNG)}$ of 0.0025 has been

implemented (see table 5.5.2). These emission factors have been developed through an extensive research programme, and further details on this research are provided below.

Nitrous oxide emissions from urine and dung have been studied in a number of regions across New Zealand (Carran et al., 1995; Muller et al., 1995; de Klein et al., 2003). The research carried out field trials to measure emissions from pastoral soils of different drainage classes in all four seasons. The results of these studies were assessed by Kelliher et al. (unpublished(b), unpublished(c)), to determine an appropriate national annual value for emissions from manure on pasture. The approach weighted the value based on the distribution of the key pastoral soil drainage classes across New Zealand and was developed on the basis that N_2O emission rates are strongly governed by soil water content. Soil water content depends on soil drainage, meaning that drainage classes of pastoral soils are a suitable surrogate for soil water content.

Further research found that cattle and sheep excreta emissions could also be separated into urine and dung components. Luo et al. (2009) assessed all available $EF_{3(PRP-DUNG)}$ data in relation to pastoral soil drainage classes to determine an appropriately weighted national annual mean value. This review confirmed that a disaggregation of the emission factor for dung and urine is warranted. Luo et al. (2009) recommended that the N_2O emission factor for cattle and sheep urine remains at the country-specific value of 0.01, and the N_2O emission factor for cattle and sheep dung be reduced to 0.0025.

In 2016, N_2O emissions from *Urine and dung deposited by grazing animals* (grazing manure) contributed 5,503.3 kt CO_2-e (64.0 per cent of emissions from *Agricultural soils*, or 14.2 per cent of total agricultural emissions). This is an increase of 371.4 kt CO_2-e (7.2 per cent) from the 1990 level of 5,131.8 kt CO_2-e. Emissions for each livestock category are given in table 5.5.5. Emissions from *Urine and dung deposited by grazing animals* were identified as a key category (level and trend assessment).

Table 5.5.5 **Trends and relative contribution of direct nitrous oxide emissions from urine and dung deposited by grazing animals per livestock category between 1990 and 2016**

Livestock category	Emissions (kt CO₂-e)		Change from 1990–2016		Share of Agricultural soils category (%)		Share of total Agriculture sector (%)	
	1990	2016	kt CO₂-e	%	1990	2016	1990	2016
Dairy cattle	1,274.0	2,813.7	1,539.7	120.9	19.0	32.7	3.7	7.3
Non-dairy cattle	1,028.6	940.4	−88.2	−8.6	15.4	10.9	3.0	2.4
Sheep	2,659.1	1,637.0	−1,022.1	−38.4	39.7	19.0	7.7	4.2
Deer	89.3	89.1	−0.2	−0.3	1.3	1.0	0.3	0.2
Minor livestock	80.8	23.2	−57.7	−71.4	1.2	0.3	0.2	0.1

Note: Percentages presented are calculated from unrounded values.

Nitrous oxide from crop residue returned to soil (CRF 3.D.1.4)

This emissions category includes emissions from nitrogen added to soils by above- and below-ground crop residue (including residue left behind by crop burning), and the nitrogen added as a result of mineralisation of forages during pasture renewal. It includes both nitrogen-fixing and non-nitrogen-fixing crop species. Crop residues are materials left in an agricultural field or orchard after the crop has been harvested. Pasture renewal is the destruction of low quality pasture followed by the sowing of improved pasture species and/or varieties. It is promoted as a simple method to increase farm productivity. The direct emissions from agricultural residue burning are reported under section 5.7.

Thomas et al. (2008) recommend that New Zealand does not include an adjustment for crop residue removed for feed and bedding in this calculation until activity data are available.

Nitrogen from crop residue: The non-nitrogen-fixing crops grown in New Zealand are barley, wheat, oats, potatoes, maize seed and other seed crops. For the 2012 submission onwards, New Zealand has reported emissions from additional cropping activity not previously estimated, such as onions, squash and sweetcorn (Thomas et al., 2011). The nitrogen-fixing crops grown in New Zealand include peas grown for both processing and seed markets as well as lentil production and forage legume seeds grown for pasture production.

A country-specific methodology is used to calculate emissions from crop residue (Thomas et al., 2008):

$$N_2O_{FCR} \; emissions = \frac{44}{28}(N_2O - N)_{FCR} = \frac{44}{28}(AG_N + BG_N) \cdot EF_1$$

Where: AG_N and BG_N are the annual nitrogen residue returned to soils from above- and below-ground crop residue, and crop-specific values are given in annex 3, table A3.1.7 and the country-specific value of EF_1 of 0.01 is used (see table 5.5.2).

$$AG_N = AG_{DM} \cdot N_{AG}$$
$$BG_N = (AG_{DM} + Crop_T) \cdot R_{BG} \cdot N_{BG}$$

Where: AG_{DM} is the mass of the above-ground residue dry matter (explained in the equation below)

$Crop_T$ is the crop yield, or mass removed during harvest

N_{AG} and N_{BG} are the above- and below-ground crop-specific nitrogen concentration factors, and

R_{BG} is the crop-specific root:shoot ratio of below-ground dry matter against the total above-ground crop biomass (crop gathered, $Crop_T$, plus above-ground residue dry matter, AG_{DM}), 0.1 (see annex 3, table A3.1.7).

$$AG_{DM} = \left(\frac{Crop_T}{HI}\right) - Crop_T \cdot Frac_{BURN} \cdot C_f$$

Where: HI is the crop-specific harvest index or fraction of the crop that is harvested (see annex 3, table A3.1.7)

$Frac_{BURN}$ is the fraction of residue burned in the field (see table 5.5.3), and

C_f is the combustion factor; a value of 0.7 is recommended (Thomas et al., 2008).

The country-specific value for $Frac_{BURN}$, the fraction of residue burned in the field, was derived from Statistics New Zealand data and farmer surveys (Thomas et al., 2011). The parameters used to estimate the nitrogen added by above- and below-ground crop residues were compiled from published and unpublished reports for New Zealand-grown crops (Cichota et al., 2010) and 'typical' values derived for use in the OVERSEER® nutrient budget model for New Zealand. The OVERSEER® model provides average estimates of the fate of nitrogen for a range of pastoral, arable and horticultural systems (www.overseer.org.nz).

The per-year harvested tonnage of most non-nitrogen-fixing crops in New Zealand is supplied by Statistics New Zealand from its Agricultural Production census and survey. Additional information on potatoes is provided by Potatoes New Zealand, and updated information on seed crops is provided by AsureQuality, which provides verification and certification services for the seed industry (Thomas, unpublished; S Thomas, pers. comm., 2014). The tonnage of nitrogen-fixing crops is supplied by Statistics New Zealand from its Agricultural Production census and survey (lentils and legumes) and Horticulture New Zealand (peas) (S Thomas, pers. comm., 2014).

Nitrogen from pasture renewal: Of the four categories of perennial forage that the IPCC (2006) lists for pasture renewal, only two categories are appropriate for New Zealand (Thomas et al., 2014): these are Grass–clover pastures and Lucerne, a nitrogen-fixing perennial forage. New Zealand has calculated emissions from pasture renewal per plant species type, T, separately:

$$F_{CR-RENEW} = $$

$$\sum_T \left[Crop_T \times Area_T \times Frac_{RENEW(T)} \times \left[R_{AG(T)} \times N_{AG(T)} \times \left(1 - Frac_{REMOVE(T)} \right) + R_{BG(T)} \times N_{BG(T)} \right] \right]$$

Where: $Area_T$ is the total annual area harvested (hectares per year). No burning is used for pasture renewal in New Zealand

$Frac_{RENEW(T)}$ is the fraction of the area under each crop that is renewed

$R_{AG(T)}$ is the ratio of above-ground residue dry matter (DM) to harvested yield (kg N/kg DM)

$N_{AG(T)}$ is the nitrogen content of above-ground residue (kg N/kg DM)

$Frac_{REMOVE(T)}$ is the fraction of above-ground residue removed annually for feed, assumed zero for New Zealand

$R_{BG(T)}$ is the ratio of below-ground residue DM to harvest yield (kg N/kg DM), and

$N_{BG(T)}$ is the nitrogen content of below-ground residue (kg N/kg DM).

The areas for each perennial forage crop were obtained from the Statistics New Zealand Agricultural Production census and survey, which include the area of grassland and annual crops from 1990–2016. The disaggregation of grass–clover systems has been considered, but there is insufficient activity data for pastures of different compositions in New Zealand, because the proportion of clover varies widely in high nitrogen input systems, meaning disaggregated data on the nitrogen content are not presently available.

The contribution of crop residues and pasture renewal to overall agricultural emissions is small, with 175.5 kt CO_2-e (0.5 per cent of agricultural emissions) in 1990 and, in 2016, 252.6 kt CO_2-e (0.7 per cent of agricultural emissions).

Nitrogen mineralisation from loss of soil organic matter in mineral soils (CRF 3.D.1.5)

Nitrogen mineralisation is the process by which organic nitrogen is converted to plant-available inorganic forms. Nitrogen mineralisation occurs when soil carbon is lost due to land-use or management change. Most of New Zealand's emissions due to nitrogen mineralised during the loss of soil organic matter are covered under the LULUCF sector. The exception is for activities under the *Cropland remaining cropland* land-use category, which are reported under the Agriculture sector (IPCC, 2006).

The following equations are used to determine emissions from this activity:

$$N_2O_{FSOM} = \frac{44}{28}(F_{SOM} \cdot EF_1) \cdot 10^{-6}$$

Where: N_2O_{FSOM} is the N_2O emitted as a result of nitrogen mineralisation from loss of soil organic matter in mineral soils (kt), and

F_{SOM} is the nitrogen mineralisation from loss of soil organic matter in mineral soils through land management for cropland remaining cropland (kg).

The emission factor EF_1 is 0.01 (Kelliher and de Klein, unpublished).

And:

$$F_{SOM} = \frac{\Delta C_{Mineral,CrC}}{R} \cdot 10^3$$

Where: $\Delta C_{Mineral,CrC}$ is the loss of soil carbon (C) in mineral soil during management of cropland (kt), and

R is the C:N ratio; the IPCC (2006) default value of 10 is used.

Activity data on the soil carbon loss associated with cropland since 1990 were provided by calculations under the LULUCF sector (refer to section 6.5).

The contribution of nitrogen mineralisation from loss of soil organic matter to overall agricultural emissions is small, with 0.03 kt CO_2-e in 1990 and, in 2016, 0.17 kt CO_2-e.

Cultivation of organic soils (CRF 3.D.1.6)

The management of organic soils is a source of N_2O emissions. The area of managed organic soils (histosols) in New Zealand includes both the area of cultivated organic soils (as reported under the LULUCF sector) and the area of mineral agricultural soils with a peaty layer that is cultivated (Dresser et al., 2011). Mineral soils with a peaty layer are included in the definition of organic soils because these soils have similar emissions behaviour to that of organic soils (Dresser et al., 2011). The full definition used in the Agriculture sector for organic soils (plus mineral soils with a peaty layer) is:

- 17 per cent organic matter content (includes slightly peaty, peaty and peat soils of 17–30 per cent, 30–50 per cent and greater than 50 per cent organic matter content)

- 0.1 metres of this depth occurring within 0.3 metres of the surface.

The total area of managed cultivated organic soils in New Zealand is 160,385 hectares, with 135,718 hectares being organic soils and 24,667 hectares mineral soils with a peaty layer. It is assumed that 5 per cent of organic soils (plus mineral soils with a peaty layer) under agricultural pasture is cultivated on an annual basis (Dresser et al., 2011; Kelliher et al., unpublished(a)). This results in 8,019 hectares of 'organic agricultural soils' being cultivated annually.

Emissions from organic soils are calculated using the Tier 1 methodology for all years of the time series by multiplying the area of cultivated organic soils by the default value of emission factor EF_2, of 8 kg N_2O-N/ha (IPCC, 2006).

The annual contribution of organic soils (plus mineral soils with a peaty layer) to the overall agricultural emissions is very small and has remained at 30.0 kt CO_2-e (0.1 per cent of agricultural emissions) since 1990 to the present.

Indirect nitrous oxide emissions from managed soils (CRF 3.D.2)

In addition to direct N_2O emissions from managed soils, emissions of N_2O also occur through two indirect pathways: volatilisation, and leaching and runoff.

Volatilisation (CRF 3.D.2.1)

Some of the nitrogen deposited or spread on agricultural land is emitted into the atmosphere through volatilisation in the form of NH_3 and NO_x. A fraction of this volatilised nitrogen returns to the ground during rainfall and is then re-emitted as N_2O. The fraction of nitrogen that becomes N_2O during this process is calculated using the parameters $Frac_{GASF}$ for synthetic nitrogen fertiliser and $Frac_{GASM}$ for organic inputs from animal excreta. New Zealand uses country-specific values for both of these parameters.

In New Zealand, nitrogen added to agricultural soils from synthetic nitrogen fertiliser (F_{SN}), organic nitrogen fertiliser from the spreading of managed manure (F_{ON}), and excreta from grazing livestock on pasture (F_{PRP}) all contribute to N_2O emissions from volatilisation. The collection of activity data for F_{SN}, F_{ON} and F_{PRP} is described above under Direct N_2O emissions from managed soils (CRF 3.D.1). Volatilisation from manure stored in manure management systems (prior to application to land) is reported under the *Manure management* category (see section 5.3.2).

New Zealand uses a Tier 1 methodology with country-specific emission factors for $Frac_{GASF}$ and $Frac_{GASM}$ and a default value for the EF_4 emission factor to calculate emissions from volatilisation:

$$N_2O_{ATD}\ emissions = \frac{44}{28}(N_2O_{ATD} - N) = \frac{44}{28}\left[(F_{SN} \cdot Frac_{GASF}) + ((F_{ON} + F_{PRP}) \cdot Frac_{GASM})\right] \cdot EF_4$$

Where: N_2O_{ATD}–N is the annual amount of N_2O-N produced by atmospheric deposition of volatilised nitrogen from agricultural soils (kg N_2O-N/year)

F_{SN}, F_{ON} and F_{PRP} are defined above (kg N/year)

$Frac_{GASF}$ is the fraction of nitrogen from synthetic fertiliser that volatilises as NH_3 and NO_x (see table 5.5.3)

$Frac_{GASM}$ is the fraction of nitrogen from manure spreading and grazing manure that volatilises as NH_3 and NO_x (see table 5.5.3), and

EF_4 is the emission factor for N_2O emissions from atmospheric deposition of nitrogen on soils and water (kg N_2O-N/kg N).

New Zealand has a country-specific value of 0.1 for $Frac_{GASF}$, the fraction of volatilised nitrogen from synthetic nitrogen fertiliser. This value is based on a review by Sherlock et al. (2008) of relevant New Zealand and international research. The review determined that a value of 0.096 for $Frac_{GASF}$ was suitable for New Zealand conditions. Because this value of 0.096 is almost identical to the IPCC default value of 0.1, the value of 0.1 was adopted by New Zealand as a country-specific value for $Frac_{GASF}$.

The review by Sherlock et al. (2008) also recommended a country-specific value of 0.1 for $Frac_{GASM}$, the fraction of volatilised nitrogen from manure spreading and grazing manure. The review showed that the default value of 0.2 for $Frac_{GASM}$ (IPCC, 2006) was too high for New Zealand conditions and that 0.1 was more appropriate. This value was also confirmed by subsequent field experiments (Laubach et al., 2012).

In 2016, N_2O emissions from volatilisation contributed 2.4 per cent (910.1 kt CO_2-e) to total agricultural emissions, an increase of 28.2 per cent from the 1990 value of 710.2 kt CO_2-e.

Leaching and runoff (CRF 3.D.2.2)

Nitrous oxide emissions from leaching and runoff originate from the following sources: synthetic nitrogen fertiliser (F_{SN}), organic nitrogen additions from the spreading of animal manure (F_{ON}), above- and below-ground crop residues (F_{CR}), nitrogen mineralisation associated with loss of soil organic matter from cropland land management (F_{SOM}) and excreta from grazing livestock on pasture, range and paddock (F_{PRP}) (IPCC, 2006). The collection of activity data for F_{SN}, F_{ON}, F_{CR}, F_{PRP} and F_{SOM} is described above under Direct N_2O emissions from managed soils (CRF 3.D.1).

New Zealand reports all emissions from leaching under the *Agricultural soils* category. As discussed under *Manure management* (see section 5.3.2), New Zealand livestock are

predominantly grazed outdoors (see table 5.3.2). New Zealand uses a Tier 1 methodology with the country-specific default parameters, to calculate indirect N_2O emissions from nitrogen leaching:

$$N_2O_L \ emissions = \frac{44}{28}(N_2O_L - N) = \frac{44}{28} \cdot (F_{SN} + F_{ON} + F_{PRP} + F_{CR} + F_{SOM}) \cdot Frac_{LEACH-H} \cdot EF_5$$

Where: N_2O_L–N is the annual amount of N_2O-N from runoff and leaching from agricultural soils (kg N_2O-N/year)

F_{SN}, F_{ON}, F_{PRP}, F_{CR} and F_{SOM} are defined above (kg N/year)

$Frac_{LEACH-H}$ is the fraction of nitrogen added to, or mineralised from, agricultural soils where leaching and runoff occur that is lost through leaching and runoff (see table 5.5.3), and

EF_5 is the IPCC (2006) default factor for N_2O emissions from leaching and runoff.

New Zealand uses a country-specific value for $Frac_{LEACH}$, the fraction of nitrogen applied to agricultural land that is lost through leaching and runoff.[43] Research has indicated that a value of 0.07 for $Frac_{LEACH}$ more closely reflects leaching in New Zealand. Thomas et al. (2005) compared nitrogen leaching estimates for different farm systems based on IPCC methodology (a value of 0.30 kg N/kg of fertiliser or manure) with estimates from a New Zealand-specific nutrient budgeting model, OVERSEER® (Wheeler et al., 2003). The IPCC-based estimates were found, on average, to be 50 per cent higher than those estimated using the OVERSEER® nutrient budget model (using a $Frac_{LEACH}$ of 0.15[44]).

The OVERSEER® model provides average estimates of the fate of nitrogen for a range of pastoral, arable and horticultural systems. In pastoral systems, nitrate (NO_3) leaching is determined by rainfall, soil type, and the amount of nitrogen entering the farm system, for example, in nitrogen-based fertilisers, and dung and urine applied as dairy farm effluent and directly excreted by grazing animals. The latter is calculated from the difference between nitrogen intake by grazing animals and nitrogen retained in animal products – milk, meat, velvet and so on. This is based on user inputs of stocking rate or production and an internal database with information on the nitrogen content of pasture and animal products, and calibrated against field measurements.

In 2016, N_2O emissions from leaching and runoff made up 1.3 per cent (501.6 kt CO_2-e) of total agricultural emissions, an increase of 31.3 per cent from the 1990 value of 382.0 kt CO_2-e.

Incorporation of nitrous oxide mitigation technologies into the Agriculture inventory

Urease inhibitors

The N_2O emissions reported under *Agricultural soils* take into account the use of urease inhibitors, a greenhouse gas mitigation technology. Urea is the main type of synthetic nitrogen fertiliser applied to pastures. Urease inhibitors restrict the action of the enzyme, urease. Urease is a catalyst for the volatilisation of the nitrogen contained in urea fertiliser and urine into NH_3 gas.

Urease inhibitor mitigation is included in New Zealand's Agriculture inventory by adjusting the value of the existing country-specific N_2O parameter: $Frac_{GASF}$. Saggar et al. (2013) assessed the mitigating effect of the urease inhibitor nBTPT (sold as 'Agrotain'), the most widely used

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[43]   For reporting under the 1996 IPCC Guidelines, this parameter was defined as $Frac_{LEACH}$; under the 2006 IPCC Guidelines, it is defined as $Frac_{LEACH - (H)}$.

[44]   A New Zealand parameter for $Frac_{LEACH}$ of 0.15 was used in inventories submitted before 2003.

product. Saggar et al. (2013) showed that the presently recommended country-specific value of $Frac_{GASF}$ of 0.1 be reduced to 0.055. This finding was based on field and laboratory studies conducted both in New Zealand and worldwide.

Indirect N_2O emissions from volatilisation from all synthetic nitrogen fertilisers (including urea and other nitrogen fertilisers, with and without urease inhibitors applied to the urea component) are calculated as shown below:

$$N_2O_{ATD-FSN} \ emissions = \frac{44}{28}(N_2O_{ATD-FSN} - N) = \frac{44}{28} \sum_S [F_{SN} \cdot Frac_{GASF}] \cdot EF_4$$

Where: $N_2O_{ATD-FSN}$–N is the annual amount of N_2O-N produced by atmospheric deposition of volatilised nitrogen from all synthetic nitrogen fertiliser applied to agricultural soils (kg N_2O-N/year)

S is urea fertiliser (untreated), urea fertiliser (treated) or non-urea nitrogen fertiliser

F_{SN} is the total annual amount of synthetic nitrogen fertiliser applied (kg N/year) per fertiliser type, S

$Frac_{GASF}$ is the fraction of nitrogen from synthetic nitrogen fertiliser that volatilises as NH_3 and NO_x; 0.055 for treated urea fertiliser and 0.1 for untreated urea and other nitrogen fertiliser, and

EF_4 is the emission factor for N_2O emissions from atmospheric deposition of nitrogen on soils and water; 0.01 per cent.

All other emission factors and parameters relating to animal excreta and synthetic nitrogen fertiliser use ($Frac_{GASM}$, $Frac_{LEACH}$ and EF_1) do not change as a result of including urease inhibitors in the calculations. An adjustment for $Frac_{GASM}$ was not recommended because the effect of urease inhibitors on reducing NH_3 volatilisation from animal urine could not be accurately assessed (Saggar et al., 2013).

Urea fertiliser coated with urease inhibitors was first used commercially in 2001 in New Zealand. Activity data on urease inhibitor usage are provided by the Fertiliser Association of New Zealand from sales records.[45] This activity data records the total amount of nitrogen in urea fertiliser that has been treated with a urease inhibitor. Some urea fertiliser coated with urease inhibitors is also blended into other fertiliser products.

Estimates of the mitigation impact of urease inhibitors on N_2O emissions from volatilisation for the calendar years 2001 to 2016 are shown in table 5.5.6. In 2014 and 2016 there were large increases in the use of urease inhibitors.

Table 5.5.6   Mitigation impact of urease inhibitors on nitrous oxide emissions from volatilisation, from 2001 to 2016

Year	Percentage of urea fertiliser applied that included urease inhibitor (urea treated/total urea)	Estimated greenhouse gas mitigation from using urease inhibitor kt CO$_2$-e
2001	5.6	2.2
2002	3.8	1.9
2003	4.6	2.6
2004	8.1	4.8
2005	1.6	1.0
2006	8.4	4.7

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[45]   Activity data on urease inhibitor usage before 2016 was provided by Ballance Agri-Nutrients Limited.

Year	Percentage of urea fertiliser applied that included urease inhibitor (urea treated/total urea)	Estimated greenhouse gas mitigation from using urease inhibitor kt CO_2-e
2007	5.0	3.0
2008	5.2	3.0
2009	9.4	4.7
2010	6.9	4.1
2011	5.3	3.5
2012	7.0	4.6
2013	8.6	5.9
2014	20.2	13.6
2015	16.2	13.1
2016	26.5	20.1

Source: Fertiliser Association of New Zealand and Ballance Agri-Nutrients Limited

Nitrification inhibitor dicyandiamide

A methodology has been developed to incorporate the nitrification inhibitor DCD, an N_2O mitigation technology, into the inventory. The N_2O emissions reported in the *Agricultural soils* category take into account the use of nitrification inhibitors on dairy farms using the methodology described in Clough et al. (2008). Greenhouse gas mitigation estimates from DCD are reported in the inventory only up until 2012, because it was no longer used after this time. Sales were suspended due to the detection of low levels of DCD residues in milk.

Research has shown that DCD reduces N_2O emissions and nitrate (NO_3-) leaching in pastoral grassland systems grazed by ruminant animals. The inventory methodology incorporates DCD use by modifying the emission factors $EF_{3(PRP)}$ and the parameter $Frac_{LEACH}$ (see table 5.5.4). These were modified based on comprehensive field-based research that showed significant reductions in direct and indirect N_2O emissions and NO_3- leaching where the DCD was applied. It was determined that, on a national basis, reductions in $EF_{3(PRP)}$ and $Frac_{LEACH}$ of 67 per cent and 53 per cent respectively could be made (Clough et al., 2008).

There has been some research into the effect of the inhibitor on dung ($EF_{3(PRP-DUNG)}$); however, these data are limited and further work would need to be carried out before incorporating this research into the inventory. Application of this inhibitor was found to have no effect on NH_3 volatilisation, which is supported by the results of field studies (Clough et al., 2008; Sherlock et al., 2008). Therefore, the parameter for volatilisation remains unchanged.

The DCD weighting factors are calculated based on reductions in emission factors and parameters, and the fraction of dairy land treated with the inhibitor, as follows:

$$DCD\ weighting\ factor = \left(1 - \frac{\%\ reduction\ in\ EF_x}{100} \cdot \frac{DCD\ area\ treated}{Total\ area\ of\ dairy}\right)$$

The appropriate weighting factor is then used as an additional multiplier in the current methodology for calculating indirect and direct emissions of N_2O from grazed pastures. The calculations use a modified $EF_{3(PRP)}$ of 0.0099 and $Frac_{LEACH}$ of 0.0696 for the dairy grazing area in the months that the inhibitor is applied (May to September). The modified emission factors (see table 5.5.7) are based on information from Statistics New Zealand's Agricultural Production survey that 2.9 per cent of the effective dairying area in New Zealand received the inhibitor in 2012.

Activity data on livestock numbers come from the Agricultural Production survey. The inhibitor is applied to pastures based on good management practice to maximise N_2O emission reductions. This is an application rate of 10 kilograms per hectare, applied twice per year in autumn and early spring within seven days of the application of animal excreta. 'Good practice' application methods of DCD can be by slurry or DCD-coated granule.

Mitigation estimates for calendar years 2007 to 2012 are shown in table 5.5.7.

Table 5.5.7   **Emission factors, parameters and mitigation for New Zealand's DCD inhibitor calculations from 2007 to 2012**

	2007	2008	2009	2010	2011	2012
Percentage of dairy area applied with inhibitor	3.5	4.5	3.1	2.2	3.0	2.9
Final modified emission factor or parameter, $EF_{3(PRP)}$ (kg N_2O-N/kg N)	0.00992	0.00990	0.00993	0.00995	0.00993	0.00994
Final modified emission factor or parameter, $Frac_{LEACH}$ (kg N_2O-N/kg N)	0.06957	0.06944	0.06962	0.06973	0.06963	0.06964
Mitigation (Gg CO_2-e)	18.7	25.4	18.3	13.7	19.5	19.6

Note: $EF_{3(PRP)} = 0.01$ and $FRAC_{LEACH} = 0.07$ when inhibitor is not applied. All other emission factors and parameters relating to animal excreta and fertiliser use ($Frac_{GASM}$, $Frac_{GASF}$, EF_4 and EF_5) remain unchanged when the inhibitor is used as an N_2O mitigation technology.

5.5.3   Uncertainties and time-series consistency

To ensure consistency in the calculations involving animal manure, a single livestock population characterisation and feed-intake estimate is produced by the Tier 2 model for the major livestock categories. This is used in different parts of the calculations for the inventory to estimate: CH_4 emissions for the *Enteric fermentation* category, CH_4 and N_2O emissions for the *Manure management* category and N_2O emissions for the *Urine and dung deposited by grazing animals* (grazing manure) category.

Uncertainties in N_2O emissions from *Agricultural soils* are calculated using an analytical method developed by Kelliher et al. (2017). This method estimated the uncertainty of the *Agricultural soils* category to be ±55.4 per cent for 2016.

The benefit of using the analytical method is that it can be updated annually by the Agriculture sector inventory compilers. Kelliher et al. (2017) also compared the analytical method with the previously used Monte Carlo method and found that both produced similar results.

Uncertainties were assessed for the 1990, 2002 and 2012 inventories using the Monte Carlo method. For the 1990 and 2002 inventories, the uncertainties were assessed using a Monte Carlo simulation of 5,000 scenarios with the @RISK software (Kelliher et al., unpublished(c)) (see table 5.5.8). For the 2012 inventory, the uncertainty in the annual estimate was calculated using the 95 per cent confidence interval determined from the 2002 Monte Carlo simulation as a percentage of the mean value (i.e., in 2002, the uncertainty in annual emissions was +74 per cent and –42 per cent).

Table 5.5.8   New Zealand's uncertainties in nitrous oxide (N_2O) emissions from Agricultural soils for 1990, 2002, 2012 and 2016 estimated using Monte Carlo simulation (1990, 2002), the 95 per cent confidence interval (2012) and the analytical method (2016)

Year	N_2O emissions from Agricultural soils (kt/annum)	95% confidence interval minimum (kt/annum)	95% confidence interval maximum (kt/annum)
1990	25.3	14.7	44.0
2002	32.2	18.7	56.0
2012	33.4	19.3	58.0
2016	28.8	20.7	37.0

Note: The N_2O emissions listed for each year were calculated based on the reporting rules and methodologies used at that time.

The overall inventory uncertainty analysis shown in annex 2 demonstrates that the uncertainty in annual emissions from *Agricultural soils* is a major contributor to uncertainty in New Zealand's total greenhouse gas emissions and to the uncertainty in the trend from 1990. The uncertainty between years was assumed to be correlated. Therefore, the uncertainty is mostly associated with the emission factors, with the uncertainty associated with the trend being much lower than the uncertainty for an annual estimate. The uncertainty in emissions from *Agricultural soils* is largely due to the parameter $EF_{3(PRP)}$ and emissions from urine and dung deposited by grazing animals. This uncertainty reflects natural variance in EF_3 due to weather, climate and soil type (Kelliher et al., unpublished(c)).

5.5.4   Source-specific QA/QC and verification

In preparation for this inventory submission, the data underwent Tier 1 and Tier 2 quality checks.

Verification of activity data

Research has been carried out to verify the activity data for crops. In 2008 and 2011, the Ministry for Primary Industries commissioned reports investigating N_2O emission factors and activity data for crops (Thomas et al., 2008, 2011). The reports compared activity data from Statistics New Zealand's Agricultural Production survey with the Foundation for Arable Research production database. Data for wheat and maize between the two data sources were very similar, although there were differences for some of the other crops.

The accuracy of synthetic nitrogen fertiliser data has also been assessed by comparing fertiliser sales data received from the Fertiliser Association of New Zealand with data collected from the Agricultural Production survey.

The Fertiliser Association sales data are used rather than the Agricultural Production survey data because the sales data are considered to be more accurate. Around 98 per cent of New Zealand synthetic nitrogen fertiliser is provided by two large companies that provide sales data to the Fertiliser Association. The Fertiliser Association provides an estimate of the additional synthetic nitrogen fertiliser sold by other companies (2 per cent). In contrast, the Agricultural Production survey data is collected from around 35,000 individual farmers. There are a large number of differently named fertilisers, and the survey respondents often have difficulty filling in the fertiliser component in the annual questionnaire. Some farmers use contract fertiliser spreading companies (including aerial spreading) and may not have an accurate estimate of the tonnes of fertiliser applied. The Agricultural Production census and survey data verified the long-term trend of the increasing use of synthetic nitrogen fertiliser.

Table 5.5.9 compares New Zealand's IEFs for EF_1 (synthetic nitrogen fertiliser) and $EF_{3(PRP)}$ (urine and dung deposited by grazing animals) with the 2006 IPCC default values and emission factors used by Australia. The New Zealand EF_1 value is lower than the IPCC default. This reflects New Zealand's country-specific emission factor for urea fertiliser and the incorporation of effect of urease inhibitors. For EF_3, the New Zealand value is lower than the IPCC default. This reflects research that has developed country-specific emission factors for dung and urine.

Table 5.5.9 **Comparison of New Zealand's implied emission factors (IEFs) for EF$_1$ (synthetic nitrogen fertiliser) and EF$_{3(PRP)}$ (grazing manure) with the IPCC default and the Australian-specific value**

	EF$_1$ (kg N$_2$O-N/kg N)	EF$_3$ (kg N$_2$O-N/kg N excreted)
IPCC (2006) developed temperate climate/Oceania default value	0.01	0.02 (cattle, poultry and pigs) 0.01 (sheep and other animals)
Australian-specific IEF 2015 value	0.004	0.004
New Zealand-specific IEF 2016 value	0.007	0.008

Source: UNFCCC (http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_ submissions/items/10116.php)

Table 5.5.10 compares the New Zealand-specific values Frac$_{GASF}$, Frac$_{GASM}$ and Frac$_{LEACH-H}$ with the 2006 IPCC default and fractions used by Australia. New Zealand has taken a country-specific value for Frac$_{GASF}$ of 0.1, and it is the same as the IPCC default and that of Australia. Research showed that the 0.1 value was appropriate for New Zealand conditions (Sherlock et al., 2008).

However, research showed that the default value of 0.2 for Frac$_{GASM}$ was too high and, therefore, New Zealand has a lower value of 0.1. It was adopted after an extensive review of scientific literature (Sherlock et al., 2008) and was also confirmed by subsequent field experiments (Laubach et al., 2012). The reduction in Frac$_{GASM}$ is due to the proportion of the different sources that make up this value. In New Zealand, 96.9 per cent of all animal excreta is deposited onto pasture and only 3.1 per cent is managed. In contrast, the 2006 IPCC default value was calculated taking into account a much higher percentage of manure management and storage. Manure management and storage result in a much higher proportion of nitrogen being volatilised and, hence, the higher Frac$_{GASM}$ for the default value compared with the country-specific New Zealand value.

New Zealand also has a much lower value of Frac$_{LEACH-H}$. Research suggests that New Zealand applies a much lower rate of nitrogen fertiliser than what was assumed when the IPCC default value was developed (Thomas et al., unpublished, 2005). When the OVERSEER® nutrient budget model (Wheeler et al., 2003) took this lower rate into account, the rate of leaching was much lower than when compared with farms with a high nitrogen fertiliser rate, which can be typical in other developed countries.

Table 5.5.10 **Comparison of New Zealand's country-specific factors for volatilisation (Frac$_{GASF}$, Frac$_{GASM}$) and leaching and run-off (Frac$_{LEACH-(H)}$) with the IPCC default value and the Australian implied emission factor (IEF)**

	Frac$_{GASF}$ (kg NH$_3$-N and NO$_x$-N/kg of N input)	Frac$_{GASM}$ (kg NH$_3$-N and NO$_x$-N/kg of N excreted)	Frac$_{LEACH-(H)}$ (kg N/kg fertiliser or manure N)
IPCC (2006) default value	0.1	0.2	0.3
Australian-specific 2015 value	0.1	0.2	0.3
New Zealand-specific IEF 2016 value	0.1	0.1	0.07

Source: UNFCCC (http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_ submissions/items/10116.php)

5.5.5 Source-specific recalculations

Emissions estimates have also been updated with the latest available activity data from the sources described in section 5.1.4.

Correction of calculation for nitrogen retained in wool

In 2017 it was found that the 2017 (1990–2015) version of the inventory model was overestimating the amount of nitrogen retained in the production of wool by sheep by a factor of ten. This error caused estimates of nitrogen excretion for sheep to be lower than they should have been, resulting in lower estimates of N_2O emissions from sheep dung and urine. This has now been corrected and applied to all years.

The correction of this error caused estimated emissions from *Agricultural soils* to increase by 28.8 per cent in 1990 and 8.6 per cent in 2016 (see table 5.5.11). The large fall in the sheep population between 1990 and 2016 (see figure 5.1.3b) helps explain the difference between the 1990 change and the 2016 change.

Table 5.5.11 **Comparison of current and previous emissions estimates before and after nitrogen wool correction, 1990 to 2016**

Emissions (kt CO₂-e)		1990	2016	Change in emission outputs between 1990 and 2016 (kt CO₂-e)	Percentage change in emission outputs between 1990 and 2016
Total emissions from Agricultural soils (kt CO₂-e)	2018 (1990–2016) emissions estimate *without* nitrogen wool correction	5,200.9	7,911.5	2,710.6	52.1
	2018 (1990–2016) emissions estimate *with* nitrogen wool correction	6,697.5	8,593.3	1,895.8	28.3
	Difference in emission estimates compared with current inventory	1,496.6	681.8	−814.8	
	Percentage difference in emission estimates	28.8	8.6		

5.5.6 Source-specific planned improvements

New Zealand is carrying out ongoing research to improve estimates of emissions from the *Agricultural soils* category.

New methodology for nitrous oxide emissions on hill country

New Zealand scientists have been researching the effects of hill slope on N_2O emissions from animal excreta and developing a methodology to incorporate this into the inventory (Giltrap and Saggar, unpublished). Research has confirmed that emissions of N_2O from excreta (dung and urine) applied to sloping hill pastoral land are significantly lower than those from excreta deposited on flat pastoral land. In New Zealand, sheep, non-dairy (beef) cattle and deer are generally grazed on hill country with sloping pastures. Dairy cattle may also be grazed on low sloping pasture.

The new methodology will factor in the effect of slope and delineate between *Non-dairy cattle*, *Sheep* and *Deer* livestock categories. Currently, work is under way to collect further data to improve the robustness of the emission factors on the different slope classes and different animal species (see below).

Field trials for nitrous oxide emissions from cattle

Research is under way to collect field data to improve the emission factor for excreta on pasture (EF_3). This involves field trials to measure N_2O emissions from both dairy and non-dairy cattle, focusing on slope classes that are under-represented in the current hill-country data set. This work is due for completion in 2018.

Partitioning nitrogen in excreta between dung and urine

Research has shown that nitrogen in urine and dung has different emission factors when converted to N_2O (Luo et al. 2009). An assessment of the current method used to partition nitrogen in urine and dung found that a new methodology would provide a more robust prediction. Further research is planned for 2018 that will assess a new method used to partition nitrogen in excreta between dung and urine.

5.6 Prescribed burning of savanna (CRF 3.E)

5.6.1 Description

Prescribed burning of savanna is reported under the LULUCF sector from the 2016 submission onwards.

5.7 Field burning of agricultural residues (CRF 3.F)

5.7.1 Description

Burning of agricultural residues produced 24.0 kt CO_2-e (0.1 per cent of emissions from the Agriculture sector) in 2016. This was a decrease of 3.3 kt CO_2-e (18.1 per cent) below the level of 27.4 kt CO_2-e in 1990. Burning of agricultural residues was not identified as a key category in 2016.

New Zealand reports emissions from burning barley, wheat and oats residue in this category. Maize, legume and other crop residues are not usually burned in New Zealand.

The area of burning of residues varies between years due to climatic conditions and the amount of residue removed before burning straw (Thomas et al., 2011). Burning of crop residues is not considered to be a net source of CO_2, because the CO_2 released into the atmosphere was absorbed by those crops earlier in the year. However, burning is a source of emissions of CH_4, carbon monoxide (CO), N_2O and NO_x (IPCC, 2006).

5.7.2 Methodological issues

The emissions from burning agricultural residues are estimated using country-specific methodology and parameters (Thomas et al., 2008, 2011). A modification of the IPCC (1996) methodology takes into account differences in the available crop activity data between 1990–2004 and 2005–16.

Following the IPCC (1996) methodology, CH_4, CO, N_2O and NO_x emissions are calculated from the carbon and nitrogen released from the burned live and dead biomass residue using the ratios in table 5.7.1; the nitrogen released is derived from the carbon released using a carbon-to-nitrogen ratio.

Table 5.7.1   Emission ratios for agricultural residue burning

Gas	Emission ratio (Revised IPCC 1996 Guidelines)	Conversion ratio from carbon or nitrogen to specified greenhouse gas (Revised IPCC 1996 Guidelines)
CH_4	0.005	16/12
CO	0.06	28/12
N_2O	0.007	44/28
NO_x	0.121	46/14

The total emissions (CH_4, CO, N_2O and NO_x) are calculated:

$$Emissions_{BURN} = AG_{BURN} \cdot Frac_{OX} \cdot ER \cdot GCR$$

Where: AG_{BURN} is the above-ground biomass burned (kt)

$Frac_{OX}$ is the fraction oxidised (see table 5.7.2)

ER is the gas-specific emission ratio, and

GCR is the gas-conversion ratio (see table 5.7.1).

The calculation for AG_{BURN} is different for the 1990 to 2004 years and the 2005 to 2016 years to account for changes in the availability of activity data over this period. Statistics New Zealand did not collect data on crop residue burning prior to 2005. Therefore, from 1990 to 2004, calculation of the amount of biomass residue burned (AG_{BURN}) is based on the total mass of crop production (from the Statistics New Zealand Agricultural Production census and survey) and assumed fractions burned for each crop, where:

$$AG_{BURN} = AG_{DM} \cdot Frac_{AREA-BURN} \cdot Frac_{RESIDUE} \cdot Frac_{BURN} \cdot 10^{-3}$$

Where: AG_{DM} is the above-ground residue (defined below)

$Frac_{AREA-BURN}$ is the proportion of crop area burned of the total production area (discussed further below)

$Frac_{RESIDUE}$ is the proportion of residue remaining after harvest (see table 5.7.2), and

$Frac_{BURN}$ is the proportion of remaining residue burned (see table 5.7.2).

The above-ground residue, AG_{DM} (tonnes), is:

$$AG_{DM} = \frac{Prod_{DM}}{HI} - Prod_{DM}$$

Where: HI is the harvest index (crop-specific, table 5.7.2), that is, the mass harvested over the total mass of above-ground biomass.

The dry matter, $Prod_{DM}$ (tonnes), available to be burned is:

$$Prod_{DM} = Crop_{PROD} \cdot Frac_{DM}$$

Where: $Crop_{PROD}$ is the annual crop production (tonnes) (Statistics New Zealand Agricultural Production census and survey), and

$Frac_{DM}$ is the fraction of crop that is dry matter (crop specific, table 5.7.2).

Table 5.7.2   Values used to calculate New Zealand emissions from burning of agricultural residues

	Barley	Wheat	Oats
Fraction oxidised	0.9	0.9	0.9
Residue remaining in field	1	1	1
Fraction of residue actually burned	0.7	0.7	0.7
Harvest index	0.46	0.41	0.30
Dry-matter fraction	0.86	0.86	0.86
Fraction of nitrogen in biomass	0.005	0.005	0.005
Fraction of carbon in biomass	0.4567	0.4853	0.4567

Source: Thomas et al. (2011)

From 2005 to 2016, calculation of the amount of biomass residue burned is based on collected information about the area of crop residue burning from the Statistics New Zealand Agricultural Production census and survey. These are the first New Zealand-wide data for the area of crop residues burned.

Biomass burned after 2004, AG_{BURN} (as previously defined), is:

$$AG_{BURN} = AG_{DM} \cdot Frac_{RESIDUE} \cdot Frac_{BURN} \cdot 10^{-3}$$

Where: AG_{DM} is the amount of above-ground residue (tonnes)

$Frac_{RESIDUE}$ is the proportion of residue remaining after harvest (see table 5.7.2), and

$Frac_{BURN}$ is the proportion of remaining residue burned.

The above-ground residue, AG_{DM} (tonnes), is:

$$AG_{DM} = \frac{Prod_{DM}}{HI} - Prod_{DM}$$

Where: HI is the harvest index (crop specific, table 5.7.2); that is, the mass harvested over the total mass of above-ground biomass, and

$Prod_{DM}$ (measured in tonnes) is the dry-matter production of the area burned and is determined as follows:

$$Prod_{DM} = Area_{BURN} \cdot Y \cdot Frac_{DM}$$

Where: $Area_{BURN}$ is the annual area burned (hectare)

Y is the average crop yield (tonnes per hectare), and

$Frac_{DM}$ is the fraction of crop that is dry matter (crop specific, table 5.7.2).

The country-specific parameters for the proportion of residue actually burned, harvest indices, dry-matter fractions, the fraction oxidised and the carbon and nitrogen fractions of the residue (see table 5.7.2) are derived from the OVERSEER® nutrient budget model for New Zealand (Wheeler et al., 2003) and are the same as those used for estimates of emissions from crop residues (see section 5.5.2). Further detail is provided in Thomas et al. (2011).

The recommended proportion of crop area burned for 1990 to 2004 was determined by a farmer survey and assumed to be 70 per cent of wheat, 50 per cent of barley and 50 per cent of oat crops (Thomas et al., 2011). These values are in alignment with Statistics New Zealand data for 2005–07 (2005 being the first year Statistics New Zealand gathered these data) and are, therefore, applied to the years 1990–2004. From 2005, data on the total area of crop residues burned in New Zealand were collected but, while the data show total residue burned at a regional and national level, they do not differentiate between cereal crop types.

For 2005 onwards, the same proportions of crop area burned for wheat (70 per cent), barley (50 per cent) and oats (50 per cent) were used. However, these areas were then multiplied by a constant factor K such that the total area burned is consistent with the Agricultural Production survey. This captures year-to-year variability, such as reduced burning during very dry years.

$$K = \frac{Total\ Area\ Burnt}{0.7 \times Area\ Burnt_{Wheat} + 0.5 \times Area\ Burnt_{Barley} + 0.5 \times Area\ Burnt_{Oats}}$$

Expert opinion suggests that, if crop residue is to be burned, there is generally no prior removal for feed and bedding. Therefore, 100 per cent of residue is left for burning after the harvested proportion has been removed (i.e., $Frac_{REMOVE}$ is assumed to be zero; Thomas et al., 2011). This is consistent with section 5.5.2.

5.7.3   Uncertainties and time-series consistency

The fraction of agricultural residue burned in the field was considered to make the largest contribution to uncertainty in the estimated emissions. Expert opinion for the fraction of crops burned in fields between 1990 and 2004 was taken from farmer surveys in the Canterbury area, where 80 per cent of cereal production occurs. Between 2005 and 2009, an average of 86 per cent of total residue burning occurred in Canterbury. Estimates of crop burning for 2016 were 37.5 per cent and have ranged from a high in 2006 of 61.5 per cent to a low in 2015 of 29.3 per cent, reflecting variations in annual weather patterns.

The country-specific values for these parameters are those from the OVERSEER® nutrient budget model for New Zealand (Wheeler et al., 2003) and are the same as those used for estimates of emissions from crop residues. This provides consistency between the two emissions estimates for crop residue and crop burning.

IPCC good practice guidance suggests that an estimate of 10 per cent of residue burned may be appropriate for developed countries but also notes that the IPCC default values: "are very speculative and should be used with caution. The actual percentage burned varies substantially by country and crop type. This is an area where locally developed, country-specific data are highly desirable" (IPCC, 2000). The proportion of residue actually burned has been estimated as 70 per cent for the years 1990 to 2004 because this takes into account required fire break areas and differences in the methods used. It is also assumed that the farmers will generally be aiming to have as close to complete combustion as possible.

Although country-specific parameters have been developed, a conservative approach to uncertainty is taken, using the IPCC (2000) value of ±20.0 per cent. Given that emissions from field burning are low, compared with the rest of Agriculture inventory, the uncertainties from field burning have little impact on total emission uncertainties.

5.7.4   Source-specific QA/QC and verification

Plant and Food Research reviewed the implementation of the methodology to estimate emissions of N_2O from crop residues, nitrogen-fixing crops and field burning of agricultural residues. This analysis is detailed in Thomas et al. (2008, 2011).

5.7.5   Source-specific recalculations

One improvement was made to the estimation of emissions from *Field burning of agricultural residues*. The following paragraphs and section 10.1.3 explain this improvement in more detail.

Calculation of areas burned after harvest

This improvement relates to the estimation of the areas of crops between 2005 and 2016 that are burned after harvest, for barley, oats and wheat. This is a critical part of estimating emissions from field burning.

The improvement was undertaken because a severe drought in 2015 uncovered shortcomings with the current crop burning area methodology. The improvement was proposed at the 2017 Agricultural Inventory Advisory Panel meeting, and panel members recommended that it be incorporated into the inventory.

The implementation of this improvement caused estimated emissions from *Field burning of agricultural residues* to decrease by 2.5 kt CO_2-e (9.4 per cent) in 2016 (see table 5.7.3). Emissions in 1990 are unaffected, because a different method is used to estimate crop burning areas between 1990 and 2004 (due to a lack of data collection on crop burning before 2005), which is still regarded as robust given the available data.

Table 5.7.3   **Effect of crop burning area methodology improvement on field burning emissions estimates**

Emissions (kt CO_2-e)		1990	2016	Change in emission outputs between 1990 and 2016 (kt CO_2-e)	Percentage change in emission outputs between 1990 and 2016
Total emissions from field burning (kt CO_2-e)	2018 (1990–2016) emissions estimate *before* crop burning area improvement	27.4	26.5	–0.9	–3.1
	2018 (1990–2016) emissions estimate *after* crop burning area improvement	27.4	24.0	–3.3	–12.2
	Difference in emission estimates compared with current inventory	0	–2.5	–2.5	
Per cent	Percentage difference in emission estimates	0	–9.4		

This improvement also affects *Agricultural soils* emissions slightly as changes in crop burning areas also affect the amount of crop residues that are left to decay. However, the effect of this change on *Agricultural soils* is very small (less than 0.01 per cent), as emissions caused by the decay of crop residues make up only a small proportion of emissions from the *Agricultural soils* category.

5.7.6   Source-specific planned improvements

No improvements are currently planned.

5.8   Liming (CRF 3.G)

5.8.1   Description

In New Zealand, lime and dolomite fertilisers are mainly applied to acidic grassland and cropland soils to reduce soil acidity and to maintain or increase production of pasture and crops. Prior to the 2015 submission, emissions from lime and dolomite fertilisers were reported under the LULUCF chapter (see chapter 6).

Emissions from the application of lime produced 514.4 kt CO_2 in 2016. This was an increase of 154.3 kt CO_2 (42.9 per cent) above the level of 360.1 kt CO_2 in 1990. In 2016, emissions from the application of lime contributed 1.3 per cent of New Zealand's total agricultural emissions and 0.7 per cent of New Zealand's gross greenhouse gas emissions. *Liming* was identified as a key category for the Agriculture sector in 2016 (level assessment).

5.8.2   Methodological issues

Data on agricultural lime (limestone and dolomite) application are collected by Statistics New Zealand, as a part of its five-yearly Agricultural Production census and survey. Analysis of the data indicates that, each year, around 90 per cent of agricultural lime used in New Zealand is applied to grassland, with the remaining 10 per cent applied to cropland.

There is no country-specific methodology on CO_2 emissions from liming and dolomite fertilisers that has been developed in New Zealand. Emissions associated with liming are estimated by following the Tier 1 methodology (equation 11.12; IPCC, 2006), using default emission factors for carbon conversion of 0.12 and 0.13 for limestone and dolomite respectively.

5.8.3   Activity data

Due to availability, limestone application is more common than dolomite application in New Zealand. Limestone occurs widely in New Zealand whereas dolomite is only available from a smaller, localised source. Activity data sourced from the Statistics New Zealand Agricultural Production census shows that limestone application has declined since 2002, while dolomite use peaked in 2010 and has fallen since then. The quantity of lime applied as limestone and dolomite varies each year and is influenced by a number of factors, including farm profitability (see figures 5.8.1 and 5.8.2).

Figure 5.8.1   Limestone usage on agricultural land in New Zealand from 1990 to 2016
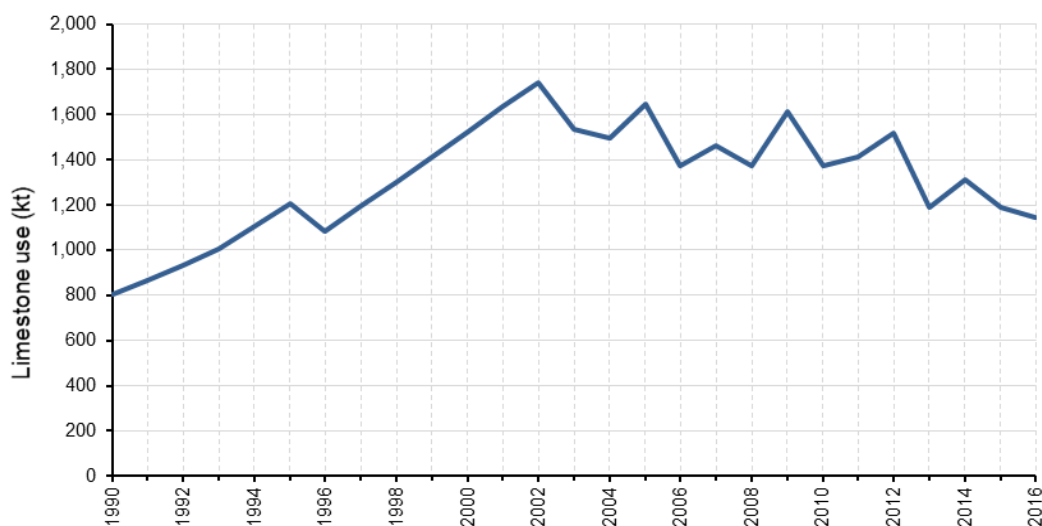
Figure 5.8.2   Dolomite usage on agricultural land in New Zealand from 1990 to 2016
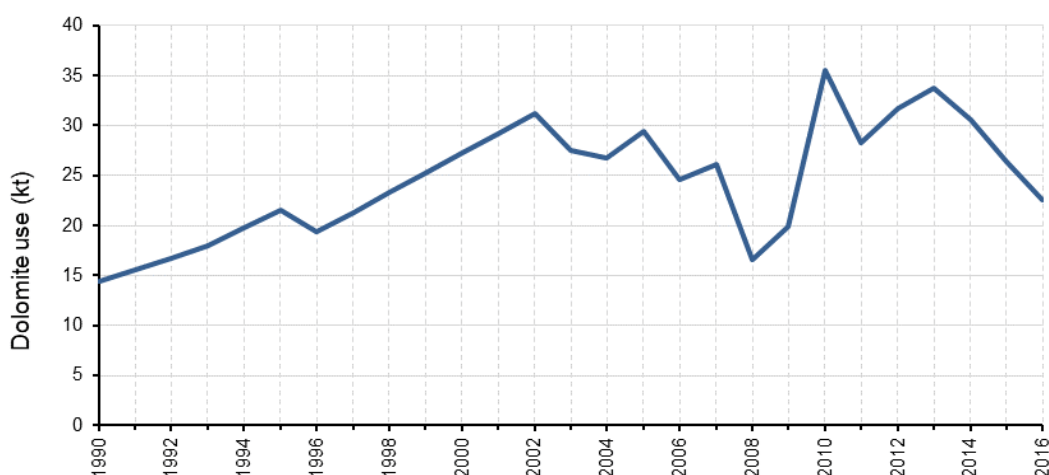
5.8.4   Uncertainties and time-series consistency

Using the IPCC (2006) Tier 1 methodology, default emission factors are used, which assume conservatively that all carbon in lime is emitted as CO_2 into the atmosphere. The default emission factors are assumed certain, given this assumption.

The Agricultural Production census and survey data used in the inventory have gaps in the time series: no data are available for 1991 or between 1997 and 2001. In the absence of other supporting data, linear interpolation has been used to estimate the data for these years.

5.8.5   Source-specific QA/QC and verification

In the preparation of this inventory, the data for *Liming* underwent Tier 1 quality checks. Statistics New Zealand, the agency that collects the activity data for *Liming*, also carries out a series of quality-assurance and quality-control procedures as part of the data collection carried out each year.

5.8.6   Source-specific recalculations

No changes in activity data for lime and dolomite fertilisers were reported and therefore no source-specific recalculations were performed for *Liming* in 2016.

5.8.7   Source-specific planned improvements

New Zealand will continue to update activity data on *Liming* as the data become available from Statistics New Zealand. No other future improvements are currently planned.

5.9   Urea application (CRF 3.H)

5.9.1   Description

Urea fertiliser accounts for the majority of synthetic nitrogen fertiliser used in New Zealand. It is mainly applied to dairy pasture land to boost pasture growth during the autumn and spring months.

Carbon dioxide emissions from the application of urea produced 574.4 kt CO_2 in 2016. This was an increase of approximately 1,365.5 per cent above the level of 39.2 kt CO_2 in 1990. *Urea application* was identified as a key category for the Agriculture sector in 2016 (level and trend assessment). Emissions from the application of urea contributed 1.5 per cent of New Zealand's total agricultural emissions and 0.7 per cent of New Zealand's gross greenhouse gas emissions.

5.9.2   Methodological issues

There is no country-specific methodology on CO_2 emissions from *Urea application* for New Zealand. Emissions associated with the application of urea are estimated using a Tier 1 methodology (equation 11.13; IPCC, 2006), using the default emission factor for carbon conversion of 0.20.

Research into urease inhibitors (see section 5.5.2) has demonstrated that they are effective in slowing down the activity of the urease enzyme that hydrolyses urea to ammonium (as reported in section 5.5.2), but they do not reduce the release of CO_2 (S Saggar, pers. comm., 2014).

5.9.3   Activity data

Data on synthetic nitrogen fertiliser use are provided by the Fertiliser Association of New Zealand from sales records for 1990 to 2016. Data on the percentage of synthetic nitrogen fertiliser derived from urea are sourced from the International Fertilizer Industry Association online database and are used to calculate the amount of applied urea fertiliser. There has been a substantial increase in elemental nitrogen applied to agricultural land as urea fertiliser, from 24,586 tonnes in 1990 to 360,300 tonnes in 2016. This is consistent with the increase in the total amount of synthetic nitrogen fertiliser, which is now six times greater than that used in 1990 (see reporting on *Agricultural soils* category and figure 5.5.2). This is also consistent with the increase in the proportion of urea fertiliser applied to agricultural land and has increased since 1990 from around 41 per cent to 83 per cent of all synthetic nitrogen fertilisers applied to agricultural soils.

5.9.4   Uncertainties and time-series consistency

Under the IPCC (2006) Tier 1 methodology, the default emission factors are used, which assume conservatively that all carbon in the urea is emitted as CO_2 into the atmosphere. The default emission factor is assumed certain, given this assumption.

Sales data for synthetic nitrogen fertiliser have been supplied for all years by the Fertiliser Association of New Zealand, but the uncertainties in this data are not known.

5.9.5   Source-specific QA/QC and verification

In the preparation of this inventory, the data for urea fertiliser underwent Tier 1 quality checks. The Fertiliser Association of New Zealand, the organisation that collects the sales activity information for synthetic nitrogen fertiliser, also carries out a series of quality-assurance and quality-control procedures as a part of the data collection carried out each year.

5.9.6   Source-specific recalculations

No recalculations have been performed for CO_2 emissions from urea in the 2018 submission.

5.9.7 Source-specific planned improvements

New Zealand will continue to update activity on urea as the data become available from the Fertiliser Association of New Zealand.

5.10 Other carbon-containing fertilisers (CRF 3.I)

5.10.1 Description

The IPCC (2006) Guidelines do not provide guidance for reporting on other carbon-containing fertilisers. Other carbon-containing synthetic fertilisers besides limestone, dolomite and urea (see sections 5.8 and 5.9) are not applied to agricultural land in New Zealand (T van der Weerden and C de Klein, pers. comm., 2015).

Chapter 5: References

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Chapter 6: Land Use, Land-Use Change and Forestry (LULUCF)

6.1 Sector overview

Emissions summary

2016

In 2016 net emissions by the Land Use, Land-Use Change and Forestry (LULUCF) sector were –22,773.7 kilotonnes carbon dioxide equivalent (kt CO_2-e). This comprises net removals of 22,964.7 kt CO_2, emissions of 99.6 kt CO_2-e of methane (CH_4) and 91.4 kt CO_2-e of nitrous oxide (N_2O). The category contributing the most to both removals and emissions is *Forest land remaining forest land*. This is because large removals result from the growth of all forests on this land and there are also large emissions from the sustainable harvest of New Zealand's plantation forests.

1990–2016

Net emissions in 2016 have increased by 6,765.8 kt CO_2-e (22.9 per cent) from the 1990 level of –29,539.5 kt CO_2-e (see table 6.1.1, and figures 6.1.1 and 6.1.2). This is largely due to the increased harvest rate that is occurring in plantation forests as a larger proportion of the estate is at harvest age when compared with the 1990 rate. Increased emissions in the *Grassland* category are primarily due to the conversion of plantation forests to grassland that has been occurring since 2003. The biomass emissions from land-use change are reported in the *Land converted to* category from the year of the event; changes in the mineral soil carbon stock are estimated as occurring over a 20-year period.

Table 6.1.1 New Zealand's greenhouse gas emissions for the LULUCF sector by land use category in 1990 and 2016

Land use category	Emissions (kt CO_2-e)		Difference (kt CO_2-e)	Change (%)
	1990	2016	1990–2016	1990–2016
Forest land	–28,909.3	–21,845.9	7,063.4	24.4
Cropland	476.8	418.9	–57.9	–12.1
Grassland	896.7	4,464.3	3,567.6	397.8
Wetlands	–10.9	20.0	30.9	282.6
Settlements	67.7	78.9	11.1	16.4
Other land	12.4	36.6	24.2	195.2
Harvested wood products	–2,072.9	–5,946.4	–3,873.5	–186.9
Total LULUCF	**–29,539.5**	**–22,773.7**	**6,765.8**	**22.9**

Note: Net removals are expressed as a negative value in the table to help the reader in clarifying that the value is a removal (of CO_2-e from the atmosphere) and not an emission. Columns may not total due to rounding. Percentages presented are calculated from unrounded values.

Emissions in the LULUCF sector are primarily caused by the harvest of production forests, deforestation, and the decomposition of organic material following these activities. Removals are primarily from the sequestration of carbon that occurs due to plant growth and increases in the size of the harvested wood products pool. Nitrous oxide can be emitted from the ecosystem

as a by-product of nitrification and de-nitrification, and the burning of organic matter. Other gases released during biomass burning include CH_4, carbon monoxide (CO), other oxides of nitrogen (NO_x) and non-methane volatile organic compounds (NMVOCs).

2015–2016

Net emissions from the LULUCF sector increased between 2015 and 2016 (by 2,087.4 kt CO_2-e; 8.4 per cent). The largest change occurred within the *Forest land* category as the harvest rate increased and the deforestation rate decreased between 2015 and 2016. Emissions from the *Grassland* category therefore decreased due to the reduction in deforestation. This decrease in emissions in the *Grassland* category was largely compensated for by an increase in emissions in the *Harvested wood products* category.

New Zealand has adopted the six broad categories of land use as described in the *IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4, Agriculture, Forestry and Other Land Use* (2006 IPCC Guidelines) (IPCC, 2006a), and also reports for the *Harvested wood products* category.

The land use categories *Forest land remaining forest land*, *Land converted to forest land*, *Cropland remaining cropland*, *Grassland remaining grassland*, *Land converted to grassland* and *Harvested wood products* are key categories for New Zealand in 2016.

Figure 6.1.1   New Zealand's annual emissions from the LULUCF sector from 1990 to 2016
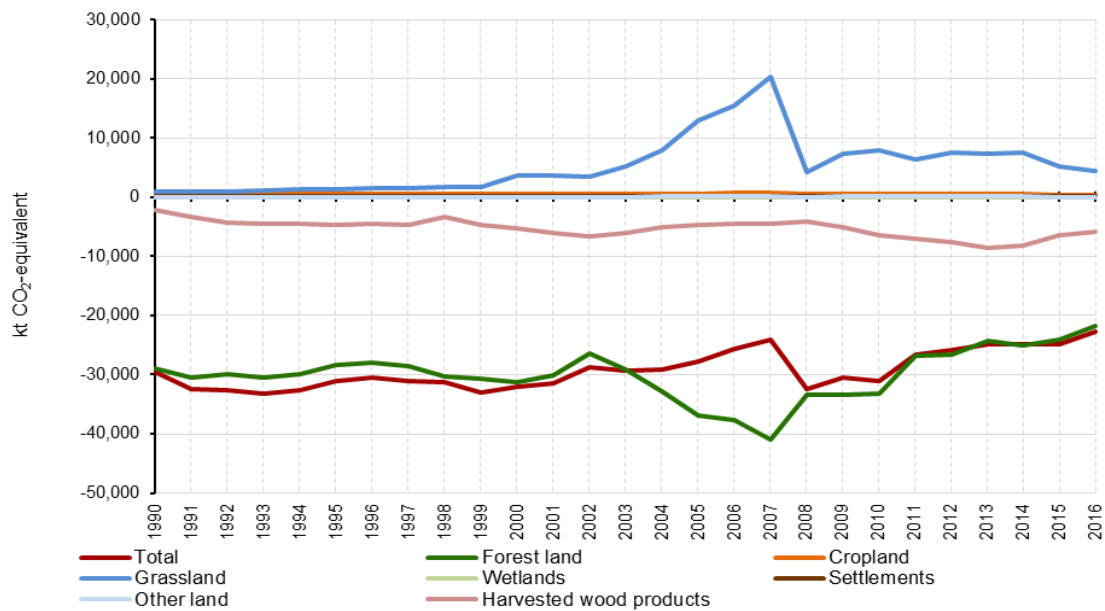
Figure 6.1.2   Change in New Zealand's emissions from the LULUCF sector from 1990 to 2016
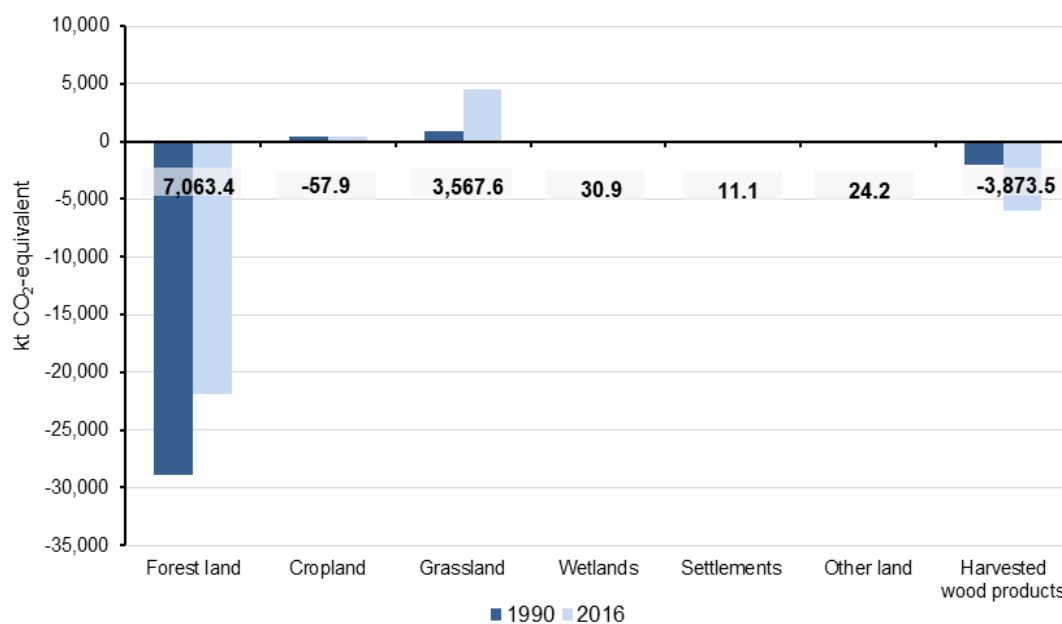
Recalculations since 2017 submission

Since the 2017 submission, there have been recalculations to the LULUCF sector emissions. Further details on these recalculations are provided in section 6.1.4 as an overview, in each relevant land use category and in chapter 10.

6.1.1   Land use, land-use change and forestry in New Zealand

New Zealand has a land area of approximately 270,000 square kilometres with extensive coastlines (19,800 kilometres). New Zealand has a temperate climate, which is highly influenced by the surrounding ocean. Sixty per cent of the land is hilly or mountainous, with many lakes and fast-flowing rivers and streams.

Since 1990, approximately 4.9 per cent of New Zealand's total land area has undergone land-use change.

Before human settlement, natural forests were New Zealand's predominant land cover, estimated at 85 per cent to 90 per cent of total land area (McGlone, 2009). In 2016, pre-1990 natural forest covers around 29.1 per cent of the total land area of New Zealand (see table 6.1.2). Nearly all lowland areas have been cleared of indigenous vegetation for agriculture, horticulture, plantation forestry and urban development. Much of the remaining indigenous vegetation, however, is now legally protected, whether in private ownership or on public conservation land.

Table 6.1.2   Land use in New Zealand in 2016

Category	Land use	Area (hectares)	Proportion of total area (%)
Forest land	Pre-1990 natural forest	7,822.4	29.1
	Pre-1990 planted forest	1,424.9	5.3
	Post-1989 forest	656.1	2.4
	Subtotal	*9,903.4*	*36.8*
Cropland	Annual	372.6	1.4
	Perennial	105.1	0.4
	Subtotal	*477.7*	*1.8*

Category	Land use	Area (hectares)	Proportion of total area (%)
Grassland	High producing	5,963.1	22.1
	Low producing	7,403.0	27.5
	With woody biomass	1,375.3	5.1
	Subtotal	*14,741.4*	*54.7*
Wetlands	Open water	538.1	2.0
	Vegetated	145.2	0.5
	Subtotal	*683.3*	*2.5*
Settlements		225.3	0.8
Other land		894.0	3.3
Total		**26,925.2**	**100.0**

Note: Areas as at 31 December 2016. This includes deforestation of post-1989 forest since 1990. Columns may not total due to rounding. Percentages presented are calculated from unrounded values.

Forestry and agriculture industries form the core of New Zealand's economy, and they are the main determinants of New Zealand's LULUCF emissions profile. Intensive forest management combined with a temperate climate, fertile soils and high rainfall means New Zealand has one of the highest rates of exotic forest growth among Annex I countries.

New Zealand's exotic forest plantation estate is intensively managed for production forestry, with rapid-growing genotypes selected and enhanced for optimum growth. In 2016 plantation forests covered approximately 2.04 million hectares – around 7.6 per cent of New Zealand's total land area. This also includes areas not managed for timber supply; for instance, areas planted for erosion control.

The terms 'post-1989' and 'pre-1990' are used throughout this inventory to distinguish between forests that existed at 1990 and those that did not. The terms 'natural' and 'planted' forest are used to distinguish between the different species compositions of the forests.

6.1.2   Methodological issues for the LULUCF sector

New Zealand uses a combination of Tier 1, Tier 2 and Tier 3 methods for estimating emissions for the LULUCF sector. A Tier 1 approach has been used to estimate carbon stock change in the four biomass pools (above-ground and below-ground biomass, dead wood and litter) for all land uses except *Forest land*, perennial cropland and grassland with woody biomass, which use Tier 2 or Tier 3 approaches.

For all land uses, Tier 1 approaches have been used to estimate carbon stock changes in organic soils, and a Tier 2 modelling approach has been used to estimate soil organic carbon changes for mineral soils.

Different methods are used to obtain emission factors when estimating emissions and removals for post-1989 natural forest and post-1989 forest planted for timber production. This ensures the different growth characteristics are reflected in the estimates. These divisions are combined into a single land use of post-1989 forest when reporting emissions in the common reporting format (CRF) tables.

Grassland with woody biomass consists of grassland areas where the cover of woody species is less than 30 per cent and/or does not meet, nor have the potential to meet, the New Zealand forest definition. The land classified as grassland with woody biomass is therefore diverse. To allow for this, the category is further subdivided into 'permanent' and 'transitional' types for

modelling the emissions from land-use change. Separate emission factors for these two types of grassland with woody biomass are derived from the Land Use and Carbon Analysis System (LUCAS) plot network (Wakelin and Beets, unpublished).

Emission factors

The emission factors required to estimate carbon stock changes are provided in tables 6.1.3 and 6.1.4. Table 6.1.3 contains biomass carbon stocks in each land use prior to conversion, and table 6.1.4 contains the annual growth in biomass carbon stock after land-use change.

Table 6.1.3   **New Zealand's biomass carbon stock emission factors in land use before conversion**

Land use category	Land use type	Reference carbon stock values (t C ha⁻¹)	Carbon pools	Reference
Forest land	Pre-1990 natural forest: shrub*	Based on an annual carbon stock yield table	All biomass pools	LUCAS plot-based estimate
	Pre-1990 natural forest: tall forest*	257.74	All biomass pools	Holdaway et al. (2016)
	Pre-1990 planted forest	Based on an age-based carbon yield table	All biomass pools	LUCAS plot-based estimate
	Post-1989 natural forest	Based on an age-based carbon yield table	All biomass pools	LUCAS plot-based estimate
	Post-1989 planted forest	Based on an age-based carbon yield table	All biomass pools	LUCAS plot-based estimate
Cropland	Annual	5	Above- and below-ground biomass	IPCC (table 5.9, 2006a)
	Perennial	18.76	Above-ground biomass	Davis and Wakelin (unpublished)
Grassland	High producing	6.345	Above- and below-ground biomass	Calculated based on table 6.4, IPCC (2006a)
	Low producing	2.867	Above- and below-ground biomass	Calculated based on table 6.4, IPCC (2006a)
	With woody biomass – transitional	13.05	All biomass pools	Wakelin and Beets (unpublished)
	With woody biomass – permanent	60.57	All biomass pools	Wakelin and Beets (unpublished)
Wetlands		0	All biomass pools	IPCC (section 7.2.1.1, 2006a)
Settlements		0	All biomass pools	IPCC (section 8.2.1.1, 2006a)
Other land		0	All biomass pools	IPCC (section 9.2, 2006a)

Note: * For conversions from natural forest, the carbon stock emitted instantaneously depends on the vegetation present (tall forest or shrub) immediately before conversion; this is described later in this section. 'All biomass pools' includes above- and below-ground biomass, litter and dead organic matter. See section 6.3 and each category-specific section under 'Methodological issues' for further details on how emissions are estimated.

Table 6.1.4 New Zealand's emission factors for annual growth in biomass carbon stock in land after conversion

Category	Land use	Annual carbon stock change (t C ha⁻¹)	Carbon stock maturity cycle	Carbon pools	Reference
Forest land	Pre-1990 natural forest	Based on net annual growth increment	NA	All biomass pools	LUCAS plot-based estimate
	Pre-1990 planted forest	Based on an age-based carbon yield table	NA	All biomass pools	LUCAS plot-based estimate
	Post-1989 natural forest	Based on an age-based carbon yield table	NA	All biomass pools	LUCAS plot-based estimate
	Post-1989 planted forest	Based on an age-based carbon yield table	NA	All biomass pools	LUCAS plot-based estimate
Cropland	Annual	5	1	Above- and below-ground biomass	IPCC (table 5.9, 2006a)
	Perennial	0.67	28	Above-ground biomass	Davis and Wakelin (unpublished)
Grassland	High producing	6.345	1	Above- and below-ground biomass	IPCC (table 6.4, 2006a)
	Low producing	2.867	1	Above- and below-ground biomass	IPCC (table 6.4, 2006a)
	With woody biomass – transitional	0.47	28	All biomass pools	Wakelin and Beets (unpublished)
	With woody biomass – permanent	NO	NA	NA	NA
Wetlands		0	NA	All biomass pools	IPCC (section 7.2.1.1, 2006a)
Settlements		0	NA	All biomass pools	IPCC (section 8.2.1.1, 2006a)
Other land		0	NA	All biomass pools	IPCC (section 9.2, 2006a)

Note: NA = not applicable; NO = not occurring. 'All biomass pools' includes above- and below-ground biomass, litter and dead organic matter.

New Zealand estimates carbon stock change for each of the five Kyoto Protocol carbon pools (to meet Kyoto Protocol reporting requirements) and aggregates the results to the three pools required for reporting under the United Nations Framework Convention on Climate Change (the Convention). Table 6.1.5 summarises the methods being used to estimate carbon (C) by pool for each land use.

Table 6.1.5   Relationships between land-use, carbon pool and method of calculation used by New Zealand

Convention reporting pool		Living biomass		Dead organic matter		Soils	
Kyoto Protocol reporting pool		Above-ground biomass	Below-ground biomass	Dead wood	Litter	Soil organic matter	
						Mineral soils	**Organic soils**
Land uses	Pre-1990 natural forest	Allometric equations	Percentage of above-ground biomass	Allometric equations	Lab analysis	Tier 2, country-specific data and model	Not applicable
	Pre-1990 natural forest [D]	Emission factor based on the vegetation type present (tall forest or shrub) before deforestation occurring since 1 January 1990					
	Pre-1990 planted forest	Age-based carbon yield table by biomass pool derived from the LUCAS plot network and the Forest Carbon Predictor model				Tier 2, country-specific data and model	IPCC Tier 1 default parameters
	Post-1989 natural forest [AR and D]	Allometric model	Percentage of above-ground biomass	Allometric model	Allometric model	Tier 2, country-specific data and model	IPCC Tier 1 default parameters
	Post-1989 planted forest [AR and D]	Age-based carbon yield table by biomass pool derived from the LUCAS plot network and the Forest Carbon Predictor model				Tier 2, country-specific data and model	IPCC Tier 1 default parameters
	Cropland – annual	IPCC Tier 1 default parameters	IPCC Tier 1 default parameters (NE)			Tier 2, country-specific data and model	IPCC Tier 1 default parameters
	Cropland – perennial	Country-specific emission factor	IPCC Tier 1 default parameters (NE)			Tier 2, country-specific data and model	IPCC Tier 1 default parameters
	Grassland (high and low producing)	IPCC Tier 1 default parameters	IPCC Tier 1 default parameters (NE)			Tier 2, country-specific data and model	IPCC Tier 1 default parameters
	Grassland with woody biomass – transitional and permanent	Country-specific emission factor				Tier 2, country-specific data and model	IPCC Tier 1 default parameters
	Wetlands	IPCC Tier 1 default parameters (NE)				Tier 2, country-specific data and model	IPCC Tier 1 default parameters
	Settlements	IPCC Tier 1 default parameter (NE)				Tier 2, country-specific data and model	Not estimated
	Other land	IPCC Tier 1 default parameter (NE)				Tier 2, country-specific data and model	Not estimated

Note: AR = afforestation/reforestation; D = deforestation; NE = not estimated. See the methodology sections for an explanation of soil carbon calculations (section 6.3) and forest models, C_Change and Forest Carbon Predictor (section 6.4.2).

Approach used to calculate deforestation emissions

Pre-1990 natural forest

As described in table 6.1.3, the methods for calculating emissions from *Forest land* differ from those that apply a single reference carbon stock value.

Estimates of deforestation emissions for pre-1990 natural forest are based on the type of vegetation deforested (tall forest or shrub). The area of natural forest deforestation is sub-classified as tall forest or shrub using spatial data on land cover.

Because stock change has been detected as statistically significant in only the shrub component of pre-1990 natural forest, the annual average carbon stock estimate for the shrub area provides the emission factor that is applied to the shrub proportion at deforestation. Tall forest is instead deforested at the average carbon stock for this type of forest because the carbon stock of this is not changing from year to year.

Table 6.1.6 shows the areas of pre-1990 natural forest deforestation split by these two types (tall forest and shrub).

Table 6.1.6   **New Zealand's areas of pre-1990 natural forest deforestation estimated by type from 1990 to 2016**

Natural forest type	Area of natural forest deforestation (ha)									
	1990–2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Tall forest	8,300	204	867	818	444	281	301	237	416	416
Shrub	26,852	703	1,718	1,077	419	409	292	94	458	458
Total	**35,153**	**907**	**2,586**	**1,894**	**863**	**689**	**594**	**332**	**874**	**874**

Note: Columns may not total due to rounding.

Pre-1990 planted forest

Deforestation emissions for pre-1990 planted forest are calculated based on the planting date estimated from historical satellite imagery. In the absence of this information, the deforestation age is based on the carbon stock of the forest at the average age at which the forests are harvested.

Post-1989 forest

Harvest and deforestation in post-1989 forests includes a mix of short rotation crops and the early harvest of longer rotation crops that have not reached their normal harvest ages. The average harvest age includes short rotation crops of around 500 hectares a year, with the remainder attributed to the early harvest of longer rotation crops. Longer rotation crops are assumed to be harvested at the oldest possible age in a given year (e.g., the age of 26 years in 2016) because they have not yet reached their normal harvest ages (i.e., 28 years or older). The deforestation age in post-1989 forests is derived from the planting date estimated from historical satellite imagery.

Calculation of national emission estimates

To calculate emissions for the New Zealand LULUCF sector, the following data are used:

- land use and land-use change area data from 1962 to 1989, which provide land in a transition state as at 1990 for each land use

- annual land use and land-use change area data from 1990 to 2016 (see section 6.2)

- biomass carbon stocks per hectare prior to land-use conversion, and annual growth in biomass carbon stocks per hectare following conversion (see tables 6.1.3 and 6.1.4)

- age-based biomass carbon yield tables for pre-1990 planted forests and post-1989 forests (see section 6.4.2)

- growth increment for pre-1990 natural forest (see section 6.4.2)

- emission factors and country-level activity data on Biomass burning (see section 6.11.5)

- IPCC default conversion factors for converting C to CO_2.

The formula used to calculate emissions from biomass changes on land-use conversion is:

$$\left(\begin{array}{c} \text{\textit{Loss of biomass}} \\ \text{\textit{present in}} \\ \text{\textit{previous crop}} \end{array} \times \begin{array}{c} \text{\textit{Activity data}} \\ \text{\textit{(Area)}} \end{array} \right) + \left(\begin{array}{c} \text{\textit{Annual growth in}} \\ \text{\textit{biomass carbon stocks}} \\ \text{\textit{in new land use}} \end{array} \times \begin{array}{c} \text{\textit{Activity data}} \\ \text{\textit{(Area)}} \end{array} \right) \quad (1)$$

The formula used to calculate emissions from mineral soil changes on land-use conversion is:

$$\frac{\begin{array}{c} \text{\textit{Mineral soil carbon at}} \\ \text{\textit{steady state in the new}} \\ \text{\textit{land use}} \end{array} - \begin{array}{c} \text{\textit{Mineral soil carbon at}} \\ \text{\textit{steady state in the previous}} \\ \text{\textit{land use}} \end{array}}{\text{\textit{20 years (transition period)}}} \times \left(\begin{array}{c} \text{\textit{Activity}} \\ \text{\textit{data}} \\ \text{\textit{(Area)}} \end{array} \right) \quad (2)$$

For example, the annual change in carbon stock in the first year of conversion of 100 hectares of low producing grassland to perennial cropland would be calculated as follows:

Biomass change $= (-2.867 \times 100) + (0.67 \times 100) = -219.7$ tonnes C *(1)*

Mineral soil change $= (((105.98 - 88.44) / 20) \times 100) = -87.7$ tonnes C *(2)*

Total carbon stock change $= -307.4$ tonnes C

Total emissions $=$ (carbon stock change $/ 1{,}000 \times -1) \times (44/12)$

Total emissions $= 1.127$ kt CO_2

Note: New Zealand follows the Tier 1 guidance in the 2006 IPCC Guidelines for calculating emissions for organic soils (IPCC, 2006a).

These calculations have been performed to produce estimates of annual carbon stock and carbon stock changes since 1990 to inform the Convention and Kyoto Protocol reporting.

New Zealand Land Use and Carbon Analysis System

New Zealand's LULUCF estimates are calculated using a programme of data collection and modelling called the Land Use and Carbon Analysis System. The LUCAS Data Management System stores, manages and retrieves data for international greenhouse gas reporting for the LULUCF sector. The Data Management System comprises: the Geospatial System, a data warehousing 'Gateway' and the Calculation and Reporting Application. These systems are used for managing the land use spatial databases and the plot and reference data, and for combining the two sets of data to calculate the numbers required for reporting under the Convention and the Kyoto Protocol. Details on these databases and applications are provided in annex 3.2.4.

6.1.3   Uncertainties in LULUCF

Uncertainty for the LULUCF sector has been calculated as 55.2 per cent. Given this uncertainty, net emissions from the LULUCF sector could range from $-10{,}199.9$ kt CO_2-e to $-35{,}347.8$ kt

CO₂-e. Table 6.1.7 shows the four land use categories within the LULUCF sector that make the greatest contribution to uncertainty in the net carbon emissions for the sector. These are given in descending order.

Table 6.1.7 Land use categories making the greatest contribution to uncertainty in the LULUCF sector

Land use category	Absolute emissions by category (kt CO₂)	Uncertainty introduced into emissions for LULUCF (%)
Pre-1990 natural forest remaining pre-1990 natural forest	6,139.3	±34.2
Pre-1990 planted forest remaining pre-1990 planted forest	1,912.7	±33.9
Harvested wood products	5,946.4	±17.8
Low producing grassland converted to post-1989 forest	11,266.5	±16.7

A Monte Carlo simulation approach was used to assess the main sources of uncertainty in carbon stock and carbon stock change in *Pre-1990 natural forest remaining pre-1990 natural forest*. The regenerating component of pre-1990 natural forest was found to be a statistically significant carbon sink, sequestering 1.39 ± 0.55 tonnes C ha^{-1} yr^{-1}. Statistically insignificant carbon change was found in the tall forest component of pre-1990 natural forest (0.34 ± 0.43 tonnes C ha^{-1} yr^{-1}) (Holdaway et al., 2016). The variation between individual plot estimates of biomass carbon change in regenerating and tall pre-1990 natural forest results in a combined uncertainty of ±126.6 per cent. Large removals in the regenerating component, coupled with large uncertainties for the category, result in this being the largest contributor to uncertainty in the LULUCF sector.

Pre-1990 planted forest remaining pre-1990 planted forest contributes the second-largest uncertainty to the LULUCF sector. The age structure of the pre-1990 planted forest estate results in large removals from growth and large emissions from harvesting, leaving a relatively small net change. The uncertainties are calculated on emissions and removals relative to net change. This results in high uncertainty introduced into emissions for LULUCF despite relatively low uncertainty in carbon stocks (±11.4 per cent).

Harvested wood products provides the third-greatest contribution to uncertainty in the LULUCF sector. This is driven by large removals in the category and relatively high uncertainty associated with the end-use and discard rates of New Zealand wood (±67.4 per cent).

Low producing grassland converted to post-1989 forest contributes the fourth-greatest level of uncertainty due to large removals from forest growth and the biomass uncertainty for this land-use conversion (±29.2 per cent).

Further details on the emission factor and activity data uncertainties for specific land uses and non-carbon emissions are given within the relevant sections of this chapter. Further detailed analysis of LULUCF uncertainties is presented in annex 3.2.3.

6.1.4 Recalculations in LULUCF

For the 2018 submission, New Zealand has recalculated its emission estimates for the LULUCF sector from 1990 to 2015 to incorporate new activity data and updated default emission factors. These recalculations have improved the accuracy, consistency and completeness of the LULUCF estimates.

As a result of the recalculations, estimates of emissions in 1990 have increased by 1.9 per cent, and emissions in 2015 have decreased by 4.5 per cent (see table 6.1.8).

Table 6.1.8   Recalculations to New Zealand's total net LULUCF emissions for 1990 and 2015

Year	Reported net emissions		Change in estimate	
	2017 submission (kt CO$_2$-e)	2018 submission (kt CO$_2$-e)	(kt CO$_2$-e)	(%)
1990	−30,122.4	−29,539.5	+582.9	+1.9
2015	−23,782.6	−24,861.1	−1,078.4	−4.5

The main differences between this submission and previous estimates of New Zealand's LULUCF emissions reported in the 2017 submission are the result of the following changes (in decreasing order of magnitude).

- New Zealand's *Harvested wood products* estimates now include market-specific activity data and emission factors for export raw materials.

- The post-1989 planted forest yield table has been revised for the 2018 submission. The revised yield table is based on three measurements of post-1989 planted forest permanent sample plots carried out in 2008–09 and 2011–12 and when making the transition to a continuous inventory in 2016. The analysis of the data collected has provided a plot-based estimate of carbon stock and mean carbon density within this forest type.

- Emissions estimates from peat extraction are reported for the first time.

- An estimate for controlled burning in *Grassland remaining grassland* is provided for the first time in this submission. This activity involves the clearance of vegetation for pasture regeneration.

- The 1990, 2008 and 2012 land use maps continue to be improved.

The impact of these recalculations on net CO$_2$-e emissions in each land use category is provided in table 6.1.9.

Table 6.1.9   Recalculations to New Zealand's net LULUCF emissions for 1990 and 2015 by category

Land use category	Net emissions (kt CO$_2$-e)				Change in 1990 estimate (%)	Change in 2015 estimate (%)
	2017 submission: 1990 estimate	2018 submission: 1990 estimate	2017 submission: 2015 estimate	2018 submission: 2015 estimate		
Forest land	−29,807.6	−28,909.3	−23,355.2	−24,068.8	+3.0	−3.1
Cropland	476.7	476.8	455.0	427.6	+0.02	−6.0
Grassland	878.5	896.7	4,652.1	5,150.0	+2.1	+10.7
Wetlands	−20.3	−10.9	1.9	18.7	+46.2	+890.6
Settlements	67.7	67.7	85.8	78.0	+0.05	−9.1
Other land	10.9	12.4	147.5	35.8	+13.3	−75.7
Harvested wood products	−1,728.2	−2,072.9	−5,769.7	−6,502.4	−19.9	−12.7
Total	**−30,122.4**	**−29,539.5**	**−23,782.6**	**−24,861.1**	**1.9**	**−4.5**

Note: Net removals are expressed as a negative value in the table to help clarify that the value is a removal (of CO$_2$-e from the atmosphere) and not an emission. Columns may not total due to rounding.

Detailed information on the recalculations is provided below in the relevant source-specific recalculations sections and in chapter 10.

6.1.5   LULUCF planned improvements

Category-specific planned improvements are reported separately under each of the relevant sections of this chapter. The major themes are to:

- continue with method development to implement the 2006 IPCC Guidelines (IPCC, 2006a). Research is currently under way to improve dead wood estimates in natural forests

- complete the 2016 land use map, including mapped deforestation for 2015 and 2016 to replace the estimates used in this submission

- revisit, for the 2019 submission, the assumption that controlled burning of post-harvest residues on afforested land does not occur, due to the increasing harvest rate in these forests as they reach maturity

- re-measure the complete planted forest plot network (pre-1990 and post-1989) on a continuous basis (at five-year intervals) from 2016. These data will be incorporated into the National Inventory Report as they become available and on a regular basis.

6.2 Representation of land areas

The total land area of New Zealand is 26,925.2 kilohectares. This includes all significant New Zealand land masses: the two main islands, the North Island and South Island, as well as Stewart Island, Great Barrier Island, Little Barrier Island, the Chatham Islands, the sub-Antarctic islands and other, small outlying islands.

New Zealand has used a combination of Reporting Methods 1 and 2, and Approaches 2 and 3 to determine land-use changes occurring between 1 January 1990 and 31 December 2016 (section 3.1.1, IPCC, 2006a). The total land use areas as at 1 January 1990, 1 January 2008 and 31 December 2012 are based on wall-to-wall mapping of satellite and aircraft remotely sensed imagery taken in, or close to the start of, 1990, 2008 and 2013 respectively, as described in section 6.2.2. The mapping of forest areas in these three maps includes improvements made up to August 2017 using aerial photography and data from the New Zealand Emissions Trading Scheme (NZ ETS). Deforestation occurring between 2008 and 2014 has been mapped by year using ancillary satellite imagery and oblique aerial photography. All other land-use changes occurring between 1990 and 2016 have been interpolated from other sources. This is described in further detail in section 6.2.3.

6.2.1 Land use category definitions

The land use categories and matching land uses New Zealand reports for are shown in table 6.2.1. These are consistent with those used for the 2016 submission.

Table 6.2.1 New Zealand's land use categories and land uses

IPCC category	New Zealand land use
Forest land	Pre-1990 natural forest
	Pre-1990 planted forest
	Post-1989 forest[1]
Cropland	Annual cropland
	Perennial cropland
Grassland	High producing grassland
	Low producing grassland
	Grassland with woody biomass
Wetlands	Open water
	Vegetated wetland
Settlements	Settlements
Other land	Other land

Note: (1) Mapped as a single land use but stratified into 'post-1989 natural forest' and 'post-1989 planted forest' for calculating carbon using data from the plot network.

The land uses were chosen for their conformance with the dominant types in New Zealand, while still enabling reporting under the land use categories specified in the 2006 IPCC Guidelines (IPCC, 2006a).

The national thresholds used by New Zealand to define *Forest land* for both the Convention and Kyoto Protocol reporting are:

- a minimum area of 1 hectare

- a crown cover of at least 30 per cent

- a minimum height of 5 metres at maturity *in situ* (Ministry for the Environment, 2006a).

The definitions of New Zealand's land uses, as they have been mapped, are provided in table 6.2.2. Further details are included in *Land Use and Carbon Analysis System: Satellite imagery interpretation guide for land use classes* (2nd edition) (Ministry for the Environment, 2012).

Table 6.2.2   New Zealand's mapping definitions for each land use

Land use	Definition
Pre-1990 natural forest	Areas that, on 1 January 1990, were and presently include: • tall indigenous forest • self-sown exotic trees, such as wilding pines and grey willows, established before 1 January 1990 • broadleaved hardwood shrubland, mānuka–kānuka (*Leptospermum scoparium–Kunzea ericoides*) shrubland and other woody shrubland (≥30 per cent cover, with potential to reach ≥5 metres at maturity *in situ* under current land management within 30–40 years) • areas of bare ground of any size that were previously forested but, due to natural disturbances (e.g., erosion, storms, fire), have temporarily lost vegetation cover • areas that were planted forest at 1990 but are subsequently managed to regenerate with natural species that will meet the forest definition • roads and tracks less than 30 metres in width and other temporarily unstocked areas associated with a forest land use.
Pre-1990 planted forest	Areas that, on 1 January 1990, were and presently include: • radiata pine (*Pinus radiata*), Douglas fir (*Pseudotsuga menziesii*), eucalypts (*Eucalyptus* spp.) or other planted species (with potential to reach ≥5 metre height at maturity *in situ*) established before 1 January 1990 or replanted on land that was forest land as at 31 December 1989 • exotic forest species that were planted after 31 December 1989 on land that was natural forest • riparian or erosion control plantings that meet the forest definition and that were planted before 1 January 1990 • harvested areas within pre-1990 planted forest (assumes these will be replanted, unless deforestation is later detected) • roads, tracks, skid sites and other temporarily unstocked areas less than 30 metres in width associated with a forest land use • areas of bare ground of any size that were previously forested at 31 December 1989 but, due to natural disturbances (e.g., erosion, storms, fire), have lost vegetation cover.
Post-1989 forest	Includes post-1989 planted forest, which consists of: • exotic forest (with the potential to reach ≥5 metre height at maturity *in situ*) planted or established on land that was non-forest land as at 31 December 1989 (e.g., radiata pine, Douglas fir, eucalypts or other planted species) • riparian or erosion control plantings that meet the forest definition and that were planted after 31 December 1989 • harvested areas within post-1989 forest land (assuming these will be replanted, unless deforestation is later detected). Includes post-1989 natural forest, which consists of: • forests arising from natural regeneration of indigenous tree species as a result of management change after 31 December 1989 • self-sown exotic trees, such as wilding conifers or grey willows, established after 31 December 1989. Includes areas within post-1989 natural forest or post-1989 planted forest that are: • roads, tracks, skid sites and other temporarily unstocked areas associated with a forest land use • areas of bare ground of any size that were previously forested (established after 31 December 1989) but, due to natural disturbances (e.g., erosion, storms, fire), have lost vegetation cover.

Land use	Definition
Annual cropland	Includes: • all annual crops • all cultivated bare ground • linear shelterbelts associated with annual cropland.
Perennial cropland	Includes: • all orchards and vineyards • linear shelterbelts associated with perennial cropland.
High producing grassland	Includes: • grassland with high-quality pasture species • linear shelterbelts that are <1 hectare in area or <30 metres in mean width (larger shelterbelts are mapped separately as grassland with woody biomass) • areas of bare ground of any size that were previously grassland but, due to natural disturbances (e.g., erosion), have lost vegetation cover.
Low producing grassland	Includes: • low-fertility grassland and tussock grasslands (e.g., *Chionochloa* and *Festuca* spp.) • mostly hill country • montane herbfields either at an altitude higher than above-timberline vegetation or where the herbfields are not mixed up with woody vegetation • linear shelterbelts that are <1 hectare in area or <30 metres in mean width (larger shelterbelts are mapped separately as grassland with woody biomass) • other areas of limited vegetation cover and significant bare soil, including erosion and coastal herbaceous sand-dune vegetation.
Grassland with woody biomass	Includes: • grassland with matagouri (*Discaria toumatou*) and sweet briar (*Rosa rubiginosa*), broadleaved hardwood shrubland (e.g., māhoe – *Melicytus ramiflorus*), wineberry (*Aristotelia serrata*), *Pseudopanax* spp., *Pittosporum* spp.), mānuka–kānuka (*Leptospermum scoparium–Kunzea ericoides*) shrubland, coastal and other woody shrubland (<5 metres tall and any percentage of cover) where, under current management or environmental conditions (climate and/or soil), it is expected that the forest criteria will not be met over a 30- to 40-year period • above-timberline shrubland vegetation intermixed with montane herbfields (does not have the potential to reach >5 metres in height *in situ*) • grassland with tall tree species (<30 per cent cover), such as golf courses in rural areas (except where the Land Cover Database has classified these as settlements) • grassland with riparian or erosion control plantings (<30 per cent cover) • linear shelterbelts that are >1 hectare in area and <30 metres in mean width • areas of bare ground of any size that previously contained grassland with woody biomass but, due to natural disturbances (e.g., erosion, fire), have lost vegetation cover.
Open water	Includes: • lakes, rivers, dams and reservoirs • estuarine–tidal areas including mangroves.
Vegetated wetland	Includes: • herbaceous and/or non-forest woody vegetation that may be periodically flooded. Includes scattered patches of tall tree-like vegetation in the wetland environment where cover reaches <30 per cent • areas under peat extraction • estuarine–tidal areas including mangroves.
Settlements	Includes: • built-up areas and impervious surfaces • grassland within 'settlements' including recreational areas, urban parklands and open spaces that do not meet the forest definition • major roading infrastructure • airports and runways • dam infrastructure • urban subdivisions under construction.
Other land	Includes: • montane rock and/or scree • river gravels, rocky outcrops, sand dunes and beaches, coastal cliffs, mines (including spoil), quarries • permanent ice and/or snow and glaciers • any other remaining land that does not fall into any of the other land use categories.

Further refinements are planned to improve New Zealand's estimates of land-use change, as stated in section 6.2.7. Land areas reported as 'converted' and 'remaining' within each land use category are the best current estimates and will be improved, should additional activity data become available.

6.2.2 Land use mapping methodology

Areas of land use and land-use change between 1990 and 2016 are based on three wall-to-wall land use maps derived from satellite imagery at nominal mapping dates of 1 January 1990, 1 January 2008 and 31 December 2012. Area information from these maps is interpolated and extrapolated to obtain a complete time series of land-use change occurring between 1990 and 2016 (see section 6.2.3).

Satellite image acquisition and pre-processing

Each of the national land use maps is based on a collection of either Landsat or SPOT satellite imagery acquired over the summer periods (October to March) as described in table 6.2.3. This type of satellite imagery is only acquired over New Zealand during the summer months because a high sun angle is required to reduce shadowing and increase the dynamic range of the signal received from the ground.

Table 6.2.3   Satellite imagery used for land use mapping in 1990, 2008 and 2012

Land use map	Satellite imagery	Resolution (metres)	Acquisition period
1990	Landsat 4 and Landsat 5	30	November 1988 – February 1993
2008	SPOT 5	10	November 2006 – April 2008
2012	SPOT 5	10	October 2011 – March 2013

All the imagery was orthorectified and atmospherically corrected and then standardised for spectral reflectance using the Ecosat algorithms documented in Dymond et al. (2001), Shepherd and Dymond (2003) and Dymond and Shepherd (2004). This standardisation process removes the effect of terrain slope from the imagery and effectively 'flattens' the imagery so that individual land cover types are a more consistent colour across the whole image. By minimising the effects of terrain, a more accurate and consistent classification of land use is possible. This is particularly important in New Zealand, due to the extensive areas of steep terrain.

The final step in image preparation was the mosaicking of the satellite image scenes into a seamless national image. To minimise the effect of cloud and cloud shadows in the mosaic, cloud masks were digitised for each scene. These masks were then used to prioritise the order of inclusion of each scene in the mosaic to obtain a near cloud-free image of New Zealand at each mapping date.

1990 and 2008 land use maps

Mapping approach

The 1990 and 2008 land use maps were created using a common mapping approach based on difference detection from an intermediate reference land-cover layer that was derived from Landsat 7 ETM+ imagery acquired in 2000–01. A semi-automated approach was used to classify woody land cover[46] in the 1990 and 2008 image mosaics. These layers were then differenced from the 2001 reference layer to create a 1990–2001 potential woody change layer and a 2001–08 potential woody change layer.

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[46] Land cover consistent with pre-1990 natural forest, pre-1990 planted forest, post-1989 forest and grassland with woody biomass land uses.

The potential woody change layers were visually checked to confirm change and then the changes were combined with the 2001 reference layer to create the 1990 and 2008 woody land cover layers. Area and proximity rules were used to convert these layers from woody land cover to woody land use, making allowances for unstocked areas within forest extents and areas of regenerating shrubland in a forest context. This process is described in Shepherd and Newsome (unpublished(b)).

To determine the spatial location of the other land uses as at 1990 and 2008, information from two Land Cover Databases, LCDB1 (1996) and LCDB2 (2001) (Thompson et al., 2004), hydrological data from Land Information New Zealand (a government agency) and the New Zealand Land Resource Inventory (NZLRI) (Eyles, 1977) were used (Shepherd and Newsome, unpublished(a)).

The NZLRI database defined the area of high and low producing grassland. Areas tagged as 'improved pasture' in the NZLRI vegetation records were classified as high producing grassland in the land use maps. All other areas were classified as low producing grassland. Figure 6.2.1 illustrates this mapping process.

Figure 6.2.1   New Zealand's land use mapping process
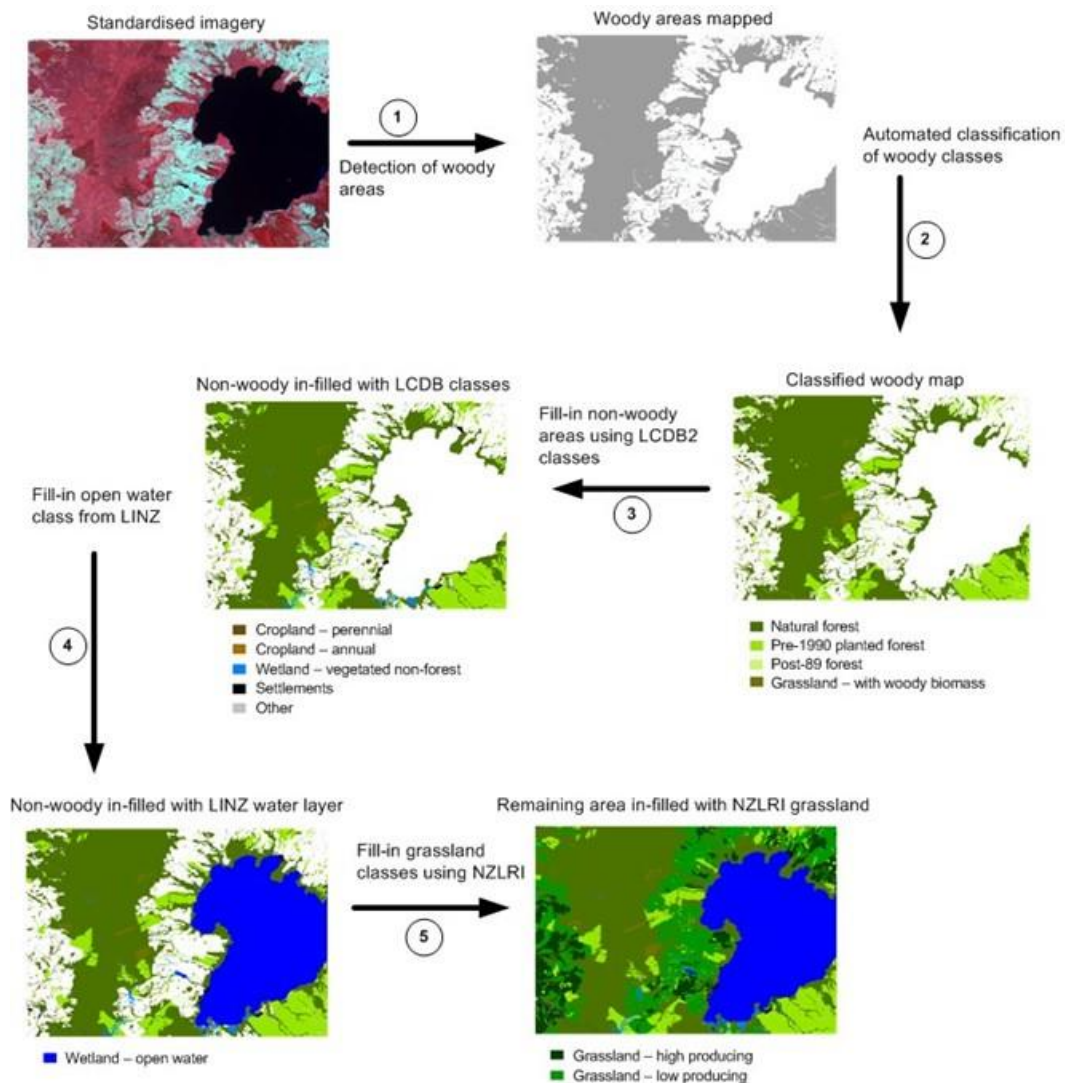
Note: LCDB = Land Cover Database; LINZ = Land Information New Zealand; NZLRI = New Zealand Land Resource Inventory.

An interpretation guide for automated and visual interpretation of satellite imagery was prepared and used to ensure a consistent basis for all mapping processes (Ministry for the Environment, 2012). Independent quality control was performed for all mapping. This involved an independent agency looking at randomly selected points across New Zealand and using the same data as the original operator to decide within what land use the point fell. The two operators were in agreement at least 95 per cent of the time. This is described in more detail in Joyce (unpublished).

Figure 6.2.2 and figure 6.2.3 show the land use map of New Zealand as at 1 January 1990 and 1 January 2008 respectively.

Figure 6.2.2   Land use map of New Zealand as at 1 January 1990
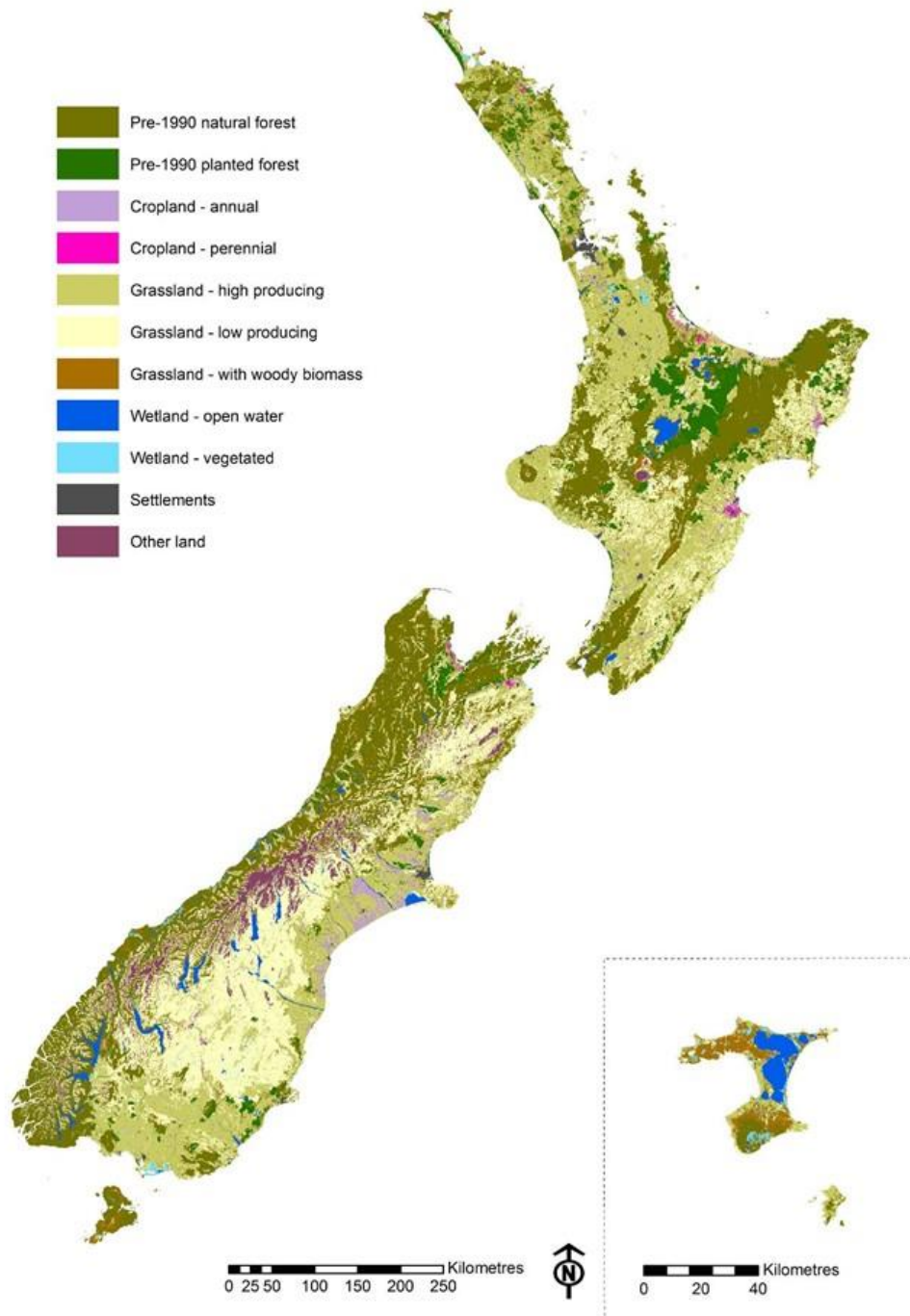
Note: The inset map is of the Chatham Islands, which lie approximately 660 kilometres south-east of the south-eastern corner of the North Island.

Figure 6.2.3   Land use map of New Zealand as at 1 January 2008
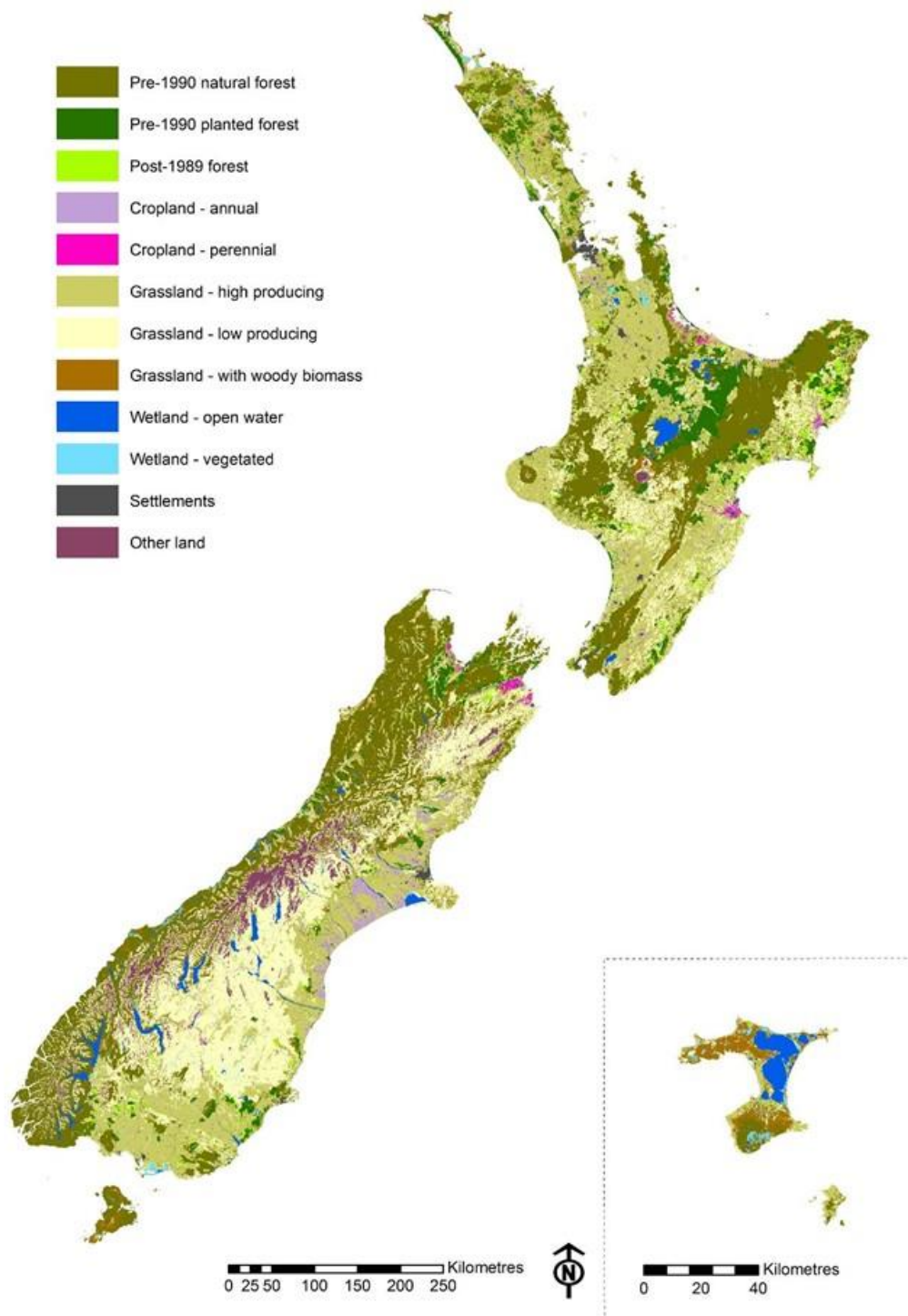
Legend:
- Pre-1990 natural forest
- Pre-1990 planted forest
- Post-1989 forest
- Cropland - annual
- Cropland - perennial
- Grassland - high producing
- Grassland - low producing
- Grassland - with woody biomass
- Wetland - open water
- Wetland - vegetated
- Settlements
- Other land

Note: The inset map is of the Chatham Islands, which lie approximately 660 kilometres south-east of the south-eastern corner of the North Island.

Decision process for mapping post-1989 forests

The use of remotely sensed imagery has some limitations; in particular, a limited ability to map young planted forest of less than three years of age. Where trees are planted within three years of the image acquisition date, they (and their surrounding vegetation) are unlikely to show a distinguishable spectral signature in satellite imagery. This occurs particularly with coarse-resolution (30 metres) Landsat 4 and 5 imagery captured around 1990. This situation is

compounded by the lack of ancillary data at 1990 to support land use classification decisions. However, since 2009, the NZ ETS has provided valuable spatial information that has been used to confirm 1990 forest land use classifications.

Owners of post-1989 forest are able to lodge their forests with the NZ ETS to obtain credit for increases in carbon stock since 1 January 2008. Mapping received by the Ministry for Primary Industries for these applications is used to improve LUCAS land use maps.

Mapping from the NZ ETS has also provided a significant source of planting date information, which helps determine the correct classification of planted forest. The Forestry Allocation Plan, which forms part of the NZ ETS, partially compensates private owners of pre-1990 planted forest for the loss in land value arising from the introduction of penalties for deforesting pre-1990 forest land. Forest owners must apply for this compensation, providing detailed mapping and evidence of their forest planting date. These mapping data are used regularly to improve the classification accuracy of the LUCAS land use maps.

To aid the decision-making process, nationwide cloud-free 1996 SPOT and 2001 Landsat 7 satellite image mosaics are also used to determine the age of forests that have been planted within two to three years of 1990. Figure 6.2.4 illustrates how mapping operators use the spectral signature in later imagery and ancillary information, to determine the status of an area of planted forest established around 1990.

Where possible, information obtained directly from forest owners and the national planted forest plot network is also used to improve the accuracy of the pre-1990 and post-1989 forest classification.

Figure 6.2.4   Identification of post-1989 forest in New Zealand

1990   1996

2000   2008

Images:	1990 Landsat 4 (top left)
	1996 SPOT 2 (top right)
	2000 Landsat 7 ETM+ (bottom left)
	2008 SPOT 5 (bottom right)
Location:	2,017,800, 5,730,677 (NZTM)
1990 land use:	Low producing grassland
2008 land use:	Post-1989 forest
Explanation:	In the Landsat 1990 imagery acquired on 2 December 1990, there is little evidence of the forest within the blue box that is clearly apparent in later imagery. The strength of the spectral response in the SPOT 1996 imagery suggests that the forest must have been planted near to 1990. Final confirmation of the planting date is provided via the NZ ETS application (delineated in green in the 2008 imagery), which states that the forest was planted in 1990 and, therefore, is classed as a post-1989 forest.

2012 land use mapping

The 2012 land use map was created by detecting change between 2008 and 2012 and updating these areas in the 2008 land use map. A multi-date image segmentation process was used to identify areas of possible change between the 2008 and 2012 SPOT satellite imagery data sets. This process is described in Shepherd et al. (2013).

These areas of potential change were confirmed using two separate approaches: one for areas mapped as non-forest at 2008 and one for areas mapped as forest at 2008.

Mapping approach: non-forest areas

Potential changes in areas mapped as non-forest at 2008 were manually checked in the satellite imagery to determine whether a land-use change had occurred between 2008 and 2012. Operators used the 2008 and 2012 SPOT imagery along with other imagery data sets as listed in table 6.2.4 to establish whether land-use change had occurred.

Table 6.2.4   Ancillary imagery data sets used in land use mapping

Satellite imagery	Resolution (metres)	Coverage	Acquisition period
SPOT maps product	2.5	North Island, South Island and Stewart Island	2008–09
Disaster Monitoring Constellation	22	North Island, South Island and Stewart Island	November 2009 – March 2010
SPOT 5	10	Four priority areas: Northland, Waikato, Marlborough and Southland	October 2010 – March 2011
Aerial photography	Variable	All of North Island and Stewart Island and most of South Island	Various

Once change was confirmed, the area of change was delineated in the 2012 land use map.

Mapping approach: forest areas

Areas of possible change within the forest extent were considered to be potential destocking.[47] The areas of potential destocking were first checked in aerial photography to determine whether replanting had occurred. Cases of replanting were then removed from the destocking layer.

All remaining areas were field checked, with oblique aerial photography taken over each site to determine the current land use. It is not possible to determine whether deforestation has occurred using currently available satellite imagery alone; however, efficient flight planning made the oblique over-flight of all areas of destocking a realistic and cost-effective alternative.

Based on the oblique aerial photographic evidence and supporting evidence from the NZ ETS, each area was given one of the following destock classifications.

- Harvested: the area shows evidence of ongoing forestry land use such as replanting, preparation for planting or a context consistent with replanting, such as being surrounded by plantation forestry.

- Deforested: the area shows evidence of land-use change such as the removal of stumps, pasture establishment, fencing and stock.

- Awaiting: the area has been destocked for less than four years[48] and/or there is no evidence of land-use change. That is, the area is lying fallow or, in the case of natural forest areas, the vegetation has been sprayed but not cleared.[49]

- No change: the area has not been destocked and was incorrectly identified as change.

- Not forest: the area was not forested at the beginning of the change period. These areas required correction to a non-forest land use in the 2008 land use map.

- Non-anthropogenic change: destocking was not human induced – for example, erosion and there has been no land-use change.

Deforested areas were then attributed with further information, such as the year in which the deforestation occurred. This was determined by examining the ancillary imagery data sets listed in table 6.2.4, as well as a national time series of Landsat 7 satellite imagery acquired between 2007 and 2012. Figure 6.2.5 shows the process of confirming deforestation and establishing the year in which it occurred. Further information on the mapping of forest change can be found in Indufor Asia-Pacific (2013).

The final step in the 2012 land use mapping process was to add the confirmed areas of deforestation into the 2012 map. Figure 6.2.6 shows the land use map of New Zealand as at 31 December 2012.

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[47] 'Destocking' is defined here as forest loss for any reason including harvesting, deforestation or some type of non-anthropogenic change, such as wind damage or erosion.

[48] To distinguish between deforestation and temporary tree crown cover removal in forest land, New Zealand has defined the expected period between the removal of tree cover and successful natural regeneration or planting as four years.

[49] Often regenerating shrubland areas are sprayed but land-use conversion is not completed by clearing the area. In these instances, the vegetation regenerates and recovers, therefore land-use change has not occurred.

Figure 6.2.5   New Zealand's identification of deforestation
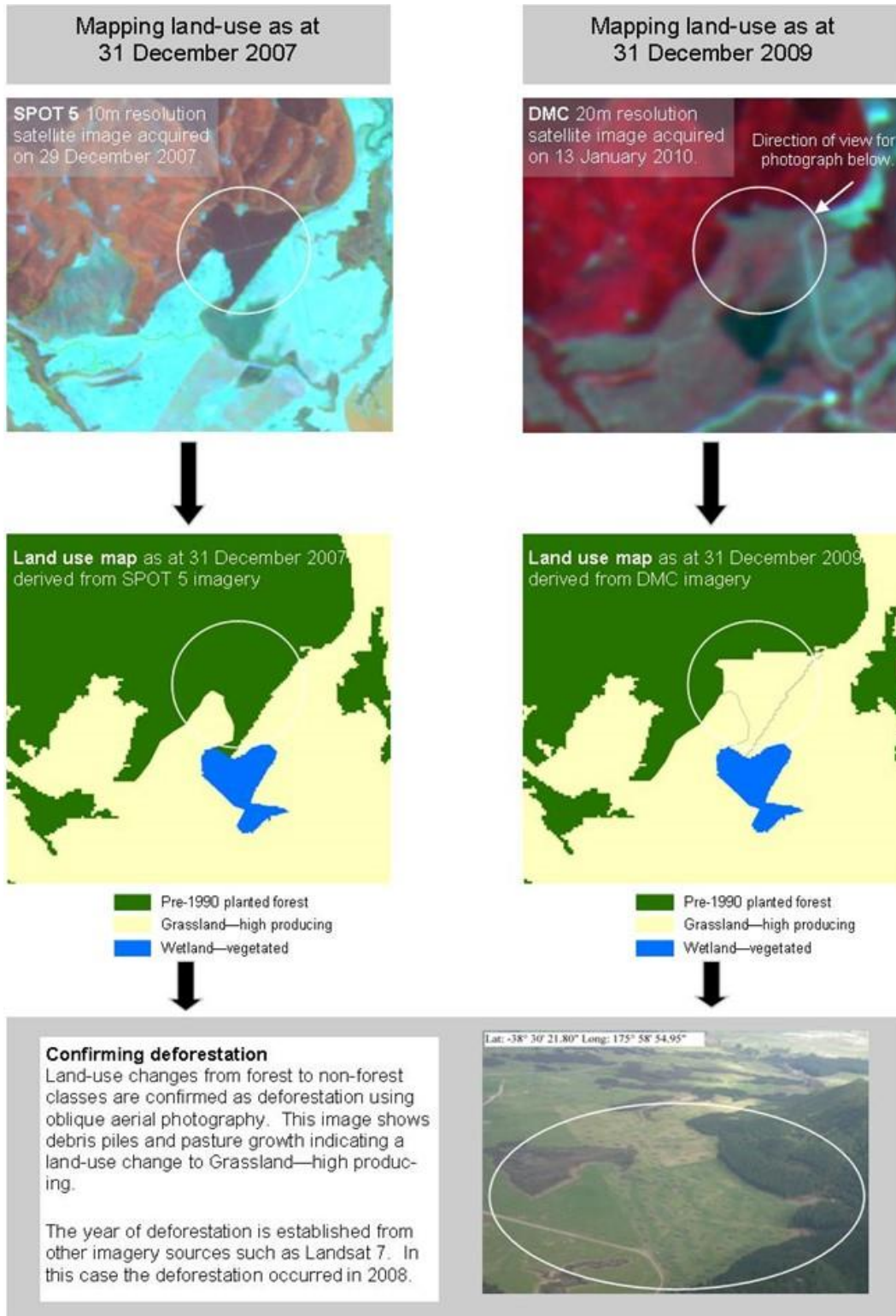
Note: DMC = Disaster Monitoring Constellation.

Figure 6.2.6   Land use map of New Zealand as at 31 December 2012
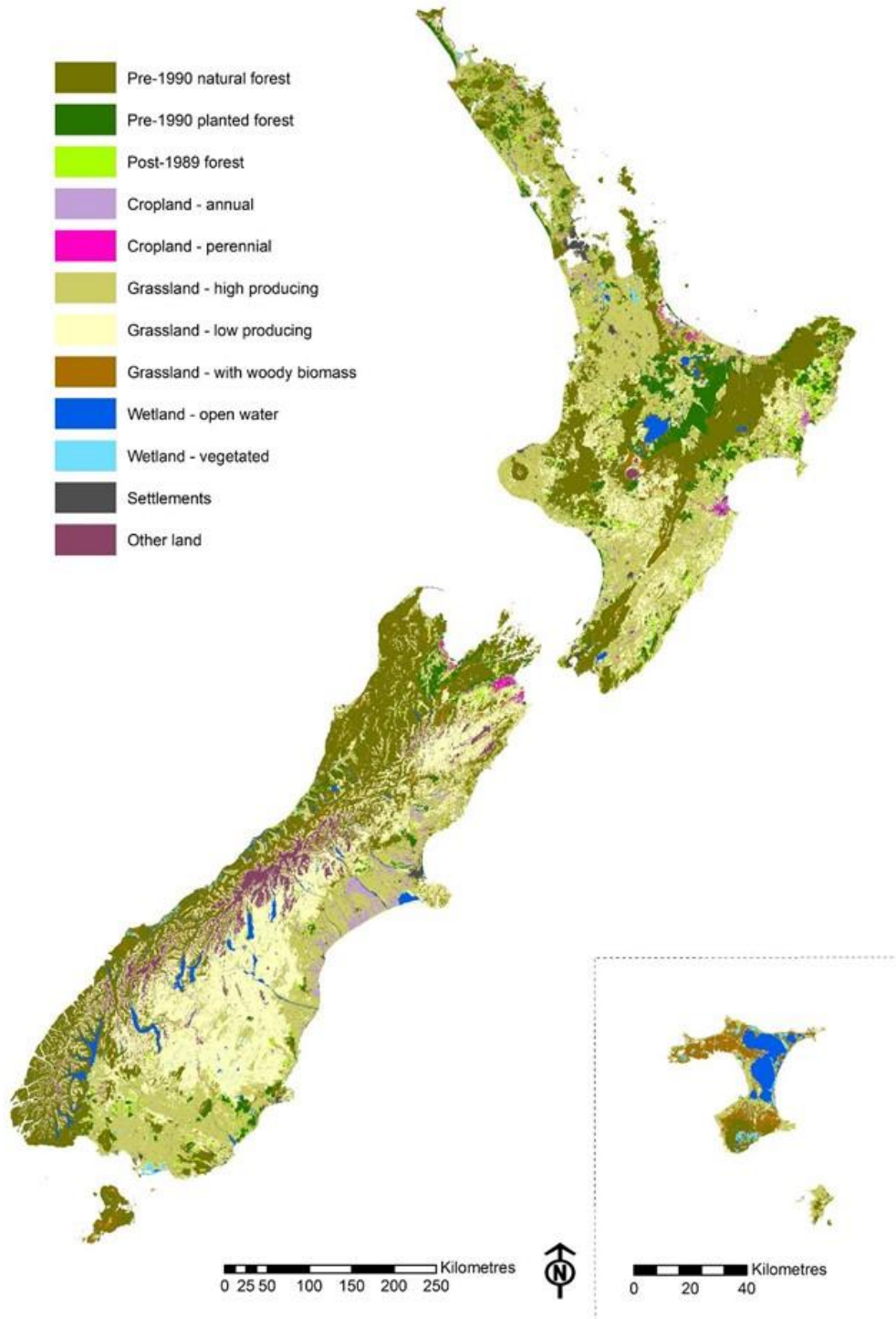
Legend:
- Pre-1990 natural forest
- Pre-1990 planted forest
- Post-1989 forest
- Cropland - annual
- Cropland - perennial
- Grassland - high producing
- Grassland - low producing
- Grassland - with woody biomass
- Wetland - open water
- Wetland - vegetated
- Settlements
- Other land

Kilometres
0 25 50   100   150   200   250

Kilometres
0   20   40

Note: The inset map is of the Chatham Islands, which lie approximately 660 kilometres south-east of the south-eastern corner of the North Island.

6.2.3   Land-use change

Land-use change prior to 1990

The estimation of land-use change prior to 1990 was introduced in the 2011 submission, and further details on the methodology used are available in that report.

A variety of data sources was used to determine land areas prior to 1990. Data sources suitable for determining land use at a national level typically comprise either maps or scaled images depicting land use or proxies for land use (e.g., a 'map of forest areas'), or tabulated land use area data collected for an administrative area (e.g., county, district or region) or production sector (e.g., the area of orchard crops).

This methodology was peer reviewed by Landcare Research Ltd (Hunter and McNeill, unpublished), which provided independent subject-matter expertise. The land-use change matrix from 1962 to 1989 is presented in table 6.2.5.

Land-use change from 1990 to 2012

Annual land-use changes from 1990 to 2012 are generally interpolated from the 1990, 2008 and 2012 land use maps. The only exception is annual deforestation occurring between 2008 and 2012, which is based on mapped data.

Two separate interpolations are used to calculate all other annual land-use changes. The first covers the period between 1990 and 2007 and the second covers the period between 2008 and 2012. Most of the land-use changes are interpolated linearly between mapping dates; however, some of the land-use changes make use of surrogate data sets to better reflect land-use change trends within these periods. This approach follows methodology outlined in section 3.3.1 of the 2006 IPCC Guidelines (IPCC, 2006a).

The surrogate data sets used between 1 January 1990 and 31 December 2007 are as follows.

- Deforestation trends between 1990 and 1 January 2008 for pre-1990 planted forest and post-1989 forest are based on the 2008 Deforestation Intentions Survey (Manley, 2009) and unpublished work by Scion (the New Zealand Forest Research Institute). The work by Scion is referred to in Wakelin (unpublished(b)).

- Afforestation trends for post-1989 planted forest are based on estimates from the National Exotic Forest Description (Ministry for Primary Industries, 2016a).

- Afforestation trends for post-1989 natural forest are based on plot analysis as described in Beets et al. (unpublished).

The surrogate data set used between 1 January 2008 and 31 December 2012 is as follows.

- Total afforestation for 2008 to 2012 is estimated from the National Exotic Forest Description (Ministry for Primary Industries, 2016a). This data set is used to provide a surrogate for afforestation occurring between 2008 and 2012. The National Exotic Forest Description data set is used to provide the total afforestation up to 2012, in preference to the total 2012 mapped afforestation, because not all new planting will have been detected in satellite imagery. Further details on the use of the National Exotic Forest Description data for estimating total afforestation can be found in section 6.4.1.

Table 6.2.6 shows a land-use change matrix for the years 1990 to 2016 based on these inputs. Annual land-use change matrices are included in annex 3.2.1.

Land-use change from 1990 to 2016

Prominent land-use changes between 1 January 1990 and 31 December 2016 include:

- forest establishment of 682,850 hectares (classified as post-1989 forest) that has occurred mostly on land that was previously grassland, primarily low producing grassland. Of this area, 26,731 hectares has since been deforested

- deforestation of 193,415 hectares. This includes the 26,731 hectares of post-1989 forest that was planted and then deforested between 1990 and 2016. Deforestation has occurred

mainly in planted forests since 2004. Between 1990 and 2004, there was little deforestation of planted forests in New Zealand, due to market conditions.

Table 6.2.7 shows a land-use change matrix for the period 31 December 2015 to 31 December 2016.

Land-use change from 2013 to 2016

Deforestation

Deforestation occurring during 2013 and 2014 has been mapped using the same methodology as that used for mapping deforestation occurring between 2008 and 2012 (described in section 6.2.2 under 'Mapping approach: forest areas'). In this case, Landsat 8 national satellite imagery mosaics from the summers of 2013/14 and 2014/15 were used to identify areas of destocking and these were field checked early in 2016 using oblique aerial photography. Areas showing evidence of land-use change have been confirmed as deforested. Where future land use remains uncertain, the areas have been classified as 'Awaiting a land use determination' and reported as unclassified deforestation (see section 11.5.3).

Deforestation of pre-1990 planted forest and post-1989 forest occurring during 2015 and 2016 has been estimated based on the Deforestation Intentions Surveys for 2015 and 2016 respectively (Manley, 2016, 2017). These reports do not distinguish between pre-1990 planted forest and post-1989 forest deforestation; therefore, the proportion of deforestation from each forest type has been estimated based on the relative proportions of deforestation of these forest types in the most recently mapped five-year period (2010–14). This ratio provides the most up-to-date estimate of the ratio of deforestation of these forest types.

The destination land use for areas of estimated deforestation has been pro-rated between the low producing and high producing grassland classes in the same proportion as the mapped destination land uses of deforestation occurring in period of 2010–14.

Deforestation of pre-1990 natural forest for 2015 and 2016 has been estimated as occurring at the same annual rate as the most recently mapped five-year period (2010–14). The destination land use has been estimated in the same manner as for pre-1990 planted forest and post-1989 forest deforestation (described above).

Afforestation

The annual area of afforestation of post-1989 planted forest for the period from 2008 to 2016 is based on estimates from the National Exotic Forest Description (Ministry for Primary Industries, 2016a). Most of the afforestation occurring between 2008 and 2012 has now been mapped in the 2012 land use map. However, the National Exotic Forest Description estimates will continue to be used until the 2012 map is finalised, which will occur once the 2016 land use map is completed. This will allow planting occurring in 2011 and 2012 to be detected in later satellite imagery and mapped explicitly into the 2012 map.

The land use prior to afforestation (original land use) has been pro-rated across all non-forest land uses in the same proportions as the original land uses of all post-1989 afforestation which has been mapped between 2008 and 2012.

Other land-use changes

All other land-use changes for the period from 2013 to 2016 have been linearly extrapolated from the changes mapped between 2008 and 2012.

Table 6.2.5   New Zealand's land-use change matrix from 1962 to 1989

1962	1989	Forest land — Natural	Forest land — Pre-1990 planted	Forest land — Post-1989	Cropland — Annual	Cropland — Perennial	Grassland — High producing	Grassland — Low producing	Grassland — With woody biomass	Wetlands — Open water	Wetlands — Vegetated	Settlements — Settlements	Other land — Other land	Net area 31 Dec 1989 (kha)
Forest land	Natural	7,842.0							46.5					7,888.5
	Pre-1990 planted	274.2	452.4					359.4	439.3					1,525.3
	Post-1989													0.0
Cropland	Annual				325.8		21.3	8.3						355.3
	Perennial				0.9	59.1	5.1	4.1						69.2
Grassland	High producing	78.1			21.2	19.0	4,870.5	486.7	389.3		50.9			5,915.8
	Low producing	416.9						7,434.1	36.6					7,887.6
	With woody biomass	56.7						416.8	1,030.9					1,504.4
Wetlands	Open water	14.4								516.3				530.6
	Vegetated										146.4			146.4
Settlements	Settlements	5.2			7.4	0.1	6.7	3.6	0.3			182.7		206.0
Other land	Other land												896.0	896.0
Area as at 1 Jan 1962 (kha)		8,687.3	452.4	0.0	355.3	78.3	4,903.6	8,713.0	1,943.0	516.3	197.3	182.7	896.0	26,925.2
Net change 1 Jan 1962–31 Dec 1989		−798.8	1,072.9	0.0	0.0	−9.0	1,012.2	−825.4	−438.6	14.4	−50.9	23.3	0.0	0.0
Net change 1962–1989 (%)		−9.2	237.1	NA	0.0	−11.6	20.6	-9.5	−22.6	2.8	−25.8	12.7	0.0	NA

Note: Units in 000s hectares; NA = not applicable. Shaded cells indicate land remaining in each land use. Land use area values are as at the date indicated (1 January for 1962 and 31 December for 1989). Columns and rows may not total due to rounding.

Table 6.2.6   New Zealand's land-use change matrix from 1990 to 2016

2016		1990 Forest land — Natural	Pre-1990 planted	Post-1989	Cropland — Annual	Perennial	Grassland — High producing	Low producing	With woody biomass	Wetlands — Open water	Vegetated	Settlements — Settlements	Other land — Other land	Net area 31 Dec 2016 (kha)
Forest land	Natural	7,821.0	1.3											7,822.4
	Pre-1990 planted	22.7	1,402.0				0.1	0.0	0.1				0.0	1,424.9
	Post-1989			-26.7	0.3	0.0	123.6	401.8	153.0	0.0	0.3	0.0	3.8	656.1
Cropland	Annual	0.0	0.5	0.3	344.9	3.1	23.0	0.7	0.1	0.0		0.0	0.1	372.6
	Perennial	0.1	0.3	0.0	6.9	59.7	34.2	3.4	0.4	0.0	0.0	0.0	0.1	105.1
Grassland	High producing	10.2	69.2	15.4	1.9	5.2	5,699.6	133.0	28.0	0.0	0.2	0.0	0.2	5,963.1
	Low producing	25.1	42.0	8.9	0.0	0.1	1.5	7,272.2	52.2	0.1	0.2		0.7	7,403.0
	With woody biomass	8.0	8.4	1.8	0.1	0.2	15.7	70.4	1,269.0	0.2	0.1	0.0	1.4	1,375.3
Wetlands	Open water	0.0	0.1	0.0	0.7	0.0	3.1	2.9	0.3	530.2	0.2	0.0	0.6	538.1
	Vegetated	0.0	0.0	0.0		0.0	0.0	0.0	0.1	0.0	145.1			145.2
Settlements	Settlements	0.3	0.6	0.1	0.5	0.9	13.9	2.1	0.7	0.0	0.0	205.9	0.2	225.3
Other land	Other land	0.970	0.787	0.154	0.007	0.034	1.153	1.101	0.622	0.039	0.230	0.001	888.9	894.0
Area as at 1 Jan 1990 (kha)		7,888.5	1,525.3	0.0	355.3	69.2	5,915.8	7,887.6	1,504.4	530.6	146.4	206.0	896.0	26,925.2
Net change 1 Jan 1990–31 Dec 2016		−66.1	−100.4	656.1	17.3	35.9	47.3	−484.7	−129.1	7.4	−1.1	19.4	−2.0	0.0
Net change 1990–2016 (%)		−0.8	−6.6	NA	4.9	51.8	0.8	−6.1	-8.6	1.4	−0.8	9.4	−0.2	NA

Note: Units in 000s hectares; NA = not applicable. Shaded cells indicate land remaining in each land use. Non-shaded cells represent the total area subject to a given land-use change between 1990 and 2016. Where an area experiences multiple land-use changes, for example post-1989 forest planted in grassland and subsequently deforested, this change area is represented in both change cells. To compensate, the change area is also deducted from both the grassland and post-1989 forest shaded land remaining cells. In the case of post-1989 forest, this leads to a negative value in the shaded post-1989 forest cell, because there was no area present at 1990 for the deforestation area to be deducted from. The minimum area shown for land-use change is 100 hectares; however, areas are mapped to 1 hectare resolution. Blank cells indicate no land-use change during the period; 0.0 indicates land-use change was less than 100 hectares. Land use area values are as at the date indicated (1 January for 1990 and 31 December for 2016). Columns and rows may not total due to rounding.

Table 6.2.7   New Zealand's land-use change matrix from 2015 to 2016

2016		2015 Forest land Natural	Pre-1990 planted	Post-1989	Cropland Annual	Perennial	Grassland High producing	Low producing	With woody biomass	Wetlands Open water	Vegetated	Settlements Settlements	Other land Other land	Net area 31 Dec 2016 (kha)
Forest land	Natural	7,822.4												7,822.4
	Pre-1990 planted	0.1	1,424.8											1,424.9
	Post-1989			651.0			0.6	3.5	1.0		0.0		0.0	656.1
Cropland	Annual				372.4	0.2	0.0	0.0	0.0	0.0				372.6
	Perennial				0.1	104.5	0.4	0.1	0.0					105.1
Grassland	High producing	0.2	2.3	0.3	0.0	0.2	5,953.8	5.6	0.8	0.0	0.0		0.0	5,963.1
	Low producing	0.7	1.2	0.3		0.0	0.0	7,398.7	2.1	0.0	0.0		0.0	7,403.0
	With woody biomass				0.0	0.0	0.1	0.8	1,374.4	0.0			0.0	1,375.3
Wetlands	Open water				0.1	0.0	0.3	0.0	0.0	537.7	0.0		0.0	538.1
	Vegetated						0.0	0.0	0.0	0.0	145.2			145.2
Settlements	Settlements				0.0	0.0	0.1	0.0	0.0			225.2	0.0	225.3
Other land	Other land					0.0	0.1	0.1	0.0	0.0	0.0		893.9	894.0
Area as at 31 Dec 2015 (kha)		7,823.4	1,428.3	651.6	372.6	104.9	5,955.4	7,408.7	1,378.3	537.7	145.3	225.2	893.9	26,925.2
Net change 31 Dec 2015–31 Dec 2016		−1.0	−3.4	4.6	0.0	0.2	7.7	−5.7	−2.9	0.4	0.0	0.1	0.1	0.0
Net change 2015–2016 (%)		0.0	−0.2	0.7	0.0	0.2	0.1	−0.1	−0.2	0.1	0.0	0.1	0.0	NA

Note: Units in 000s hectares; NA = not applicable. Shaded cells indicate land remaining in each land use. The minimum area shown for land-use change is 100 hectares; however, areas are mapped to 1 hectare resolution. Blank cells indicate no land-use change during the period; 0.0 indicates land-use change was less than 100 hectares. Land use area values are as at the date indicated (31 December for 2015 and 2016). Columns and rows may not total due to rounding.

6.2.4 Methodological change

For this submission, improvements have been made to the 1990, 2008 and 2012 land use maps. These improvements have led to a reduction to the total area of *Pre-1990 natural forest* (by 5,540 hectares) and *Post-1989 natural forest* (by 1,108 hectares) following a review that showed these areas were not succeeding to forest and are more accurately classified as *Grassland with woody biomass*.

For this submission, areas under peat extraction have been identified to enable emissions from this activity to be reported for the first time.

6.2.5 Uncertainties and time-series consistency

In 2014 an accuracy assessment was completed for the 2012 land use map. A stratified random sample of 2,000 points was made, and the land use classification was independently assessed at each point location. SPOT-6 natural colour 1.5-metre resolution imagery was used as the reference data source. This imagery met the criteria for a reference data source, having better resolution than the SPOT-5 10-metre resolution imagery used to create the 2012 land use map and being acquired over a similar period.[50]

The overall map accuracy was found to be 95.2 per cent (Poyry Management Consulting (NZ) Ltd, unpublished). The user and producer accuracies for the three forest classes were all over 94 per cent. For all forest classes, the total mapped area fell within the 95 per cent confidence interval of the total class area as determined by the accuracy assessment.

Non-forest land uses generally had user and producer accuracies of over 90 per cent. Exceptions were the *Wetlands* and *Grassland with woody biomass* categories, for which producer accuracies were 85 per cent and 60 per cent respectively (Poyry Management Consulting (NZ) Ltd, unpublished). The *Wetlands* category was slightly under-mapped. This is because two land use categories, *Vegetated wetland* and *Grassland with woody biomass*, are sometimes difficult to distinguish in imagery where the extent of flooding varies seasonally. The *Grassland with woody biomass* land use category appears to be more substantially under-mapped, with accuracy assessment operators identifying areas of high and low producing grassland that should have been mapped as grassland with woody biomass. This is also a difficult judgement call, because the boundary between areas of low producing and high producing grassland and grassland with woody biomass can be hard to define.

6.2.6 Quality assurance/quality control (QA/QC) and verification

Quality-control and quality-assurance procedures have been adopted for all data collection and data analyses, consistent with the 2006 IPCC Guidelines (IPCC, 2006a) and New Zealand's inventory quality-control and quality-assurance plan. Data quality and data assurance plans are established for each type of data used to determine carbon stock and stock changes, as well as for the mapping of the areal extent and spatial location of land-use changes.

The 1990, 2008 and 2012 land use mapping data have been checked to determine the level of consistency in satellite image classification with the requirements set out in *Land Use and Carbon Analysis System: Satellite imagery interpretation guide for land use classes* (Ministry for the Environment, 2012).

The quality-control checks performed on the 1990 and 2008 land use maps included checking approximately 28,000 randomly selected points in areas mapped as forest and grassland with

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[50] The SPOT-6 natural colour 1.5-metre resolution imagery was acquired in the summers of 2012/13 and 2013/14 making it generally one year later than the SPOT-5 multi-spectral 10-metre resolution imagery used to create the 2012 land use map.

woody biomass. These were evaluated by independent assessors. In this exercise, independent assessors agreed with the original classification 91 per cent of the time. Where there was disagreement, the points were recorded in a register and this was used to plan improvements to the 1990 and 2008 land use maps. These improvements have now been completed.

Two distinct quality-control checks were performed on the 2012 land use map. The first of these checked every polygon where land-use change had occurred from a non-forest land use between 2008 and 2012. The acceptance criterion for this check was that the land use classification had to be correct at both mapping dates at least 90 per cent of the time. This means that the land use both at the start of the land-use change event and at the end of the land-use change event had to be correct. The second quality-control measure was to check the accuracy of destock detection in areas that were in a forest land use at 2008. Sampling for this check was designed to test that at least 90 per cent of the destocking had been detected at the 95 per cent confidence level. Checks were completed on each of the 16 regions of New Zealand individually and all regions passed. During this process, 14,443 points were checked.

Each mapping improvement activity carried out on the 1990, 2008 and 2012 maps has been subjected to quality-assurance checks to ensure accuracy and consistency. Quality-assurance strategies have been tailored to each improvement activity, usually including a combination of random sampling of updated areas and analysis of the changes in land use areas.

Quality assurance of the 2013 and 2014 deforestation mapping activity was a multi-stage process. The contractor undertook initial quality assurance by cross-checking operator interpretation of oblique aerial photography acquired from light aircraft (see figure 6.2.5). All areas of mapped deforestation were then visually checked by LUCAS analysts to verify both the deforestation decision and the original mapped land use.

The approach used to implement quality-assurance processes is documented in the LUCAS Data Quality Framework (PricewaterhouseCoopers, unpublished).

6.2.7   Planned improvements

During 2018, another national land use map will be added to the time series based on Sentinel-2 imagery acquired in the summer of 2016/17. Activity data from this map will be first reported in the 2019 submission.

As part of the new map production process, improvements will be made to the entire time series of maps to ensure that they are aligned. This will include a specific focus on improving:

- the identification and delineation of old growth planted forest within a natural forest context

- mapping of woody classes within grassland based on height information from synthetic aperture radar imagery. This is particularly effective for locating willow trees, which often have a spectral signature similar to that of the surround grassland

- the mapping of the extents of settlements and wetlands

- the mapping of high and low producing grassland and particularly areas of change between these two classes.

6.3   Soils

In this submission, New Zealand uses a Tier 2 method to estimate soil carbon changes in mineral soils and follows the Tier 1 approach for organic soils.

6.3.1   Mineral soils

New Zealand's Tier 2 method for mineral soils involves estimating steady state soil organic carbon (SOC) stocks for each land use based on New Zealand soil data (described in more detail below). Changes in SOC stocks associated with land-use change are calculated according to the IPCC default method (IPCC, 2006a) using the equation:

$$\Delta C = [(\text{SOC}_0 - \text{SOC}_{(0\text{-}T)})/20] \times A \qquad (3)$$

Where: ΔC = change in carbon stocks (tonnes)

SOC_0 = stable SOC stock in the inventory year (tonnes C ha^{-1})

$\text{SOC}_{(0\text{-}T)}$ = stable SOC stock T years prior to the inventory year (tonnes C ha^{-1})

A = land area of parcels with these SOC terms (hectares)

20 = default SOC stock transition period (year).

The SOC stock for each land use is characterised with country-specific data via the Soil Carbon Monitoring System (Soil CMS) model (McNeill and Barringer, unpublished; McNeill et al., unpublished). The correct operation of the Soil CMS model involves fitting the model to the soil carbon data set and then using the coefficients for the different land use categories for each land use transition (equation 3). The interpretation of the different land use effects is informed by multi-comparison significance.

Characterising SOC stocks: New Zealand's Soil Carbon Monitoring System

Unbiased estimates of SOC stocks associated with each land use in New Zealand are calculated by using country-specific data in the Soil CMS model. The operation of the Soil CMS model to produce SOC pool estimates involves applying a linear statistical model to key factors of land use, climate and soil order, which together regulate net SOC storage. The model also includes an additional environmental factor consisting of the product of slope and rainfall (hereafter, slope × rainfall) – a term used as a proxy for erosivity, the potential for surface soil erosion to occur (Giltrap et al., unpublished). The end result is that the explanatory effect of the land use category on SOC stocks is isolated from other factors that affect SOC.

Two key assumptions underpin the operation of the Soil CMS model: first, the SOC values in the sample data set represent equilibrium SOC values for each stratified soil, climate and land use cell, and erosivity index; and, second, changes in land use are the key drivers of change in SOC at the decadal scale, while all other changes due to soil type, climate or erosivity are assumed to be constant (McNeill et al., 2014). The model allows for an explanatory effect by land use category, so that estimates grouped by land use are unbiased where a specific land use category has an effect significantly different from the pooled soil carbon value from all land use categories. Where land use category is a significant explanatory variable of SOC, incorporating land use in the model reduces the overall residual standard error associated with soil carbon (McNeill and Barringer, unpublished).

Soil carbon linear parametric model

The generalised least squares model used for the Soil CMS is a minimum variance unbiased estimator (Draper and Smith, 1998). This means that the soil carbon values, and the soil carbon changes as a result of a land use transition, are unbiased. This approach is consistent with the physically based soil carbon model outlined in the literature (Baisden et al., unpublished(b); Kirschbaum et al., unpublished; Scott et al., 2002; Tate et al., 2005).

The generalised least squares regression model for soil carbon in the 0–30-centimetre layer uses explanatory variables of the soil–climate factor, the land use category and slope × rainfall. This model is represented as an equation for the soil carbon $C_{i,j}^{0-30cm}$ in land use category i and soil–climate class j as:

$$C_{i,j}^{0-30cm} = M + L_i + S_j + b.SR + \varepsilon \qquad (4)$$

Where: M = the mean soil carbon in the 0–30-cm layer for the combination of the reference level of land use (low producing grassland), the reference level for soil climate (MstTempHAC, i.e., 'moist temperate high activity clay'), and level ground

L_i = the effect of the i-th land use, specifying the difference in soil carbon relative to the reference land use (low producing grassland), in tonnes per hectare

S_j = the effect of the j-th soil–climate class relative to the reference level

$b.SR$ = the additional soil carbon for each unit of erosivity (slope × rainfall) (millidegree × 10^{-1})

ε = the model uncertainty.

The quantities M, L_i, S_j, as well as the slope × rainfall coefficient $b.SR$, are obtained by fitting a statistical model to the Soil CMS calibration data set; all other quantities are obtained from other data sets or from separate analyses (McNeill and Barringer, unpublished). For example, the mean value of the slope × rainfall must be obtained from national statistics of rainfall and a terrain slope map, which has been calculated from geographic information system (GIS) layers (Giltrap et al., unpublished).

More elaborate alternatives to the model have been considered but were not found to be significantly better than the simple model given in equation 4 above (McNeill and Barringer, unpublished).

Soil data sets

Soil data for the Soil CMS inventory model come from five sources.

Historic soils: This data set is derived primarily from the National Soils Database (NSD), with a small number of samples from various supplementary data sets; data were collected between 1935 and 2005. The NSD represents soil profile data for over 1,500 soil pits scattered throughout New Zealand. These data contain the soil description following either the Soil Survey Method (Taylor and Pohlen, 1962) or *Soil Description Handbook* (Milne et al., 1995), as well as physical and chemical analyses from either the Landcare Research Environmental Chemistry Laboratory or the Department of Scientific and Industrial Research Soil Bureau Laboratory. This data set was collated as the first stocktake of available soil data for national greenhouse gas reporting and, as such, underwent substantial quality-assurance and quality-control checks (Baisden et al., unpublished(b); Scott et al., 2002; Tate et al., 2005).

Natural forest soils: This data set was gathered between 2001 and 2007 as part of the Natural Forest Survey, with soil subsampled on an 8-kilometre grid across the country (Garrett, unpublished; see section 6.4.2 for more details of the 8-kilometre national grid system). The natural forest soils were important in the development of the Soil CMS model because they provided spatial balancing in areas of New Zealand not adequately covered by the historic soils data set.

Cropland data set: The third source of data originated as a set of intensively spatially sampled high producing grassland, annual cropland and perennial cropland records collected for other purposes, referred to as the cropland data set (Lawrence-Smith et al., 2010).

Wetlands: The fourth source of data comprises wetland soil data from a recent research effort to combine field data with analysis of the spatial distribution of current wetlands in New Zealand (Ausseil et al., 2015). This resulted in the addition of 21 wetland mineral soil samples to the Soil CMS data set (McNeill et al., 2014).

Post-1989 forest data: This data set was added to the analysis in 2014. It contains data collected specifically for Convention reporting from 90 post-1989 forest sites across New Zealand (Basher et al., unpublished; Interpine Forestry Limited, unpublished).

Together, the five combined data sets cover most of New Zealand (see figure 6.3.1), including Stewart Island. Coverage does not extend to the Chatham Islands and other offshore islands. In addition to soil data, each record contains the site-specific climate, slope and rainfall attributes that are used in the analysis.

Figure 6.3.1   Soil samples in Soil CMS model calibration data set
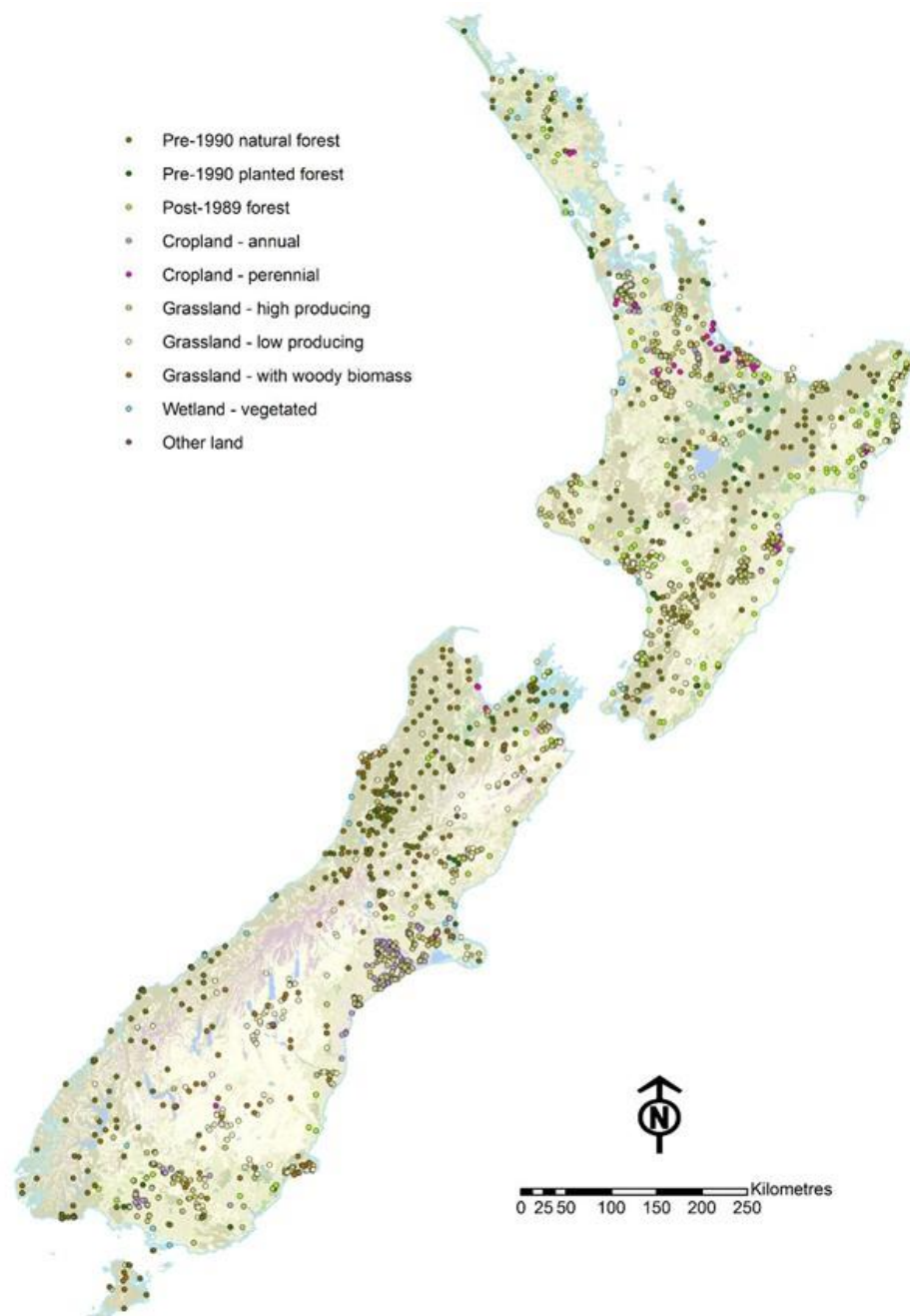
Due to a reliance on available data, coverage is dense in areas of agricultural activity, and the density of points varies widely between different regions (see figure 6.3.1). In addition, types of land use vary geographically: some are widespread (e.g., high producing grassland), whereas others are spatially constrained (e.g., cropland), so that the number of soil samples needed varies by land use (McNeill et al., unpublished).

There is a wide variation in the number of records associated with the different land use categories and soil orders, with the largest land use category (*High producing grassland*) having 767 samples and the smallest (*Other land*) only three samples. While efforts to collect or obtain additional data in undersampled land use categories have been made since LUCAS was established and, as a result, uncertainties have been reduced, considerable variability among the land use effect uncertainties remains.

Two of the 12 land use categories were not used in the model due to lack of soil carbon data: *Wetlands – open water* and *Settlements*. Both land uses are assigned the reference level carbon stock, which is the same as *Low producing grassland*, because no data are available for these land uses. The basis for using the reference level for *Settlements* is supported by the land use definition used for the category because it includes not only impervious surfaces but also green spaces (urban park land, golf courses and other recreational areas, as explained in table 6.2.2). These areas are likely to have elevated carbon stock levels compared with *Low producing grassland* due to the treatments they receive. The *Settlements* category makes up only 0.8 per cent of New Zealand's total land area and is not a key category for New Zealand (in either the level or trend analysis); therefore it is not an area prioritised for improvement within the National Inventory Report.

Ancillary data

In addition to the soil data, the following ancillary data are used in the Soil CMS Model:

S-map: S-map is a contemporary digital soil spatial information system for New Zealand (Lilburne et al., 2012), which provides the best-available knowledge of the classification of the soil order consistent with the *New Zealand Soil Classification* (Hewitt, 2010). S-map coverage is not available for all the land area, because its focus is on regions of intensive agricultural use.

Fundamental Soils Layer: Where data on soil order were unavailable in S-map, data from the Fundamental Soils Layer were used instead. The Fundamental Soils Layer (https://soils.landcareresearch.co.nz/soil-data/fundamental-soil-layers) provides GIS information on the expert-assessed classification of soil order and other soil or landscape attributes over New Zealand. It is generated from the NZLRI and NSD.

Topographic information: Topographic slope information was estimated from a digital elevation model generated from Land Information New Zealand 1:50,000 scale topographic data layers, including 20-metre contours, spot heights, lake shorelines and coastline.

Land use effects: Characterising soil carbon stocks

The 2014 version of the Soil CMS model used in this report builds on previous model versions (McNeill and Barringer, unpublished). The 'land use effect' (LUE) denotes the influence of land use on SOC stocks and corresponds to the model coefficients calculated for each land use. The LUE for a transition from low producing grassland to one of the other land uses can be obtained by using the coefficients of the soil carbon model (see table 6.3.1). Steady state SOC stocks for each land use (see table 6.3.2) are derived from the LUE coefficient in relation to the intercept (the reference of low producing grassland on high activity soils in a moist temperate climate – table 6.3.1). These values are used in equation 3 (as SOC_0 and $SOC_{(0-T)}$) to calculate soil carbon changes due to land-use change.

Table 6.3.1   Land use effect coefficients with standard errors, *t*-values, and corresponding *p*-value significance estimates, extracted from full model results

Land use	Value	Standard error	*t*-value	*p*-value
Intercept: Low producing grassland	105.98	3.96	26.79	0.000
High producing grassland	−0.64	3.13	−0.21	0.8370
Grassland with woody biomass	−7.75	3.68	−2.11	0.0350
Perennial cropland	−17.54	6.37	−2.76	0.0059
Annual cropland	−16.21	4.45	−3.64	0.0003
Vegetated wetland	30.08	8.53	3.52	0.0004
Pre-1990 planted forest	−13.54	5.78	−2.34	0.0193
Post-1989 planted forest	−14.06	4.86	−2.90	0.0038
Pre-1990 natural forest	−13.73	3.70	−3.71	0.0002
Other land	−47.61	21.05	−2.26	0.0238

Source: McNeill and Barringer (unpublished)

Note: The model intercept (estimate for *Low producing grassland*) is used for *Settlements* and *Wetlands – open water* land use categories due to lack of data.

Table 6.3.2   Steady state soil organic carbon stocks, with 95 per cent confidence intervals, calculated from Soil CMS model

Land use	Steady state carbon SOC stock (t C ha⁻¹)	95% confidence intervals (CI) 2.5% CI SOC stock (t C ha⁻¹)	95% confidence intervals (CI) 97.5% CI SOC stock (t C ha⁻¹)
Pre-1990 natural forest	92.25	84.99	99.51
Pre-1990 planted forest	92.44	81.12	103.77
Post-1989 forest	91.92	82.40	101.44
Grassland with woody biomass	98.23	91.02	105.43
High producing grassland	105.34	99.21	111.47
Low producing grassland	105.98	98.23	113.73
Perennial cropland	88.44	75.96	100.92
Annual cropland	89.77	81.04	98.49
Wetlands – open water	105.98	98.23	113.73
Wetlands – vegetated	136.06	119.33	152.78
Settlements	105.98	98.23	113.73
Other land	58.37	17.12	99.62

Source: Calculated from McNeill and Barringer (unpublished)

The residual standard error for the model is 41.3 tonnes per hectare, and the corrected Akaike information criterion value is 21,044.2. The spatial autocorrelation scale distance is 18.1 kilometres, with a nugget of 0.47 (McNeill and Barringer, unpublished). A correction for spatial correlation is necessary because the samples are located close to one another rather than evenly spread throughout New Zealand (because land use is not even throughout New Zealand). These values are consistent with earlier analyses (McNeill, unpublished(a), (b)). The use of the Akaike information criterion value as a model selection and comparison mechanism is widely supported in the literature in general and soil modelling specifically (Burnham and Anderson, 2002; Elsgaard et al., 2012; Ogle et al., 2007).

Measures of statistical validity: Assessing significant differences among SOC stocks

The uncertainty of the land use effect (the change in soil carbon, assuming the transition is stable) between two land use categories in isolation is conceptually straightforward: two estimates of land use effect are more likely to be significantly separated if their point estimates are farther apart after taking account of the covariance between the two land use effects. The standard error $\sigma_{i,j}$ of the LUE change for a transition between two land use categories with effects L_i and L_j is then estimated from:

$$\sigma_{i,j} = \sqrt{Var\ (L_i) + Var\ (L_j) - 2.\,Cov\ (L_i, L_j)} \qquad (5)$$

Where: $Var(L_i)$ = the variance of land use effect i

              $Cov(L_i, L_j)$ = the covariance between land use effects L_i and L_j (McNeill and Barringer, unpublished; McNeill et al., unpublished).

Although equation 5 provides a mathematically straightforward way to estimate the significance of a single transition from one land use category to another (a comparison-wise significance), it is often desirable to be able to determine whether a number of land use categories are likely to be significantly different or essentially the same as an ensemble. As more comparisons are made between many different land use types, it becomes more likely that at least one of the land use effect changes will be different as a result of random chance alone, resulting in an increase in the Type 1 error. Thus, the significance of all possible land use transitions must be calculated as a family of simultaneous comparisons (multiple comparison significance), rather than one at a time (McNeill and Barringer, unpublished).

To control the Type 1 error rate in multiple comparison significance testing for the soil carbon change model, all possible combinations of the land use categories were tested for equality (a two-sided test) simultaneously. For the Soil CMS model (McNeill and Barringer, unpublished), a closed-testing procedure described by Marcus et al. (1976) was used; this procedure is a general method for performing a number of hypothesis tests simultaneously implemented in the multi-comparison package in R (Bretz et al., 2010).

The closed-testing procedure described by Marcus et al. (1976) yielded point estimates and confidence intervals of a test statistic for each distinct combination of land use transitions, and the critical test is whether the confidence intervals include zero. All land use transition pairs were significant, except those involving *Other land* (see figure 6.3.2).

Figure 6.3.2   Result of applying the Marcus multi-comparison test to the adopted model
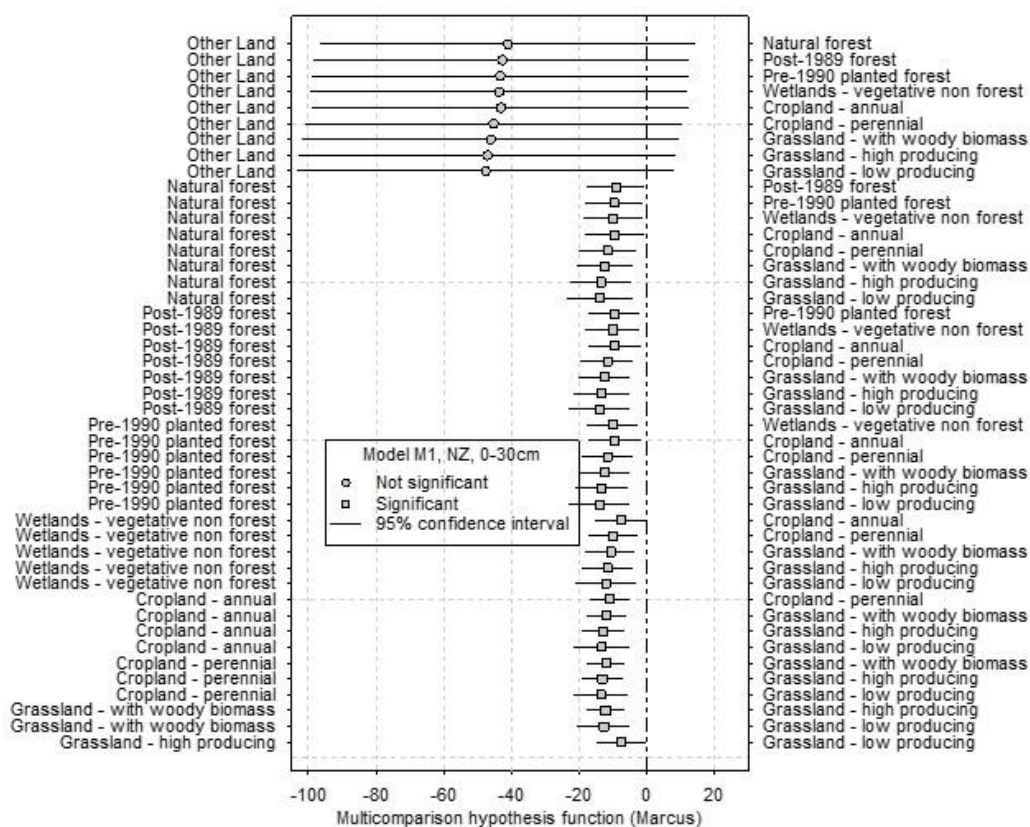
Note: The marker is the estimated value for the specified transition to indicate significance, and the error bars represent the 95 per cent confidence interval of the test statistic. Land use transitions with point estimates and confidence intervals marked with a grey square are considered highly significant differences within the set of all possible land use transitions.

As the model results show (see figure 6.3.2), all transitions are significant in the multi-comparison sense, except those involving *Other land*. Land use transitions involving *Other Land* contribute relatively little to the carbon change estimates because they make up approximately 1.0 per cent of all land-use change detected between 1990 and 2016.

It is important to note that this interpretation of significance does not alter the method of calculation of the soil carbon change as a result of land use transition. In particular, it would not be correct to substitute a value of zero for the effect of a land use transition where the transition itself is not significant in the multi-comparison sense, because, if such a substitution were to be carried out, the calculation of the soil carbon would no longer be unbiased. Avoiding the bias in this manner also reduces the residual uncertainty of the soil carbon estimates. For this reason, the effect of all land use transitions ought to be included in calculations of soil carbon change (McNeill and Barringer, unpublished; McNeill et al., 2014).

6.3.2   Organic soils

Organic soils occupy a small proportion of New Zealand's total land area (1.0 per cent), and the area of organic soils subject to land-use change is approximately 0.03 per cent of New Zealand's total land area. New Zealand uses a Tier 1 method to estimate SOC stock change in organic soils.

The definition of organic soils is derived from the *New Zealand Soil Classification* (Hewitt, 2010), which defines organic soils as those soils with at least 18 per cent organic carbon in

horizons at least 30 centimetres thick and within 60 centimetres of the soil surface. New Zealand-specific climate and soil data are used to estimate the areas of organic soil found in each climate zone. Climate data are based on the temperature data layer of the Land Environments New Zealand classification (Leathwick et al., 2002). Soil-type data are based on the Fundamental Soils Layer associated with the NZLRI (Newsome et al., 2008) and converted to the IPCC classification (Daly and Wilde, unpublished). These data layers have been analysed in a GIS system to determine the areas of organic soils in warm and cold climatic zones. These areas are compared with the land use to determine the area of organic soils in each.

The LULUCF organic soils definition is the same as that used for reporting under the Agriculture sector (Dresser et al., 2011).

New Zealand has used IPCC default emission factors for organic soils under the *Forest land*, *Grassland*, *Cropland, Wetlands* and *Settlements* categories (IPCC, 2006a) to estimate organic soil emissions (see table 6.3.3). IPCC guidance for organic soils under forest is limited to estimates associated with the drainage of organic soils in managed forests. In New Zealand, the drainage of natural forests does not occur and therefore no emissions are estimated from organic soils under natural forest. It is assumed that all planted forests on organic soils are drained prior to forest establishment. The temperate default for forest land is applied to the area of organic soils under planted forests to estimate emissions. The warm temperate and cold temperate defaults for the *Grassland*, *Cropland* and *Settlements* categories are applied in proportion to the area of land in New Zealand where the mean annual temperature is above or below 10°C, respectively. New Zealand applies IPCC default emission factors for organic soils in the *Wetlands* category for areas under peat extraction. There are no default emission factors for organic soils under *Other land*; therefore, emissions from organic soils under this land use category are not estimated.

Table 6.3.3   New Zealand emission factors for organic soils

Land use	Climatic temperature regime	IPCC Tier 1 default emission factor applied and ranges (t C ha⁻¹ yr⁻¹)	Reference
Pre-1990 natural forest	Temperate	NA	IPCC guidance applies only to drained forest organic soils, which do not occur in natural forests in New Zealand (IPCC, 2006a, section 4.2.3.2).
Pre-1990 and post-1989 planted forest	Temperate	0.68 (range 0.41–1.91)	IPCC (2006a, section 4.2.3.2, table 4.6)
Cropland	Cold temperate	5.0 ± 90%	IPCC (2006a, section 5.2.3.2, table 5.6)
	Warm temperate	10.0 ± 90%	
Grassland	Cold temperate	0.25 ± 90%	IPCC (2006a, section 6.2.3.2, table 6.3)
	Warm temperate	2.5 ± 90%	
Wetlands	NA	0.2 ± 90%	IPCC guidance applies to managed peatlands and flooded lands to which separate methodologies apply for soils. See IPCC, 2006a, chapter 7.
Settlements	Cold temperate	5.0 ± 90%	Cropland emission factors used (IPCC, 2006a, section 8.2.3.2)
	Warm temperate	10.0 ± 90%	
Other land	NA	NE	No IPCC guidance is available (IPCC, 2006a, chapter 9.3.3)

Note: NA = not applicable; NE = not estimated.

6.3.3 Uncertainties and time-series consistency

Mineral soils

For the most part, uncertainties associated with the model coefficients (see table 6.3.2) are substantially reduced from the Tier 1 default value of 95 per cent. Those land uses with higher uncertainties are those with few data points, such as *Other land*, or are dominant land uses in the country and, thus, occur across a wide range of environmental conditions, such as low producing grassland.

Uncertainties also arise from lack of soil carbon data for some soil, climate and land use combinations (Scott et al., 2002), and from variations in site selection, sample collection and laboratory analysis with data from different sources and time periods (Baisden et al., unpublished(b)). Other uncertainties in the Soil CMS include: the assumption that soil carbon reaches steady state in all land uses and the 20-year linear transition period to reach it; lack of soil carbon data and soil carbon changes estimates below 0.3 metres; potential carbon losses from mass-movement erosion; and a possible interaction between land use and the soil–climate classification (Tate et al., 2004, 2005).

Work completed since 2005 has increased the number and distribution of soil samples that are included in the model. This has led to a reduction in the uncertainties for the land use effects, meaning all land use transitions, except for those involving *Other land*, are now significant in the multi-comparison sense (McNeill and Barringer, unpublished).

Organic soils

New Zealand uses the IPCC Tier 1 default value for uncertainty of organic soils under the categories *Forest land*, *Grassland*, *Cropland, Wetlands* and *Settlements*, as given in the 2006 IPCC Guidelines (2006a, tables 4.6, 5.6, 6.3 and 7.4). These values vary from 40 per cent for managed forests to 90 per cent for the other land uses.

Further detail on uncertainty for each land use is discussed in the appropriate category sections. The same method is used for all years of reporting to ensure time-series consistency.

6.3.4 Source-specific QA/QC and verification

Quality-control and quality-assurance procedures have been adopted for all data collection and data analyses, to be consistent with 2006 IPCC Guidelines (IPCC, 2006a) and New Zealand's inventory quality-control and quality-assurance plan:

- details of the quality-management system for data collection, laboratory analyses and database management of the NSD are given in Wilde (2003)

- recent data collection, analyses and management methods are subject to the soils quality-control and quality-assurance plan

- the consolidated soils data set used within the Soil CMS has been subject to further quality-assurance procedures (Fraser et al., unpublished).

The Soil CMS model has been subject to various forms of testing, validation and recalibration. Testing of the Soil CMS was completed to evaluate its ability to predict SOC stocks at regional and local scales. The results from the Soil CMS have been compared against independent, stratified soil sampling for South Island low producing grassland (Scott et al., 2002) and for an area of the South Island containing a range of land-cover and soil-climate categories (Tate et al., 2003a, 2003b). A regional-scale validation exercise has also been performed using the largest climate–soil–land use combination cell, moist temperate and volcanic $\times$ high producing grassland, within dependent random sampling of 12 profiles taken on a fixed grid over a large area (2,000 square kilometres). Mean values derived from the random sampling were well

within the 95 per cent confidence limits of the database values (Tate et al., 2005; Wilde et al., 2004). A second study validated the Soil CMS model for a different cell, dry temperate – high-activity clay – low producing grassland, finding no significant differences among field data, calibration data and model estimates (Hedley et al., 2012). Overall, tests have indicated that the Soil CMS estimates SOC stocks reasonably well at a range of scales (Tate et al., 2005).

The system has also been validated for its ability to predict soil carbon changes between land uses at steady state for New Zealand's main land-use change, grassland converted to planted forest. This was done by comparing the Soil CMS results with estimates based on paired sites (Baisden et al., unpublished(a); Tate et al., 2003a). This validation approach compares two nearby sites that have reasonably uniform morphological properties and were previously under a single land use, for which one site has changed to a different land use and sufficient time has elapsed for it to reach steady state values for soil carbon (Baisden et al., unpublished(a), unpublished(b)). This removes the influence that differing soil types, differing climatic conditions and previous land use regimes may have on soil carbon. Therefore, any resulting changes in soil carbon can be attributed to the most recent change in land use. In one study, results indicated that, once a weighting for forest species type was applied to the paired-site data set (to remove potential bias because *Pinus radiata* was under-represented in the analysis), the predictions of mean soil carbon from the Soil CMS model and paired sites were in agreement within 95 per cent confidence intervals (Baisden et al., unpublished(a), unpublished(b)). In a more recent study comparing low producing grassland and pre-1990 planted forests (Hewitt et al., 2012), the measured decrease in SOC under pre-1990 planted forest (-17.4 tonnes ha^{-1}) matched that determined by the Soil CMS model (McNeill et al., unpublished). This supported the Soil CMS model estimate (both in magnitude and direction) that forests planted pre-1990 have significantly lower SOC stocks than the low producing grassland and that the sampling depth of 0.3 metres was adequate for the estimation of SOC stock change.

The carbon stock estimates produced by the Soil CMS model reflect the type of soils in New Zealand (over 50 per cent being high activity clay soils) and the history of land use (fairly recent human settlement and forest clearance when compared with many other countries). As a comparison, when New Zealand reported using the Tier 1 default methodology (as in the 2011 submission), low producing grassland had the second highest SOC stock of all land uses (the highest being high producing grassland). The SOC stock for low producing grassland was also higher than for pre-1990 natural forests in that analysis.

6.3.5 Source-specific planned improvements

Improvement activities include continuing to source empirical SOC data for under-represented land use categories and activity data.

6.4 Forest land (CRF 4A)

6.4.1 Description

In *New Zealand's Initial Report under the Kyoto Protocol* (Ministry for the Environment, 2006a), national forest definition parameters were specified as required by Decision 16/CMP.1 (UNFCCC, 2006). The New Zealand parameters are a minimum area of 1 hectare, a height of 5 metres and a minimum crown cover of 30 per cent. Where the height and canopy cover parameters are not met at the time of mapping, the land has been classified as *Forest land* if the land-management practice(s) and local site conditions (including climate) are such that the forest parameters will be met over a 30- to 40-year timeframe.

New Zealand also uses a minimum forest width of 30 metres from canopy edge to canopy edge. This removes linear shelterbelts from the *Forest land* category because they are not on land

managed as forest. The width and height of linear shelterbelts can vary, because they are trimmed and topped from time to time. Further, they form part of non-forest land uses, namely *Cropland* and *Grassland* (as shelter to crops and/or animals).

New Zealand has adopted the definition of managed *Forest land* as provided in the 2006 IPCC Guidelines (IPCC, 2006a, p 1.5): "Managed land is land where human interventions and practices have been applied to perform production, ecological or social functions". Accordingly, all of New Zealand's forests, both those planted for timber production and natural forests managed for conservation values, are considered managed forests. However, emissions from *Harvested wood products* are now addressed independently (see section 6.10).

Forest land is the most significant contributor to carbon stock changes in the LULUCF sector. In 2016 forests covered 36.8 per cent (just under 10 million hectares) of New Zealand's total land area. In 2016 *Forest land* contributed –21,845.9 kt CO_2-e of net emissions. This does not include emissions for the *Harvested wood products* category because these are reported separately within the CRF Reporter. The *Harvested wood products* category and calculation of emissions for this are discussed in section 6.10.

Net emissions from *Forest land* have increased by 7,063.4 kt CO_2-e (24.4 per cent) from the 1990 level of –28,909.3 kt CO_2-e (see table 6.4.1).

In 2016 *Forest land remaining forest land* and *Land converted to forest land* were key categories (trend and level assessment).

Table 6.4.1   **New Zealand's land-use change for the Forest land category, and associated CO_2-e emissions, in 1990 and 2016**

Land use category	Net area as at 1990 (ha)	Net area as at 2016 (ha)	Net emissions (kt CO_2-e) 1990	Net emissions (kt CO_2-e) 2016	Change from 1990 (%)
Forest land remaining forest land	8,568,585	9,218,608	–9,120.1	–8,766.8	+3.9
Land converted to forest land	845,222	684,795	–19,789.2	–13,079.1	+33.9
Total	**9,413,807**	**9,903,404**	**–28,909.3**	**–21,845.9**	**+24.4**

Note: Net area in 1990 is as at 1 January 1990; net area in 2016 is as at 31 December. The area of *Land converted to forest* includes land converted up to 28 years prior, and net area values include land in a state of conversion (due to land-use change prior to 1990) and afforestation since 1990. Net emission estimates are for the whole year indicated. Columns may not total due to rounding. Percentages presented are calculated from unrounded values.

For reporting under the Convention and the Kyoto Protocol for *Forest land*, New Zealand uses three *Forest land* types: pre-1990 natural forest (predominantly native forest), pre-1990 planted forest (predominantly *Pinus radiata*) and post-1989 forest (natural and planted forests established after 31 December 1989). The definitions used for mapping these land uses are given in table 6.2.2.

While the change in total area of forest land between 1990 and 2016 is relatively small, the change in net emissions for this land is large. This is because of the disproportionate influence that plantation forests have on the emissions profile for this category. Key factors are the large area of afforestation that occurred since 1990, and the increased level of harvesting in 2016 compared with 1990 as existing planted forests have reached maturity. Afforestation since 1990 is shown in figure 6.4.1 and the change in the amount of harvesting is displayed in figure 6.4.4.

Table 6.4.2 shows land-use change by forest land type since 1990 and the associated CO_2 emissions from carbon stock change only (i.e., it excludes non-CO_2 emissions). The change in the amount of harvesting is reflected in the change in net emissions from 1990 in the pre-1990 planted forest land use. The figures for post-1989 forest also vary greatly between 1990 and

2016 because in 1990 there was only one year's worth of planting contributing to the emissions figures whereas, by 2016, there is much more land and a greater biomass on this land.

Table 6.4.2 **Change in land area and associated CO$_2$ emissions from carbon stock change between 1990 and 2016 for New Zealand's Forest land**

Land use	Net area (ha) 1990	Net area (ha) 2016	Change from 1990 (%)	Net emissions (kt CO$_2$ only) 1990	Net emissions (kt CO$_2$ only) 2016	Change from 1990 (%)
Pre-1990 natural forest	7,888,505	7,822,389	–0.8	–6,344.1	–6,147.8	+3.1
Pre-1990 planted forest	1,525,302	1,424,895	–6.6	–22,842.1	–154.3	+99.3
Post-1989 forest	0	656,120	NA	81.8	–15,628.7	–19,210.5
Total	**9,413,807**	**9,903,404**	**+5.2**	**–29,104.4**	**–21,930.8**	**+24.6**

Note: Net area in 1990 is as at 1 January 1990; net area in 2016 is as at 31 December. Net area values include land in a state of conversion to forest (due to land-use change prior to 1990) and afforestation since 1990. Net emission estimates are for the whole year indicated. Columns may not total due to rounding. Emissions associated with the conversion of forest to other land uses are reported in the land use category the land is converted to.

Table 6.4.3 shows New Zealand's carbon stock change by carbon pool within the *Forest land* category from 1990 to 2016. Over this period, the total carbon stock stored in *Forest land* has increased by 221,955.7 kt C, equivalent to emissions of –813,837.7 kt CO$_2$ since 1990.

Table 6.4.3 **New Zealand's net carbon stock change by carbon pool for the Forest land category from 1990 to 2016**

Land use	Net carbon stock change 1990–2016 (kt C) Living biomass	Net carbon stock change 1990–2016 (kt C) Dead organic matter	Net carbon stock change 1990–2016 (kt C) Soils	Net carbon stock change 1990–2016 (kt C) Total	Emissions 1990–2016 (kt CO$_2$)
Pre-1990 natural forest	43,539.6	2,329.6	–144.7	45,724.5	–167,656.7
Pre-1990 planted forest	85,450.4	18,964.9	–4,123.2	100,292.1	–367,737.8
Post-1989 forest	73,557.8	9,404.2	–7,023.0	75,939.1	–278,443.3
Total	**202,547.8**	**30,698.8**	**–11,290.9**	**221,955.7**	**–813,837.7**

Note: Emissions associated with the conversion of forest are reported in the land use category the land is converted to. Columns may not total due to rounding.

Pre-1990 natural forest

Pre-1990 natural forest is the term used to distinguish New Zealand's native and unplanted (self-sown or naturally regenerated) forests that existed prior to 1990 from pre-1990 planted forests and post-1989 forests. This land use includes both mature forest as well as areas of regenerating vegetation that have the potential to return to forest under the management regime that existed in 1990. Pre-1990 natural forest ecosystems comprise a range of indigenous and some naturalised exotic species. In New Zealand, two principal types of natural forest exist: beech forests (mainly *Fuscospora* and *Lophozonia* species) and podocarp–broadleaf forests. In addition, a wide range of seral plant communities fits into the natural forest land use where they have the potential to succeed to forest *in situ*. At present, New Zealand has just over 7.8 million hectares of pre-1990 natural forest (including these successional communities). This equates to 29.1 per cent of New Zealand's total land area.

Pre-1990 planted forest

New Zealand has a substantial estate of planted forests created specifically for timber-supply purposes. In 2016 pre-1990 planted forests covered an estimated 1.42 million hectares of New Zealand (5.3 per cent of the total land area). New Zealand's planted forests are intensively managed and there are well-established data on the estate's extent and characteristics. Having a

renewable timber resource has allowed New Zealand to protect and sustainably manage its pre-1990 natural forests. *Pinus radiata* is the dominant species, making up 90 per cent of the planted forest area. These forests are usually composed of stands of trees of a single age class, and all forests are subject to relatively standard silvicultural management regimes.

Post-1989 forest

Between 1 January 1990 and 31 December 2016, the net area of forest established as a result of reforestation activities was 656,120 hectares (taking into account deforestation of post-1989 forests). It is estimated that 93.4 per cent of this forest type is planted forest, with the remaining area comprising natural forest. *Pinus radiata* comprises 90 per cent of the planted tree species in this forest type, with Douglas fir (*Pseudotsuga menziesii*) and *Eucalyptus* species making up most of the remainder (Ministry for Primary Industries, 2016a). The vegetation in the natural forest component of post-1989 forest is early successional vegetation, similar to the seral plant communities in pre-1990 natural forest but at earlier successional stages.

The new forest planting rate (afforestation) between 1990 and 2016 was, on average, 25,291 hectares per year. New planting rates were high from 1992 to 1998, averaging 60,209 hectares per year (see figure 6.4.1). This followed a change in the taxation regime, an unprecedented price spike for forest products with subsequent favourable publicity, a government focus on forestry as an instrument for regional development and the conclusion of the state forest assets sale. The removal of agricultural subsidies and the generally poor performance of the New Zealand and international share markets also encouraged investors to seek alternatives (Rhodes and Novis, 2002).

The rate of new planting declined from 1996, reaching an estimated low of 2,788 hectares in 2008. Afforestation recovered slightly from this low to reach 14,016 and 13,397 hectares of new planting in 2011 and 2012 respectively. The increase in planting between 2008 and 2012 is largely attributable to the NZ ETS (Ministry for Primary Industries, 2011), Afforestation Grant Scheme (Ministry for Primary Industries, 2015a) and Permanent Forest Sink Initiative (Ministry for Primary Industries, 2015b), which have been introduced by the New Zealand Government to encourage new planting and regeneration of natural ecosystems. Afforestation fell again after 2012 to average 4,631 hectares between 2013 and 2016. A total of 5,099 hectares of new forest was planted in 2016. This reduction in planting rates is likely caused by the relative profitability of other forms of land use, high rural land prices and a lack of confidence in the carbon market. The exclusion of international units from the scheme on 31 May 2015 and the conclusion of the NZ ETS review and the implementation of some of its findings have contributed to higher carbon prices, which are expected to encourage larger areas of afforestation in future.

There are differences between the area defined and reported as planted forest for Convention reporting and the area captured by the National Exotic Forest Description (Ministry for Primary Industries, 2016a) from which the new planting statistics are sourced. Convention reporting uses a gross stocked area standard, which includes forest tracks, skid sites and unstocked areas. The National Exotic Forest Description reports to a net stocked area standard. To account for these area differences, the net productive forest area has been identified and modelled separately. An unstocked area component is added to the new planting statistic between 2008 and 2016 to maintain consistency with the mapped area used prior to 2008. This ensures the planted forest areas used for Convention reporting are consistent with those reported by the Ministry for Primary Industries and time-series consistency is maintained for Convention reporting. The individual emission factors for the productive and unstocked areas are derived from appropriate plots in the national plot network, as described in section 6.4.2.
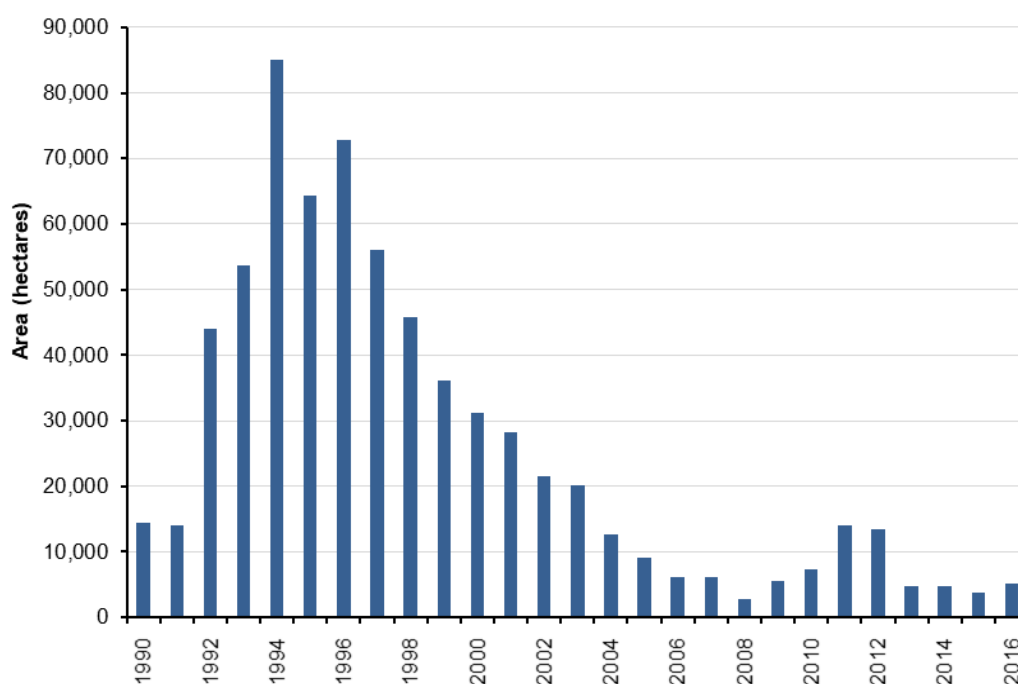
Note: Annual planting estimates are derived from annual surveys of forest nurseries, as published in the National Exotic Forest Description (Ministry for Primary Industries, 2016a) and have been scaled using a ratio derived from the LUCAS mapping of post-1989 forest area.

Post-1989 forests did not become a net sink until 1995 (see figure 6.4.2). This is due to the emissions from loss of biomass carbon stocks associated with the previous land use and the change (loss) of soil carbon with a land-use change to forestry, outweighing removals by forest growth.

Figure 6.4.2   New Zealand's net carbon dioxide removals by post-1989 forests from 1990 to 2016
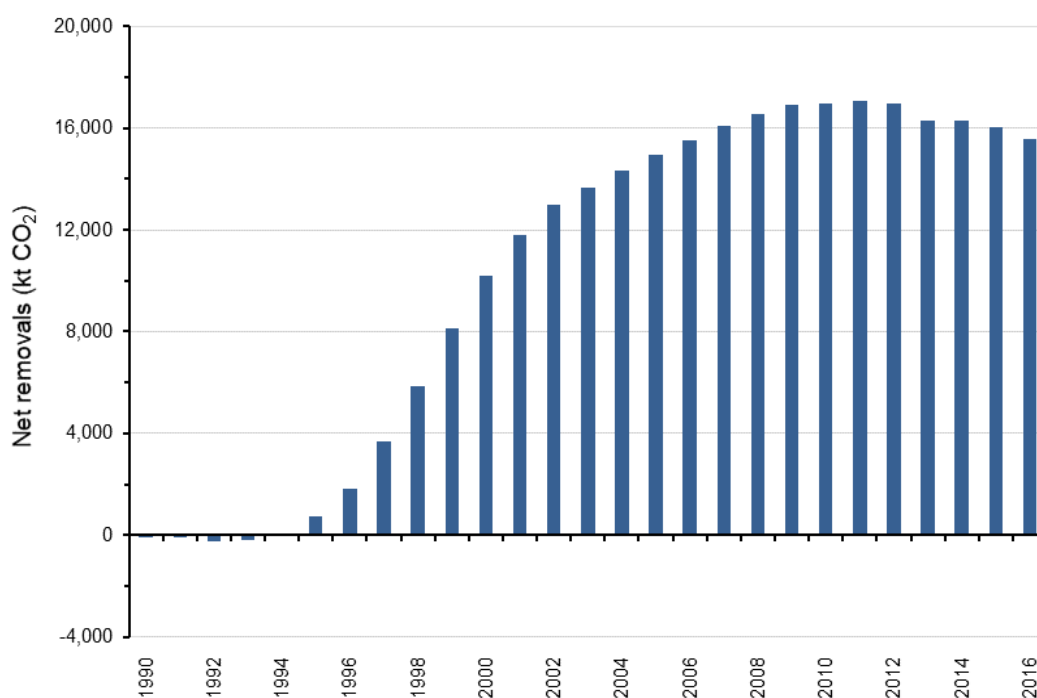
Deforestation

In 2016 an estimated 4,945 hectares of *Forest land* were converted to other land uses, primarily *Grassland*. Table 6.4.4 shows the areas of *Forest land* subject to deforestation in 2016 and since 1990. The land uses that *Forest land* has been converted to following deforestation are shown in tables 6.2.6 and 6.2.7.

Table 6.4.4   New Zealand's Forest land subject to deforestation, 1990 and 2016

| Land use | Area of forest in 1990 (ha) | Deforestation since 1990 | | Deforestation in 2016 | |
		Area (ha)	Proportion of 1990 area (%)	Area (ha)	Proportion of 1990 area (%)
Pre-1990 natural forest	7,888,505	44,766	0.57	874	0.01
Pre-1990 planted forest	1,525,302	121,918	7.99	3,524	0.23
Post-1989 forest	0	26,731	NA	547	NA
Total	**9,413,807**	**193,415**	**2.05**	**4,945**	**0.05**

Note: NA = not applicable. The 2016 areas are as at 31 December 2016; 1990 areas are as at 1 January 1990 and, therefore, differ from 1990 area values in the CRF tables, which are as at 31 December 1990. Columns may not total due to rounding.

The conversion of *Forest land* to *Grassland* is due in part to the relative profitability of some forms of pastoral farming (particularly dairy farming) compared with forestry.

Figure 6.4.3 illustrates the increase in planted forest deforestation that occurred leading up to 2008 and the decrease after the introduction of the NZ ETS in 2008.

During the first Kyoto Protocol commitment period (2008–12), it was expected that the level of deforestation would continue to be less than that seen prior to the introduction of the NZ ETS in 2008 (Manley, 2009). However, since the introduction of the NZ ETS, and throughout the first commitment period of the Kyoto Protocol, the carbon price was in steady decline and deforestation rates during this period were higher than expected. The low carbon price reduced the liability on forest owners for deforestation. The exclusion of international units from the scheme on 31 May 2015 and the conclusion of the NZ ETS review and the implementation of some of its findings have contributed to higher carbon prices. These higher carbon prices have reduced deforestation and increased the uptake of the carbon equivalent forests provision from 2015.

Figure 6.4.3   New Zealand's area of deforestation since 1990, by Forest land category
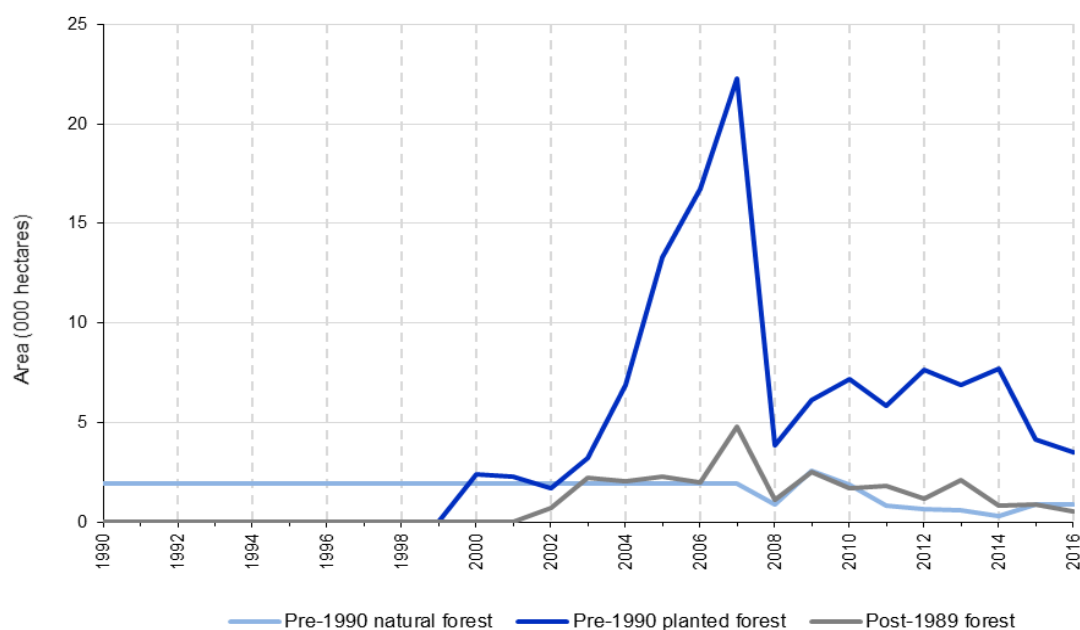
Because there are no data on the deforestation profile for pre-1990 natural forests between 1990 and 2007, the total area of deforestation detected over this period is allocated evenly across the years. The rate of pre-1990 natural forest deforestation has been confirmed from 2008 to 2012 through satellite image mapping of deforestation (see figure 6.2.5).

New Zealand assumes instant emissions of all biomass carbon at the time of deforestation, based on the following.

- The majority of deforestation since 2000 has resulted from land conversion to *Grassland*, leading to the rapid removal of all biomass as the land is prepared for farming.

- It is not practical to estimate the emission of residues following the deforestation activity, given the rapid conversion from one land use to another and multiple methods of removing residues. Furthermore, estimating residue biomass, and decay rates for multiple disposal methods, is difficult and costly.

However, estimates of biomass burning emissions associated with deforestation are provided in the National Inventory Report (see section 6.11.5).

Soil carbon changes associated with deforestation are modelled over a 20-year period using a linear change profile (see section 6.3).

These deforestation emissions are reported in the relevant *Land converted to* category, as are all emissions from land-use change. See sections 6.2.2 and 11.3.3 for further information on deforestation.

Harvesting

Figure 6.4.4 presents the estimated area of pre-planted forest harvested each year from 1990 to 2016. The estimated area between 1990 and 2009 is based on the harvested area reported in the National Exotic Forest Description (Ministry for Primary Industries, 2016a). Roundwood statistics (Ministry for Primary Industries, 2017) are used where an increase in reported harvest volume is not consistent with harvest area reported in the National Exotic Forest Description (as in 2010 and 2011) and where published area data are not yet available (as in 2016). In this situation, the roundwood statistic is multiplied by the ratio of roundwood volume-to-area harvested over the previous four years to estimate the area harvested.

Figure 6.4.4   New Zealand's area of planted forest harvest (inclusive of deforestation) from 1990 to 2016
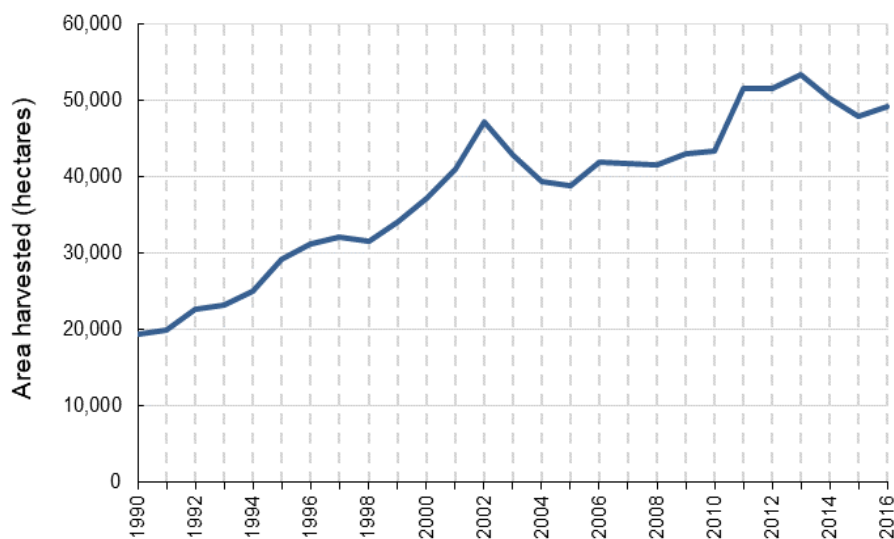
There are differences between the area defined and reported as planted forest under the Convention and the area captured by the National Exotic Forest Description from which the harvesting statistics are sourced. Reporting under the Convention applies a gross stocked area standard, which includes forest tracks, skid sites and unstocked areas. The National Exotic Forest Description generally uses a net stocked area standard. To account for these area differences, the net planted forest area for Convention reporting has been identified and modelled separately. This ensures the harvesting data used for Convention reporting are consistent with those reported by the Ministry for Primary Industries.

The total area harvested is then split by forest type.

- Pre-1990 planted forest harvesting: This was estimated as the difference between total harvesting (based on statistics from the Ministry for Primary Industries, as outlined above) and the amount of post-1989 forest harvesting estimated from mapping.

- Post-1989 forest harvesting: Post-1989 forest harvesting is estimated from the harvested area mapped between 2008 and 2016.

The harvest area in planted forests is profiled to accurately reflect the actual ages at which harvesting takes place. The harvest profile is derived from the National Exotic Forest Description (Ministry for Primary Industries, 2016a). The profiled harvesting approach is used because harvesting at a single age (e.g., 28 years) can lead to the harvest area exceeding the available area in a single age class. The profiling of harvest also maintains the integrity of the underlying age class by preventing over-mature ages from growing on unharvested. The profiling of harvest does not affect emissions because the average harvest age remains consistent between the single age class and profiled harvesting approaches.

In 2016 it is estimated that 0.06 per cent of New Zealand's total forest timber production was from the harvesting of natural forests (calculated from Ministry for Primary Industries, 2017).

No timber is legally harvested from the natural forests in the publicly owned conservation estate (an area approximately 5.5 million hectares in size; Ministry for Primary Industries, 2015c) other than in exceptional circumstances where legislation allows. On 17 April 2014, Cyclone Ita caused significant windfall damage to forests on the West Coast of the South Island. The West Coast Wind-blown Timber (Conservation Lands) Act 2014 was passed to allow the removal of timber from trees that were irreversibly damaged by Cyclone Ita. The Act does not allow timber removal from ecological areas, national parks, the Waitangiroto Nature Reserve and land covered by Te Wāhipounamu (the South West New Zealand World Heritage Area). The timber removal must be completed within a five-year period and there are restrictions on the amount of timber allowed to be salvaged from any particular area. The timber removed under the Act did not result in an increase in natural forest harvest volume in 2014 and 2015. Most other harvesting of natural forests is required by law to be undertaken on a sustainable basis.

Any harvesting that occurs in natural forests is captured within the natural forest carbon stock and stock change estimates.

6.4.2   Methodological issues

Forest land remaining forest land (CRF 4.A.1)

Only pre-1990 natural forest and pre-1990 planted forest are described in this section because post-1989 forest is included in the *Land converted to forest land* category. Land converted to post-1989 forest had been in that land use for a maximum of 26 years in 2016 so it is still within the *Land converted to forest land* category. New Zealand has chosen 28 years as the time it takes for land to reach a state of equilibrium. This is the average age at which the majority of planted radiata pine forests are harvested (Ministry for Primary Industries, 2016a). Where there

has been a land-use change between natural forest and planted forest, the associated carbon changes are reported under *Forest land remaining forest land*.

New Zealand has established a sampling framework for forest inventory purposes based on an 8-kilometre national grid system. The grid has a randomly selected origin and provides an unbiased framework for establishing plots for field and/or Light Detection and Ranging (LiDAR) measurements. The network is subdivided into a 4-kilometre grid for measurement of post-1989 forest. Forest monitoring plots are established and measured where a grid point falls in the land use to be sampled. Figure 6.4.5 shows the distribution of the pre-1990 natural and planted forest carbon monitoring plots throughout New Zealand.

Figure 6.4.5   Location of New Zealand's pre-1990 forest carbon monitoring plots
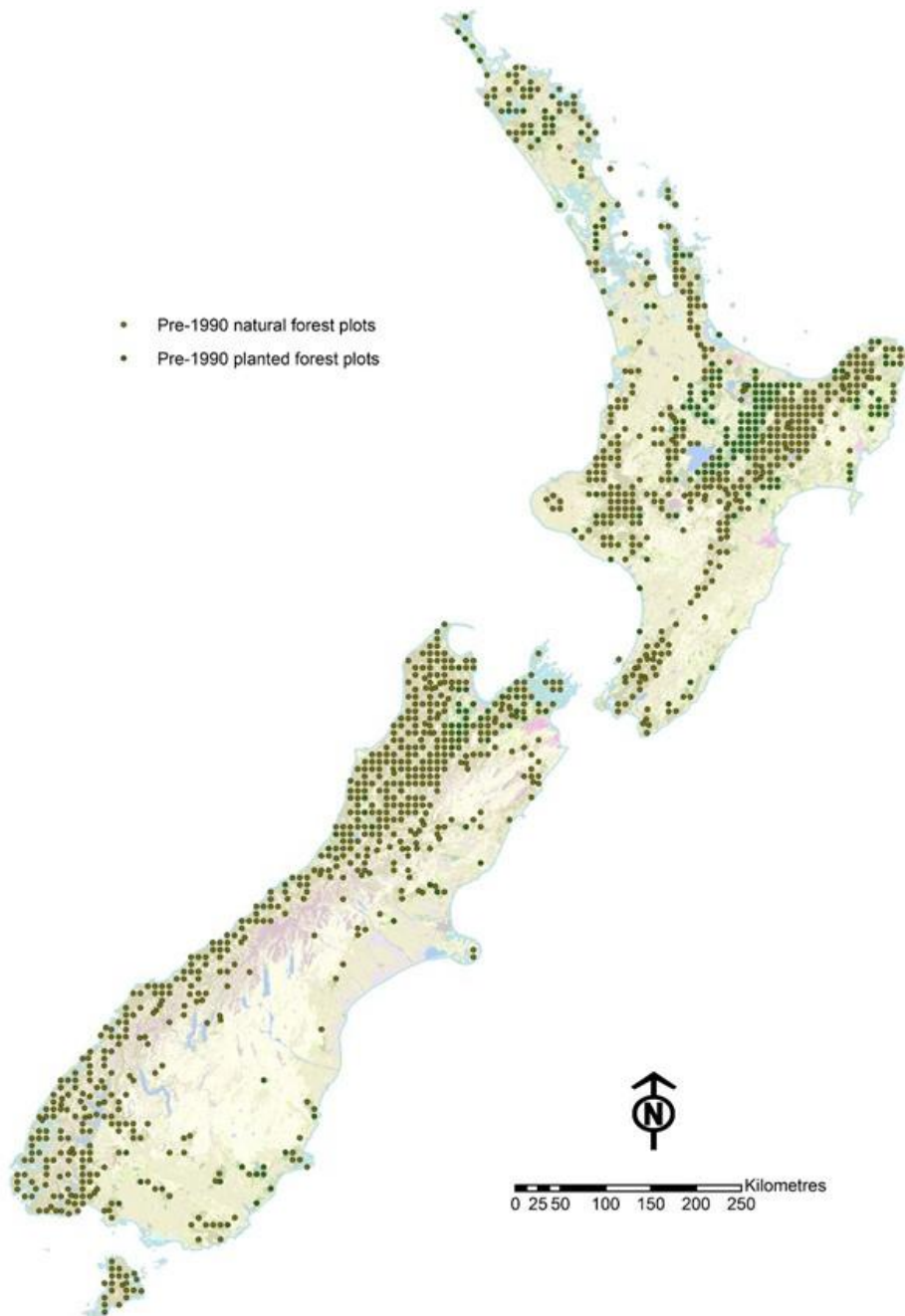
Plot network

A national monitoring programme designed to enable unbiased estimates of carbon stock and change for New Zealand's natural forests was developed between 1998 and 2001 (Coomes et al., 2002). Permanent sample plots of 0.13 hectares were installed systematically on the 8-kilometre grid across New Zealand's natural forests (see figure 6.4.5) and these were first measured over five years between 2002 and 2007.

The plots were sampled using vegetation monitoring methods designed specifically for the purpose of calculating carbon stocks (Payton et al., 2004).

Re-measurement of the plot network provides repeat measures data suitable for calculating carbon stock change in natural forest. The first re-measurement of the plot network was completed between 2009 and 2014 following methodology revised for this purpose (Ministry for the Environment, unpublished). For the third round of measurement, the programme is continuing at a reduced rate, with plots being measured on a 10-year cycle. Measurement of plots for this round began in 2014 and is scheduled for completion in 2024.

At each plot, data are collected to calculate the volumes of trees, shrubs and dead organic matter present. These measurements are then used to estimate the carbon stocks for the biomass pools of:

- living biomass (comprising above-ground biomass and below-ground biomass)

- dead organic matter (comprising dead wood and litter).

Table 6.4.5 summarises the method used to calculate the carbon stock in each biomass pool from the information collected at each plot.

Table 6.4.5   **Summary of methods used to calculate New Zealand's natural forest biomass carbon stock from plot data**

Pool		Method	Source
Living biomass	Above-ground biomass	Plot measurements; allometric equations	Holdaway et al. (2016)
	Below-ground biomass	Estimated at 20 per cent of total living biomass	Coomes et al. (2002)
Dead organic matter	Dead wood	Plot measurements; allometric equations	Holdaway et al. (2016)
	Litter	Plot samples; laboratory analysis of samples collected at plots	Holdaway et al. (2016); Garrett (unpublished)

Living biomass

Living biomass is separated into two carbon pools.

1. Above-ground biomass. The carbon content of individual trees and shrubs is calculated using species-specific allometric relationships between diameter, height and wood density (for trees), a non-specific conversion factor with diameter and height (for tree ferns) or volume and biomass (for shrubs) (Beets et al., 2012b; Holdaway et al., 2016). Shrub volumes are converted to carbon stocks using species and/or site-specific conversion factors determined from the destructive harvesting of reference samples.

2. Below-ground biomass. While the ratio of below-ground biomass to total biomass has been shown to vary from 9 per cent to 33 per cent, below-ground biomass is assumed to be 25 per cent of above-ground biomass (or 20 per cent of total biomass (as reported in Coomes et al., 2002).

Dead organic matter

Dead organic matter is separated into two carbon pools.

1. Dead wood. The carbon content of dead standing trees is determined in the same way as live trees but excludes branch and foliage biomass calculations. The carbon content of the fallen wood and stumps is derived from the volume of the piece of wood, its species (if able to be identified) and what stage of decay it is at. Dead wood comprises woody debris with a diameter greater than 10 centimetres.

2. Litter. The carbon content of the fine debris is calculated by laboratory analysis of sampled material. Litter comprises fine woody debris (dead wood from 2.5 centimetres to 10.0 centimetres in diameter), the litter (all material less than 2.5 centimetres in diameter) and the fermented humic horizons. Samples were taken at approximately one-third of the natural forest plots.

Carbon stock change

Carbon stock change in natural forest is calculated as the difference in carbon stock at time two minus time one. This is calculated for each plot, and the mean change across all plots is used as the national average. New Zealand has inventoried its pre-1990 natural forest at two points in time: 2002–07 and 2009–14. The average measurement date of the first measurement period is 2004 and average measurement date of the second measurement period is 2011.

Between 2002–07 and 2009–14, the regenerating forest component of New Zealand's pre-1990 natural forest was a net sink of carbon, sequestering 1.39 tonnes C ha^{-1} yr^{-1} (95 per cent confidence interval 0.84 to 1.94) (Holdaway et al., 2016). The data are extrapolated back to 1990 and forward to the current inventory year to calculate stock changes for all years. Due to the dominance of tall forest types, the combined overall net change across all pre-1990 natural forest was indistinguishable from zero (+0.34 tonnes C ha^{-1} yr^{-1} (95 per cent confidence interval −0.09 to 0.77); Holdaway et al., 2016). Carbon stock change in regenerating forest was driven primarily by an increase in live above-ground biomass of 1.06 tonnes C ha^{-1} yr^{-1} (95 per cent confidence interval 0.65 to 1.47) (Holdaway et al., 2016).

Soil organic carbon

Mineral SOC stocks in *Pre-1990 natural forest land remaining pre-1990 natural forest land* are estimated using a Tier 2 method. The steady state mineral SOC stock in pre-1990 natural forest is estimated to be 92.25 tonnes C ha^{-1} (see table 6.3.2).

For organic soils, IPCC good practice guidance is limited to the estimation of carbon emissions associated with the drainage of organic soils in managed forests (IPCC, 2006a, section 4.2.3.1). In New Zealand, natural forests are not drained and, therefore, oxidation processes associated with drainage are not occurring. It is therefore assumed that there are no carbon emissions from organic soils in *Pre-1990 natural forest land remaining pre-1990 natural forest land*.

Non-CO₂ emissions for pre-1990 natural forest

Direct N₂O emissions from nitrogen fertilisation of forest land and other land

New Zealand activity data on nitrogen fertilisation are not currently disaggregated by land use, and, therefore, all *Direct N₂O emissions from nitrogen fertilisation of forest land and other land* are reported in the Agriculture sector under the category *Direct N₂O emissions from managed soils*.

All planted forest land established prior to 1990, whether established for wood production or ecosystem services, is included as pre-1990 planted forest. This category also includes areas that were natural forest in 1990 but have since been planted with exotic forest. The emissions associated with this area are calculated as the removal of biomass associated with pre-1990 natural forest and the subsequent growth of pre-1990 planted forest. The pre-1990 planted forest yield table best represents the growth on ex-natural forest land because it remains in the *Forest land* category. It has been demonstrated in the development of the post-1989 forest yield table that forests planted on grassland are more productive than those planted on forest land (Paul et al., unpublished(b)).

Pre-1990 planted forest inventory

New Zealand's pre-1990 planted forest was sampled in 2010 and again in 2015. The analysis of the data collected has provided a plot-based estimate of carbon stock and mean carbon density within this forest type (Beets et al., 2012a). The pre-1990 planted forest inventory is closely linked, in terms of design and methodology, with the post-1989 planted forest inventory described later in this section.

For the pre-1990 planted forest inventory, 202 circular 0.06-hectare plots (see figure 6.4.5) were established on a systematic 8-kilometre grid consistent with that used for all forest categories. These plots were ground measured using procedures described in Herries et al. (unpublished). Stand records and ground measurements were recorded between June and September at each plot. Measurements included: tree age; stocking (stems per hectare); stem diameters at breast height of live and dead trees; a sample of tree total heights for each tree species; pruned heights; and the timing of pruning and thinning activities. Ground plot centres were located using a 12-channel differential global positioning system (GPS) for accurate LiDAR co-location and relocation for future measurements (Beets et al., 2012a).

Airborne scanning LiDAR data were collected from 351 plots, including those that were ground measured. The LiDAR-only plots are located on the same 8-kilometre (north–south) by 8-kilometre (east–west) grid as ground measured plots but with the plots located at points off the grid intersections (Paul et al., unpublished(a)).

Living biomass and dead organic matter

The crop tree plot data collected from the planted forest inventories were modelled using a forest carbon modelling system developed for the two most common plantation tree species in New Zealand (the Forest Carbon Predictor, version 4.1; Beets and Kimberley, unpublished). To enable predictions of carbon stocks and changes in New Zealand's planted forests, this system integrates:

- the 300 Index growth model (Kimberley and Dean, 2006) for *Pinus radiata*
- the 500 Index growth model for Douglas fir (Knowles, 2005)
- a wood density model (Beets et al., 2007)
- a stand tending model (Beets and Kimberley, unpublished)
- the C_Change carbon allocation model (Beets et al., 1999).

The individual components of the Forest Carbon Predictor are explained below and illustrated in figure 6.4.6.

The 300 Index and 500 Index growth models produce a productivity index for forest plots derived from stand parameters. These stand parameters include: stand age, mean top height, basal area, stocking and stand silvicultural history. Plot latitude and altitude are also required to

run the models. The growth models use these parameters to predict stem volume under bark over a full rotation (planting to harvest). A specific productivity index is produced for each plot, which is then used to estimate the total live and dead stem volume by annual increment. The growth models account for past and future silvicultural treatments using plot data, information on past silvicultural treatments and assumptions of future management events based on plot observations and standard regimes (Beets and Kimberley, unpublished).

The wood density model within the Forest Carbon Predictor uses site mean annual temperature, soil nitrogen fertility, ring age and stocking to determine the mean density of stem wood growth sheaths produced annually in *Pinus radiata*. Wood density is an important variable in the estimation of carbon. Of the parameters entered into the wood density model, temperature and stand age have the greatest influence on wood density, followed by site fertility and stocking. The combined result of these individual effects can be substantial, as shown in table 6.4.6 (Beets et al., 2007).

Table 6.4.6   Influence of individual site and management factors on predicted wood density for New Zealand planted forest

Factor affecting wood density	Range in predicted density	
	(kg m^{-3})	(% difference)
Temperature: 8°C versus 16°C	359–439	22
Age: 10-year-old versus 30-year-old	380–446	17
C:N ratio: 12 versus 25	384–418	9
Stocking: 200 versus 500 stems ha^{-1}	395–411	4

Note: C:N = carbon:nitrogen.

The stand tending model: New Zealand's plantation forests are intensively managed and, therefore, pruning and thinning provide the majority of the inputs to the dead wood and litter pools. The Forest Carbon Predictor requires silvicultural history inputs to predict changes between biomass pools over time. The information required includes initial stocking, the timing of management events, stocking following each thinning operation and the pruned height and number of stems pruned for each pruning lift. Information on silvicultural events prior to the plot measurement date is normally gathered from forest owners but sometimes these data are incomplete. A history module has been incorporated into the Forest Carbon Predictor that makes use of existing data to identify potential gaps in the stand history. Within the history module, assumptions are made to complete the stand history based on field observations, standard management regimes and known silviculture to date (Beets and Kimberley, unpublished). The history module enables reasonable estimates of stand history and, therefore, biomass transfers between pools resulting from past silvicultural events.

The C_Change carbon allocation model is integrated into the Forest Carbon Predictor and is designed to apportion carbon to needles, branches, stems, roots and reproductive parts via growth partitioning functions. Dead wood and litter pools are estimated by accounting for losses to the live pools from natural mortality, disease effects on needle retention, branch and crown mortality and silvicultural management activities, for example, pruning and thinning. Component-specific and temperature-dependent decay functions are used to estimate losses of carbon to the atmosphere (Beets et al., 1999). The Forest Carbon Predictor also takes into account biomass removals during production thinning.

The individual plot yield curves generated by the Forest Carbon Predictor are combined into estimates of above-ground live biomass, below-ground live biomass, dead wood and litter in an area-weighted and age-based carbon yield table for the productive area of each type of planted forest. Plots that are located outside the productive area within the mapped forest boundary are used to provide emission factors for unstocked areas in post-1989 forest and pre-1990 planted forest (Paul et al., unpublished(c)).

Below-ground biomass is derived from the above-ground biomass estimates. For plantation crop trees, below-ground biomass is assumed to be 15 per cent to 20 per cent of total production, depending on stand age (Beets et al., 1999). The ratio for non-crop trees and shrubs is 25 per cent (Coomes et al., 2002).

The carbon content of the dead wood pool within rotation is estimated using the Forest Carbon Predictor model as described above. Immediately following harvesting, 30 per cent of the above-ground biomass pool is transferred to the dead wood pool; the other 70 per cent is instantaneously emitted. All material in the dead wood and litter pools is decayed using an empirically derived, temperature-dependent decay profile as described in Garrett et al. (2010).

Figure 6.4.6   New Zealand's planted forest inventory modelling process
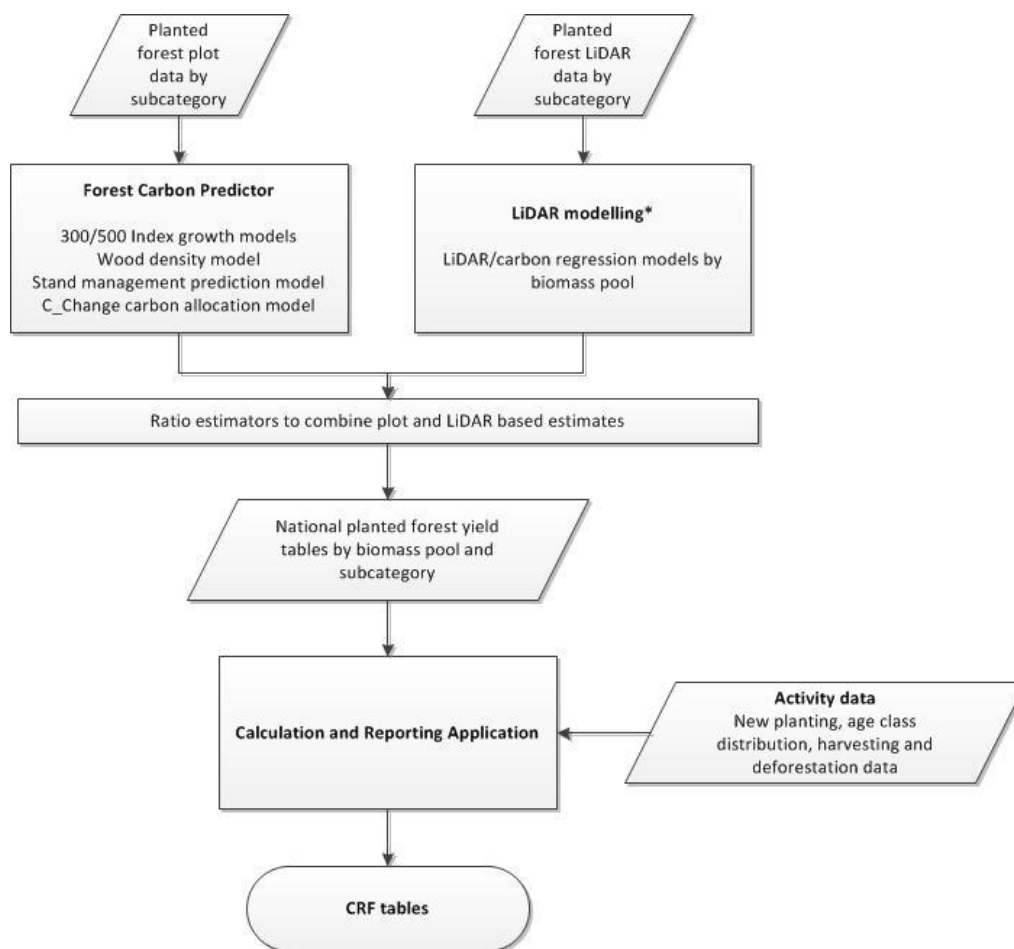
Note: CRF = common reporting format; LiDAR = Light Detection and Ranging. * LiDAR data are used for pre-1990 planted forests and were obtained in 2015.

For shrubs and non-crop tree species measured within the planted forest plot network, the carbon content is estimated using species-specific allometric equations. These equations estimate carbon content from diameter and height measurements, and wood density by species (Beets et al., 2012a).

Stock change in the productive area of pre-1990 planted forests is estimated using a forest type-specific national yield table. Plots that are located outside the productive area within the mapped forest boundary are used to provide emission factors for unstocked areas of pre-1990 planted forests (Paul et al., unpublished(a)).

To utilise both plot measurements described above under the pre-1990 planted forest inventory, a single yield table per plot was developed using:

- the earlier measurement for ages below the first measurement age

- the later measurement for ages above the later measurement age

- an interpolated estimate for the ages between the earlier and later measurements.

For plots that were measured once, a ratio estimator derived from the plots that were measured twice was applied to the predicted stocks at the missing measurement date (assuming that the correction for possible bias was the same in both strata) (Paul et al., unpublished(a)).

The following approach was used to develop a LiDAR-adjusted yield table for pre-1990 planted forests. Forest age was obtained from forest owners' stand records for LiDAR plots that were not coincident with a ground-measured plot. A regression model was developed for predicting age 20 carbon from LiDAR metrics and forest age. A ratio estimator was developed from the LiDAR-derived estimate of age 20 carbon and the estimate obtained from the ground plots. This ratio estimator was used to adjust the yield table. The adjustment was used for all ages in the yield table and was also applied to all carbon pools in the table (Paul et al., unpublished(a)).

The carbon stock in pre-1990 planted forest as at 31 December 2014, estimated directly from the national plot network, is 130.7 ± 11.4 tonnes C ha^{-1} (at the 95 per cent confidence interval) (Paul et al., unpublished(a)).

Soil organic carbon

SOC stocks in *Pre-1990 planted forest remaining pre-1990 planted forest* are estimated using a Tier 2 method for mineral soils and a Tier 1 method for organic soils (see section 6.3). The steady state mineral SOC stock in pre-1990 planted forest is estimated to be 92.44 tonnes C ha^{-1} (see table 6.3.2).

The IPCC default emission factor for organic soils under planted forest is 0.68 tonnes C ha^{-1} per annum (see table 6.3.3). Soil carbon change with harvesting is not explicitly estimated because the long-term SOC stock for this land use includes any emissions associated with harvesting.

Non-CO$_2$ emissions for pre-1990 planted forest

Direct N$_2$O emissions from nitrogen fertilisation of forest land and other land

New Zealand activity data on nitrogen fertilisation are not currently disaggregated by land use and, therefore, all *Direct N$_2$O emissions from nitrogen fertilisation of forest land and other land* are reported in the Agriculture sector under the category *Direct N$_2$O emissions from managed soils*.

Land converted to forest land (CRF 4.A.2)

All *Land converted to forest land* since 1 January 1990, either by planting or as a result of human-induced changes in land-management practice (e.g., removing grazing stock and actively facilitating the regeneration of tree species), is included as post-1989 forest. Post-1989 forest is split into two divisions for calculating emissions and removals: post-1989 natural forest and post-1989 planted forest. Reporting is at the aggregate level of post-1989 forest in the National Inventory Report.

When non-forest land is converted to forest land, all living biomass that was present at the time of forest establishment is assumed to be instantly emitted as a result of forest establishment preparation. Between 1990 and 2016, approximately 59 per cent of the non-forest land converted to post-1989 forest has been from low producing grassland, with 22 per cent

converted from grassland with woody biomass and a further 18 per cent converted from high producing grassland. Grassland with woody biomass provides the largest source of emissions associated with land-use change to forest because of the amount of biomass present prior to land-use conversion.

New Zealand's post-1989 forests have been sampled on a systematic 4-kilometre grid-based plot network consistent with that used for the other forest types, as shown in figure 6.4.7. Sampling includes both post-1989 planted forest and post-1989 natural forest; the method is described below.

Figure 6.4.7   Location of New Zealand's post-1989 forest plots
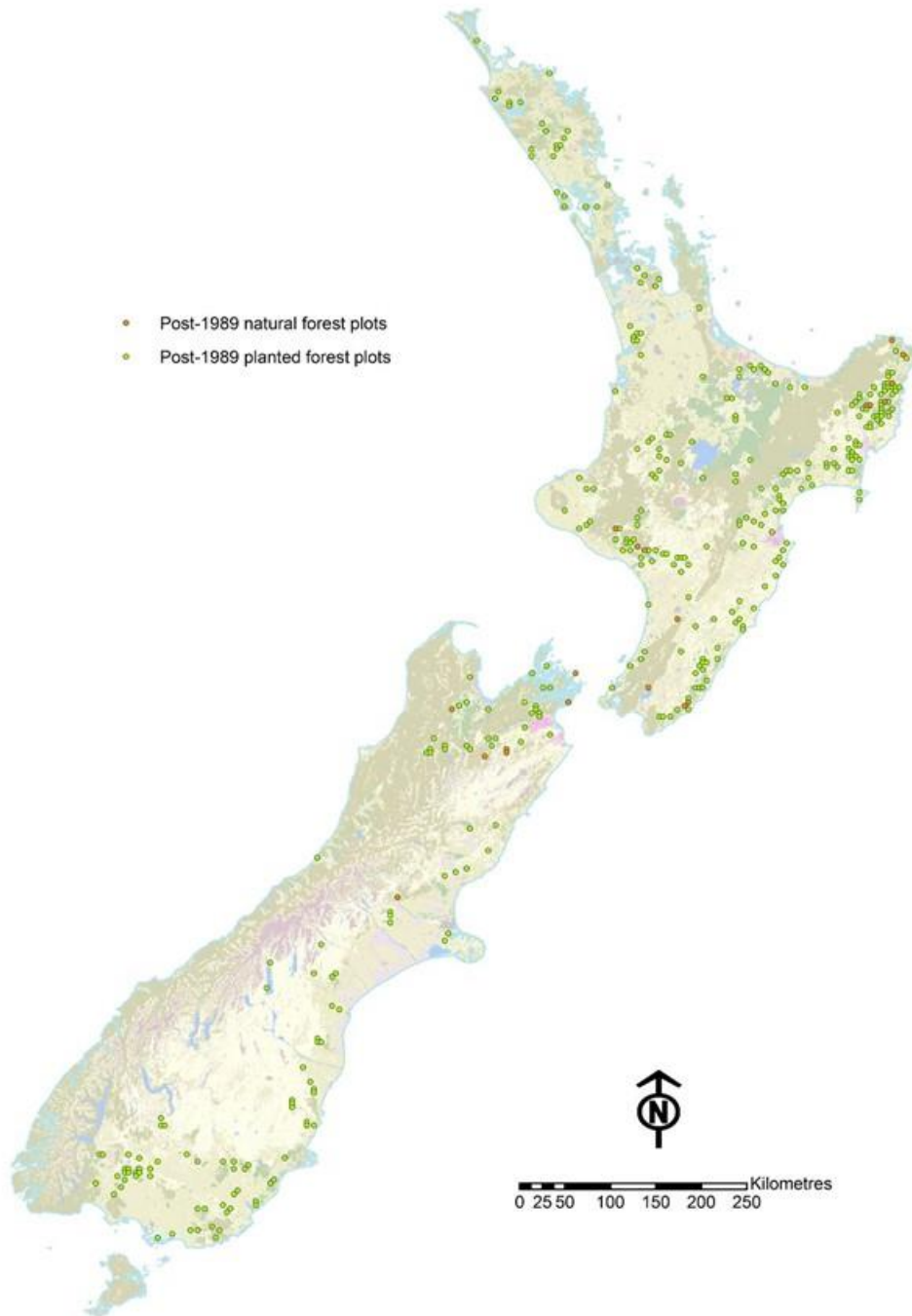
Post-1989 planted forests

All forest land planted since 1 January 1990, whether established for wood production or soil control purposes, is included as post-1989 forest.

Living biomass and dead organic matter

A plot-based forest inventory system has been developed for carbon estimation in New Zealand's post-1989 planted forest (see Beets et al., 2011a). The majority of post-1989 forests in New Zealand are privately owned and access could not be guaranteed at the beginning of the inventory. Initially, a double-sampling approach involving LiDAR was employed to reduce the possibility of sampling bias arising from unmeasured plots (Stephens et al., 2012). In practice, access to privately owned forests was generally unrestricted so LiDAR was used to improve the precision of the carbon stock estimates using a ratio estimator procedure.

In the post-1989 planted forest inventory, circular 0.06 hectares of permanent sample plots have been established within forests on a systematic 4-kilometre grid coincident with that used for the pre-1990 natural forest and pre-1990 planted forest inventories (Moore and Goulding, unpublished). Permanent sample plots were selected over temporary sample plots because change over time is more easily analysed when there are multiple measurements of the same plot set (Beets et al., 2011a).

The initial post-1989 planted forest inventory was carried out during the winters of 2007 and 2008 at 246 sites consisting of up to four sample plots in a cluster arrangement. Plots were sampled using methodology as described in Payton et al. (unpublished). A second inventory was carried out during the winters of 2011 and 2012 where the centre plot of the earlier established cluster plots was re-measured and additional plots were established. In total, 342 plots were ground measured from the mapped area of post-1989 planted forest in the second inventory. Importantly, the additional plots in the later inventory addressed a bias in the earlier estimates caused by incomplete sampling of the forest area. This was due to the initial field inventory beginning prior to the completion of the 2008 land use map. The planted forest inventory shifted from a periodic to a continuous inventory in 2016. The continuous inventory measures around 140 permanent sample plots annually over a five-year re-measurement cycle. The continuous inventory provides annual data on forest management (e.g., harvest age and thinning), natural disturbance and growth that can be incorporated into planted forest emission factors.

The ground measurements in the post-1989 planted forest inventory include: stem diameters of live and dead trees at breast height; a sample of tree total heights for each tree species; pruned heights, measurement of dead wood and soil fertility samples for predicting wood density (Beets et al., 2011a). Silvicultural information, including tree age, stocking (stems per hectare) and timing of pruning and thinning activities, was gathered from forest owners and estimated by field teams on site. Ground plot centres were located using a 12-channel differential GPS for sub-meter LiDAR co-location and for relocation in future inventories (Beets et al., 2011a).

Stock change in the productive area of post-1989 planted forests is estimated using a forest type-specific national yield table approach similar to that described above under 'Living biomass and dead organic matter' within pre-1990 planted forest. Plots that are located outside the productive area within the mapped forest boundary are used to provide emission factors for unstocked areas of post-1989 planted forests (Paul and Kimberley, unpublished).

To utilise all plot measurements described above, a single yield table per plot was developed using the estimated carbon stock at each measurement date. An interpolated estimate was used to provide carbon stock at all ages between the measurement dates. The advantage of the interpolation method is that it maintains the actual carbon stock values at individual measurement dates. Individual yield tables were combined as weighted means in a national yield table for the productive area of post-1989 planted forest (Paul and Kimberley, unpublished).

New Zealand plantation forests are actively managed, with thinning and pruning activities undertaken early in the rotation. The majority of these activities are completed before trees reach the age of 13 years. Thus the dead wood and litter pools from these management practices gradually increase leading up to this age. After the age of 13 years, when pruning and thinning cease and decay exceeds inputs, these pools then decline. Due to the age-class structure of post-1989 forest in New Zealand, this can be seen as a rapid increase in the dead wood and litter pools over consecutive years.

The carbon stock estimate for the productive area of post-1989 planted forest is 145.97 ± 21.1 tonnes C ha^{-1} (at the 95 per cent confidence interval) as at 31 December 2016 (Paul and Kimberley, unpublished). This carbon stock estimate, while high, is consistent with the international comparisons provided in table 4.8 of the 2006 IPCC Guidelines (IPCC, 2006a) and reflects the composition of this forest type, which involves fast-growing and actively managed production forestry.

Post-1989 natural forests

Post-1989 natural forest is forest land established since 1 January 1990 resulting from direct human-induced changes in land-management practice. The resulting vegetation is a seral plant community comprised of a mix of native and introduced species. It is in the early successional stages of reversion to mature forest. As this vegetation matures, it generally becomes increasingly dominated by native species and in most cases will become native forest. For example, the active facilitation of tree species regeneration through the removal of grazing stock would result in the land use changing from *Grassland* to *Forest land*. The post-1989 natural forest area covers an estimated 43,501 hectares.

Estimates of carbon stock and stock change in post-1989 natural forest are calculated based on measurements taken in a field inventory. The inventory samples post-1989 natural forest using 0.04 hectare permanent sample plots on a systematic 4-kilometre grid (consistent with the post-1989 planted forest inventory). Twenty plots in post-1989 natural forest were established and measured for the first time in 2012. The plot network design is described in Beets et al. (2012a, 2014b), and detailed methods for plot measurement are given in the data collection manual (Ministry for the Environment, unpublished).

Living biomass and dead organic matter

At permanent sample plots within post-1989 natural forest, measurements are taken of standing and fallen, live and dead plants. Destructive biomass samples taken outside of the plots are used to create plot-specific allometric equations, which are applied to these measurements to calculate above-ground live biomass.

Biomass of standing dead wood (woody debris with a diameter greater than 10 centimetres) and litter (woody debris with a diameter of less than 10 centimetres) is calculated as for living biomass but is then adjusted for decay using decay functions. Biomass of fallen dead wood is calculated from plot measurements of volume in combination with species-specific wood densities and then also adjusted for decay in the same way.

Biomass sampling on post-1989 natural forest plots includes the determination of plant age, which enables the backcasting of biomass through time. Backcast estimates of biomass are used to calculate carbon stock change. The method used to do this was developed and validated using plots for which multiple measurements in time had been obtained and for which carbon stock change was able to be measured directly (Beets et al., 2014a). Full methods for the calculation of carbon stock and stock change in post-1989 natural forest are described in Beets et al. (2014b).

The carbon stock estimate for post-1989 natural forest is 28.73 ± 7.14 tonnes C ha^{-1} (at the 95 per cent confidence interval) as at 31 December 2012 (Beets et al., 2014b). The average rate of carbon sequestration in post-1989 natural forest over the first commitment period is 2.4 tonnes C ha^{-1} yr^{-1} (calculated from Beets et al., 2014b). This rate is similar to previously reported rates of carbon sequestration in regenerating shrubland in New Zealand (Carswell et al., 2012; Trotter and MacKay, unpublished).

Soil organic carbon

SOC stocks in land converted to post-1989 forest are estimated using a Tier 2 method for mineral soils and a Tier 1 method for organic soils, as described in section 6.3. The steady state mineral SOC stock in post-1989 forest is estimated to be 91.92 tonnes C ha^{-1} (see table 6.3.2).

In the absence of data on the rate of change specific to country and land use, the IPCC default method of a linear change over a 20-year period is used to estimate the change in SOC stocks between the original land use and post-1989 forest land for any given period. For example, the soil carbon change associated with a land-use change from low producing grassland (SOC stock 105.98 tonnes C ha^{-1}) to post-1989 forest (SOC stock 91.92 tonnes C ha^{-1}) would be a loss of 14.06 tonnes C ha^{-1} over the 20-year period.

The IPCC default emission factor for organic soils under planted forest is 0.68 tonnes C ha^{-1} per annum (see table 6.3.3). This is also applied to organic soils on land converted to post-1989 forest.

Quality assurance and quality control

Quality-assurance and quality-control activities were conducted throughout the post-1989 planted and natural forest data capture and processing steps. These activities were associated with the following: inventory design (Beets et al., 2014b; Brack, unpublished; Moore and Goulding, unpublished); acquisition of raw LiDAR data and LiDAR processing; checking eligibility of plots; independent audits of field plot measurements (Beets and Holt, unpublished); data processing and modelling; regression analysis and double-sampling procedures (Woollens, unpublished); and investigating LiDAR and ground plot co-location (Brack and Broadley, unpublished). These activities, along with those undertaken within the post-1989 natural forest, are described in more detail in section 6.4.4.

Non-CO$_2$ emissions for post-1989 forest

Direct N$_2$O emissions from nitrogen fertilisation of forest land and other land

New Zealand activity data on nitrogen fertilisation are not currently disaggregated by land use and, therefore, all *Direct N$_2$O emissions from nitrogen fertilisation of forest land and other land* are reported in the Agriculture sector under the category *Direct N$_2$O emissions from managed soils*.

6.4.3   Uncertainties and time-series consistency

Emissions from *Forest land* are 8.3 per cent of New Zealand's net emissions uncertainty in 2016 (annex 2). *Forest land* introduces 5.0 per cent uncertainty into the trend in the national total from 1990 to 2016.

Pre-1990 natural forest

The uncertainty in mapping pre-1990 natural forest is ± 5.0 per cent (see table 6.4.7). Further details are given in section 6.2.5.

Uncertainty in biomass carbon stock and stock change in New Zealand's pre-1990 natural forest is calculated using a published methodology designed specifically for this purpose (Holdaway et al., 2014). The pre-1990 natural forest plot network provides biomass carbon stock estimates that are within 95 per cent confidence intervals of ±4.4 per cent of the mean (257.74 ± 11.33 tonnes C ha^{-1}) for tall natural forest and ±18.27 per cent of the mean (88.80 ± 16.23 tonnes C ha^{-1}) in regenerating natural forest (Holdaway et al., 2016). Estimates of carbon stock change in the regenerating component are within 95 per cent confidence intervals of ±39 per cent of the mean (+1.39 ± 0.55 tonnes C ha^{-1}). No significant change was found in the tall forest component of pre-1990 natural forest (0.34 ± 0.43 tonnes C ha^{-1} yr^{-1}). The variation between individual plot estimates of biomass carbon change in regenerating and tall pre-1990 natural forest provides a combined uncertainty of ±126.6 per cent for the category (Holdaway et al., 2016).

Table 6.4.7   **Uncertainty in New Zealand's 2016 estimates from Pre-1990 natural forest (including land in transition)**

Variable	Uncertainty at a 95% confidence interval (%)
Activity data	
Uncertainty in land area	±5.0
Emission factors	
Uncertainty in biomass carbon stocks	±6.7
Uncertainty in biomass carbon change	±126.6
Uncertainty in soil carbon stocks	±7.9
Uncertainty introduced into net emissions for LULUCF	**±34.2**

Note: A Monte Carlo simulation approach was used to assess the main sources of uncertainty in carbon stock and carbon stock change in pre-1990 natural forest. Land area includes land in transition in 2016. The activity data and combined emission factor uncertainty are weighted values and have been calculated using equations 3.1 and 3.2 from IPCC General Guidance and Reporting (IPCC, 2006b).

Pre-1990 planted forest

A national plot-based inventory system, in conjunction with a suite of models, is used to estimate carbon stock and change within New Zealand's planted forest (see Beets et al., 2012a). The models are collectively called the Forest Carbon Predictor version 4.1 (Beets and Kimberley, unpublished) and are described in further detail in section 6.4.2 under 'Living biomass and dead organic matter' for pre-1990 planted forest. Extensive work has been carried out to reduce the uncertainty in the estimates, including the use of a specifically designed plot network and research-based improvements to the models.

A paper has been published on the validation of the Forest Carbon Predictor model (Beets et al., 2011b) used to produce carbon yield tables for the LULUCF sector. For the plots in this study, they found that estimates of total carbon stock per plot made using the Forest Carbon Predictor were within 5 per cent of measured values. When just above-ground biomass per plot was considered, accuracy was within approximately 1 per cent. Carbon stock change was estimated within 5 per cent accuracy when linked with plot data at the start and end of each five-year period, linking closely with the scheduled duration between the national plot-based inventories (Moore and Goulding, unpublished).

New Zealand's pre-1990 planted forests were sampled in 2010 and 2015, and the analysis of the data collected has provided an unbiased plot-based estimate of carbon stock and change within this forest type. This has reduced the uncertainty of the biomass estimates and growth from the previous estimate based on the National Exotic Forest Description (Ministry for Primary Industries, 2016a). The uncertainty of the pre-1990 planted forest biomass estimate at the 95 per cent confidence interval is ±11.4 per cent (see table 6.4.8).

The uncertainty in the estimates of pre-1990 planted forest for the 2018 submission is provided in table 6.4.8.

Table 6.4.8   **Uncertainty in New Zealand's 2016 estimates from pre-1990 planted forest (including land in transition)**

Variable	Uncertainty at a 95% confidence interval (%)
Activity data	
Uncertainty in land area	±5.0
Emission factors	
Uncertainty in biomass carbon stocks	±11.4
Uncertainty in soil carbon stocks	±12.3
Uncertainty introduced into net emissions for LULUCF	**±34.0**

Note: The biomass uncertainties are low for pre-1990 planted forest (±11.4 per cent). However, the total uncertainty for the category is calculated on the net change. The age structure of the estate in 2016 results in large removals from growth and large emissions from harvesting, leaving a relatively small net change. Therefore, uncertainty is high in this category. Land area includes land in transition in 2016. The activity data and combined emission factor uncertainty are weighted values and have been calculated using equations 3.1 and 3.2 from IPCC General Guidance and Reporting (IPCC, 2006b).

Post-1989 forest

As described in section 6.4.2, post-1989 forest is split into post-1989 natural and post-1989 planted forest. The modelling process for post-1989 planted forest is similar to pre-1990 planted forest, and the uncertainty in the modelling process is outlined above. Additionally, the Forest Carbon Predictor validation is described in Beets et al. (2011b) and New Zealand's inventory approach is described in Beets et al. (2011a).

New Zealand's post-1989 planted forests were first sampled in 2007 and 2008, and were re-measured in 2011 and 2012. The planted forest inventory shifted from a periodic to a continuous inventory in 2016. The inventory provides a plot-based estimate of carbon stock within this forest type. The uncertainty of the post-1989 planted forest biomass estimate at the 95 per cent confidence interval is ±28.3 per cent (Paul and Kimberley, unpublished).

When post-1989 forests were initially inventoried in 2007 and 2008, the mapping of the forest extent had yet to be completed. Consequently, the initial post-1989 forest sample was incomplete. When the national forest map had been completed, additional plots were measured in 2012 and 2013. The continuous inventory initiated in 2016 includes new planted forest plots as they are identified. The inclusion of these plots in the analysis provided an unbiased and representative sample of post-1989 planted and natural forests.

The continuous planted forest inventory provides annual data on forest management (e.g., harvest age and thinning), natural disturbance and growth that can be incorporated into planted forest emission factors.

The inventory of post-1989 natural forest provides estimates of carbon stock that are within 24.9 per cent of the mean at the 95 per cent confidence level as at 2012 (Beets et al., 2014b).

The uncertainty in the estimates of post-1989 forest for the 2018 submission is provided in table 6.4.9.

Table 6.4.9   Uncertainty in New Zealand's 2016 estimates from post-1989 forest (including land in transition)

Variable	Uncertainty at a 95% confidence interval (%)
Activity data	
Uncertainty in land area	±8.0
Emission factors	
Uncertainty in biomass carbon stocks	±29.2
Uncertainty in soil carbon stocks	±10.4
Uncertainty introduced into net emissions for LULUCF	**±19.6**

Note: Land area includes land in transition in 2016. The biomass carbon stocks value is the weighted value for post-1989 natural and post-1989 planted forests. The activity data and combined emission factor uncertainty are weighted values and have been calculated using equations 3.1 and 3.2 from IPCC General Guidance and Reporting (IPCC, 2006b).

6.4.4   Category-specific QA/QC and verification

Carbon dioxide emissions from both *Forest land remaining forest land* and *Land converted to forest land* are key categories for both level and trend assessments. In the preparation of this inventory, the data for these emissions underwent Tier 1 quality-assurance and quality-control checks as well as Tier 2, category-specific quality-assurance and quality-control checks. Details of these checks are provided below.

Pre-1990 natural forest

Quality control and assurance are undertaken at the data collection, data entry and data analysis stages for natural forest.

During the initial measurement of the natural forest plot network (2002–07), 5 per cent of plots measured in the first field season were subject to audit (Beets and Payton, unpublished). In all subsequent field seasons, data collection followed quality-assurance and quality-control processes, as described in Payton et al. (unpublished, 2004). This included on-site quality-control checks of field data and review by senior ecologists. Data were collected in the field and recorded by hand on paper field sheets. The electronic entry of all data has been subject to ongoing quality assurance and quality control, including line-by-line checking of the transcription of all data used in carbon calculations.

During the re-measurement of the plot network from 2009–14, 10 per cent of plots measured were subject to independent audit. For the current re-measurement of the plot network, this has been reduced to 5 per cent of plots measured. This audit involves a partial re-measure of randomly selected plots, and the assessment of measurements against data quality standards as described in the data collection manual (Ministry for the Environment, unpublished). Data entry of all data is subject to quality assurance by the Ministry for the Environment for 10 per cent of plots. The data are also subject to further checking for measurement and data entry errors prior to analysis (Holdaway et al., unpublished).

Pre-1990 planted forest and post-1989 planted forest

During the planted forest inventory, 10 per cent of plots are randomly audited without the prior knowledge of the inventory teams. Plots are fully re-measured with feedback supplied no later than one month after measurement to ensure prompt identification of data collection errors and procedural issues. Differences between the inventory and audit measurements are objectively and quantitatively scored. Measurements that exceed predefined tolerances incur incremental demerit points. Demerit severity depends on the size of error and the type of measurement. Special attention is given to the most influential measurements; for example, tree diameter, tree

height and the number of trees in a plot. Plots that fail quality control have to be re-measured (Beets et al., 2011a, 2012a). Following each inventory season, the data collection manual (Herries et al., unpublished) is revised to clarify procedures and highlight potential sources of error.

The inventory data are pre-processed using Scion's Permanent Sample Plot (PSP) system. The PSP system has been programmed to check for erroneous values over a wide range of attributes. The system automatically identifies fields that do not meet predetermined validation rules so these can be repaired manually before plot data are modelled by the Forest Carbon Predictor. The PSP data validation system and the Forest Carbon Predictor model were independently reviewed by Woollens (unpublished). The Forest Carbon Predictor has been recently validated in Beets et al. (2011b).

Quality-assurance and quality-control procedures for LiDAR data collected during the planted forest inventories involved the checking of data as they were acquired following the methodology outlined in Stephens et al. (2008). To ensure that the data were supplied within the predetermined specifications, the following activities were carried out: LiDAR sensor calibration and bore-sight alignment, checking of LiDAR point positional accuracy and point densities, correct point cloud classification and accuracy of digital terrain mapping. For example, the post-1989 forest inventory LiDAR acquisition included four individual sensor calibrations; six LiDAR point positional accuracy tests; and a summary of returns describing LiDAR specifications, which were provided for all data deliveries. Sites that failed to meet the required specifications were re-flown. These analyses were carried out using the LiDAR analysis software FUSION (McGaughey, 2010) and the Esri Arc Map GIS application. LiDAR metrics or parameters describing the forest from the canopy to the ground were extracted using FUSION. The process of extracting LiDAR metrics and the extracted metrics were audited by an organisation independent of the data capture and analysis (Stephens et al., 2008).

The New Zealand estimates are 145.97 ± 21.1 tonnes C ha^{-1} for post-1989 planted forest as at 31 December 2016 (Paul and Kimberley, unpublished) and 130.7 ± 11.4 tonnes C ha^{-1} for pre-1990 planted forest as at 31 December 2014 (Paul et al., unpublished(a)). These carbon stock estimates, while high, are consistent with the international comparisons provided in table 4.8 of the 2006 IPCC Guidelines (IPCC, 2006a) and reflect that this forest category is made up of fast-growing and actively managed production forestry.

Post-1989 natural forest

As for pre-1990 natural forest, quality control and assurance were undertaken at the data collection, entry and analysis stages.

During field data collection in 2012, 10 per cent of plots were subject to an independent field audit. The audit involved randomly selected sites being re-measured by an audit field team, and the assessment of differences between inventory and audit measurements against set data quality standards as set out in Ministry for the Environment (2012). Audit results are described in Beets and Holt (unpublished). Further checks for data entry and measurement were also undertaken prior to the data analysis stage, as described in Beets et al. (unpublished).

6.4.5   Category-specific recalculations

In this submission, New Zealand has recalculated its emission estimates for the whole LULUCF sector from 1990, including the *Forest land* category. These recalculations have involved improved country-specific methods, activity data and emission factors. The impact of the recalculations on net CO_2-e emission estimates for the *Forest land* category is provided in table 6.4.10. The differences shown are a result of recalculations for all carbon pools used in reporting under the Convention and the Kyoto Protocol for the whole time series for the LULUCF sector.

Table 6.4.10   Recalculations of New Zealand's estimates for the Forest land category in 1990 and 2015

| | Net emissions (kt CO$_2$-e) | | Change from the 2017 submission (kt CO$_2$-e) | % change |
	2017 submission	2018 submission		
1990	−29,807.6	−28,909.3	898.3	+3.0
2015	−23,355.2	−24,068.8	−713.7	−3.1
Area (hectares)				
1990	9,432,515	9,426,196	−6,319	−0.1
2015	9,905,021	9,903,249	−1,772	−0.0

Note: Areas are as at the end of the year indicated.

For *Forest land*, the recalculation differences are due to the updated yield table for post-1989 planted forest and land use mapping improvements across the time series, as explained below.

Activity data

The total area of *Forest land* at 1990 has been reduced by 6,319 hectares as a result of reassessment of some areas previously classed as pre-1990 natural forest. These areas have been remapped as non-forest (in the *Grassland with woody biomass* category) throughout the time series.

The area estimates of afforestation and deforestation have been updated from the previous submission. These areas and the associated emissions are reported in the relevant *Land converted to* category.

Emission factors

The post-1989 planted forest yield table has been revised for the 2018 submission. The revised yield table is based on three measurements of permanent sample plots in post-1989 planted forest carried out in 2008–09, 2011–12 and 2016 (due to the transition to the continuous inventory). The analysis of the data collected has provided a plot-based estimate of carbon stock and mean carbon density within this forest type, and is further described in section 6.4.2.

6.4.6   Category-specific planned improvements

New Zealand will continue to measure the natural forest plot network on a 10-year cycle and analyse the data collected as they become available. Research is under way to better estimate the stock and change in the dead wood pool for natural forests.

Mapping of forest areas will be improved through the production of the 2016 land use map, which includes a number of forest-specific mapping improvement tasks such as:

- better discrimination of pre-1990 planted forest and pre-1990 natural forest
- identification of areas of missed forest through the use of radar data
- mapping of deforestation occurring during 2015 and 2016.

The assumption that controlled burning of post-harvest residues on afforested land does not occur will be revisited for the 2019 submission, due to the increasing harvest rate in these forests as they reach maturity.

The complete planted forest plot network (pre-1990 and post-1989) is scheduled for re-measurement on a continuous basis (at five-year intervals) from 2016. These data will be incorporated into the National Inventory Report as they become available.

6.5 Cropland (CRF 4B)

6.5.1 Description

In 2016 the net emissions from *Cropland* were 418.9 kt CO_2-e, comprising 409.0 kt CO_2 from carbon stock change and 0.03 kt N_2O (10.0 kt CO_2-e) from the nitrogen mineralisation on *Land converted to cropland*. Net emissions from *Cropland* have decreased by 57.9 kt CO_2-e (12.1 per cent) from the 1990 level when net emissions were 476.8 kt CO_2-e (see table 6.5.1).

Table 6.5.1   **New Zealand's land-use change by Cropland category, and associated CO_2-e emissions, 1990 and 2016**

Cropland land use category	Net area as at 1990 (ha)	Net area as at 2016 (ha)	Net emissions (kt CO_2-e) 1990	Net emissions (kt CO_2-e) 2016	Change from 1990 (%)
Cropland remaining cropland	385,848	413,557	358.1	340.5	–4.9
Land converted to cropland	38,698	64,123	118.8	78.4	–34.0
Total	**424,546**	**477,680**	**476.8**	**418.9**	**–12.1**

Note: Net area in 1990 is as at 1 January 1990; net area in 2016 is as at 31 December. *Land area converted to cropland* includes land converted up to 28 years prior. Net emission values are for the whole year indicated. Values include CO_2-e emissions from N_2O from cultivation of land.

The *Cropland remaining cropland* category is responsible for the majority of *Cropland* emissions. This category comprised 86.6 per cent of all *Cropland* area in 2016.

The majority of emissions for the *Cropland* category due to carbon stock change are in the SOC pool (3,749.1 kt C or 13,746.9 kt CO_2) (see table 6.5.2).

Table 6.5.2   **New Zealand's carbon stock change by carbon pool for the Cropland category from 1990 to 2016**

Land use	Net carbon stock change 1990–2016 (kt C) Living biomass	Dead organic matter	Soils	Total	Emissions 1990–2016 (kt CO_2)
Annual cropland	–189.3	–10.8	–2,516.0	–2,716.2	9,959.2
Perennial cropland	263.6	–6.0	–1,233.1	–975.5	3,576.8
Total	**74.3**	**–16.8**	**–3,749.1**	**–3,691.7**	**13,536.1**

Note: This table includes CO_2 emissions from carbon stock change only (emissions from N_2O disturbance are not included in this table). The reported dead organic matter losses result from the loss of dead organic matter of woody land use categories on conversion to cropland. Columns may not total due to rounding.

Table 6.5.3 shows land-use change by *Cropland* land use since 1990, and the associated CO_2 emissions from carbon stock change. The *Cropland* category in New Zealand is separated into two land use types: annual and perennial. In 2016 there were 372,598 hectares of annual cropland in New Zealand (see table 6.5.3; 1.4 per cent of total land area) and 105,081 hectares of perennial cropland (see table 6.5.3; 0.4 per cent of total land area).

Annual crops include cereals, grains, oil seeds, vegetables, root crops and forages. Perennial crops include orchards, vineyards and their associated shelterbelts except where these shelterbelts meet the criteria for the *Forest land* category.

The amount of carbon stored in, emitted by or removed from permanent cropland depends on crop type, management practices, soil properties and climate variables. Annual crops are harvested each year, with no long-term storage of carbon in biomass. However, the amount of carbon stored in woody vegetation in orchards can be significant, with the amount depending on the species, density, growth rates, and harvesting and pruning practices.

Table 6.5.3   New Zealand's land-use change by Cropland land use, and associated CO$_2$ emissions from carbon stock change, from 1990 to 2016

Land use	Net area in 1990 (ha)	Net area in 2016 (ha)	Change from 1990 (%)	Net emissions (kt CO$_2$ only) 1990	Net emissions (kt CO$_2$ only) 2016	Change from 1990 (%)
Annual cropland	355,321	372,598	+4.9	342.3	333.7	–2.5
Perennial cropland	69,225	105,081	+51.8	127.2	75.3	–40.8
Total	**424,546**	**477,680**	**+12.5**	**469.4**	**409.0**	**–12.9**

Note: Net area in 1990 is as at 1 January 1990; net area in 2016 is as at 31 December. This table includes CO$_2$ emissions from carbon stock change only. Columns may not total due to rounding.

A summary of land-use change within the *Cropland* category, by land use type and land conversion status, is provided in table 6.5.4. This shows that land-use change within the *Cropland* category has been dominated by conversions to perennial cropland, both from within the *Cropland* category and from other land use categories. This conversion has predominantly been for the establishment of vineyards (Davis and Wakelin, unpublished).

Table 6.5.4   New Zealand's land-use change for the Cropland category from 1990 to 2016

Cropland category		Net area in 1990 (ha)	Net area in 2016 (ha)	Change from 1990 (%)
Cropland remaining cropland	Annual remaining annual	325,811	344,078	5.6
	Perennial remaining perennial	59,150	59,548	0.7
	Annual to perennial	887	6,885	676.3
	Perennial to annual	0	3,046	NA
	Subtotal	*385,848*	*413,557*	*7.2*
Land in conversion to cropland	Annual cropland	29,510	25,474	–13.7
	Perennial cropland	9,188	38,649	+320.6
	Subtotal	*38,698*	*64,123*	*+65.7*
Total		**424,546**	**477,680**	**+12.5**

Note: NA = not applicable. This table shows the change between 1 January 1990 and 31 December 2016. Columns may not total due to rounding.

In 2016 *Cropland remaining cropland* was a key category (level assessment).

6.5.2 Methodological issues

Emissions and removals for the living biomass and dead organic matter pools have been calculated using IPCC Tier 1 emission factors for annual cropland, Tier 2 emission factors for perennial cropland (Davis and Wakelin, unpublished) and activity data as described in section 6.2. Emissions and removals by the SOC pool are estimated using a Tier 2 method for mineral soils and IPCC Tier 1 defaults for organic soils (section 6.3, IPCC, 2006a).

A summary of the New Zealand emission factors and other parameters used to estimate greenhouse gas emissions for the *Cropland* category is provided in table 6.5.5.

Table 6.5.5   **Summary of New Zealand's carbon stock change emission factors for Cropland**

Land use	Carbon pool	Steady state carbon stock (t C ha⁻¹)	Annual carbon stock change (t C ha⁻¹)	Years to reach steady state	Source
Annual	Biomass				
	Living biomass	5.0	NA	1	IPCC default (table 5.9, IPCC, 2006a)
	Dead organic matter	NE	NE	NA	No IPCC guidelines
	Soils				
	Mineral	89.77	*	20	NZ-specific EF (McNeill and Barringer, unpublished)
	Organic	NE	−5.0 / −10.0		IPCC Tier 1 default, (table 5.6, IPCC, 2006a)
Perennial	Biomass				
	Living biomass	18.76	0.67	28	NZ-specific EF (Davis and Wakelin, unpublished)
	Dead organic matter	NE	NE	NA	No IPCC guidelines
	Soils				
	Mineral	88.44	[*]	20	NZ-specific EF (McNeill and Barringer, unpublished)
	Organic	NE	−5.0 / 10.0		IPCC Tier 1 default (table 5.6, IPCC, 2006a)

Note: EF = emission factor; NA = not applicable; NE = not estimated. * Annual carbon stock change in mineral soils on land undergoing land-use change will depend on the land use category the land has been converted to or from; see section 6.3.

Cropland remaining cropland (CRF 4.B.1)

For *Cropland remaining cropland*, the Tier 1 assumption is that for annual cropland there is no change in biomass carbon stocks after the first year (section 5.2.1, IPCC, 2006a). The rationale is that the increase in biomass stocks in a single year is equal to the biomass losses from harvest and mortality in that same year. For perennial cropland, there is a change in carbon stocks associated with a land-use change. Where there has been land-use change between the *Cropland* land use categories, carbon stock changes are reported under *Cropland remaining cropland*.

Living biomass

To estimate carbon change in living biomass for annual cropland converted to perennial cropland, New Zealand is using Tier 1 defaults for biomass carbon stocks at harvest. The value being used for annual cropland is 5.0 tonnes C ha⁻¹ (table 5.9, IPCC, 2006a). The Tier 1 method for estimating carbon change assumes carbon stocks in biomass immediately after conversion are zero; that is, the land is cleared of all vegetation before planting crops (5.0 tonnes C ha⁻¹ is removed).

To estimate growth after conversion to perennial cropland, New Zealand uses the biomass accumulation rate of 0.67 tonnes C ha⁻¹ yr⁻¹. This value is based on the New Zealand-specific value of 18.76 tonnes C ha⁻¹ (Davis and Wakelin, unpublished), sequestered over 28 years, which is the maturity period New Zealand uses for its lands to reach steady state.

The activity data available do not provide information on areas of perennial cropland temporarily destocked; therefore, no losses in carbon stock due to temporary destocking can be calculated.

Dead organic matter

New Zealand does not report estimates of dead organic matter in this category. The notation key NE (not estimated) is used in the CRF tables in accordance with paragraph 37(b) of Decision 24/CP.19 (UNFCCC, 2014). There is insufficient information to provide a basic approach with default parameters to estimate carbon stock change in dead organic matter pools in *Cropland remaining cropland* and consequently no guidance is provided (IPCC, 2006a).

Soil organic carbon

SOC stocks in *Cropland remaining cropland* are estimated using a Tier 2 method for mineral soils and a Tier 1 method for organic soils, as described in section 6.3. The steady state mineral SOC stock for annual cropland is estimated to be 89.77 tonnes C ha^{-1}; for perennial cropland, it is estimated to be 88.44 tonnes C ha^{-1} (see table 6.3.2).

Mineral soil carbon change for annual cropland converted to perennial cropland is estimated using the IPCC default method of applying a linear rate of change over 20 years (equation 2.2.5, IPCC, 2006a).

The IPCC default emission factors for organic soils under *Cropland* are 5.0 tonnes C ha^{-1} and 10.0 tonnes C ha^{-1} per annum for cold temperate and warm temperate regimes, respectively (see table 6.3.3).

Land converted to cropland (CRF 4.B.2)

Living biomass

New Zealand uses a Tier 1 method, and a combination of IPCC default and New Zealand-specific emission factors, to calculate emissions for *Land converted to cropland*. The Tier 1 method multiplies the area of *Land converted to cropland* annually by the carbon stock change per area for that type of conversion.

The Tier 1 method assumes carbon in living biomass and dead organic matter immediately after conversion is zero; that is, the land is cleared of all vegetation before planting crops. The amount of biomass cleared when land at steady state is converted is shown in tables 6.1.3 and 6.1.4.

The Tier 1 method also includes changes in carbon stocks from one year of growth in the year conversion takes place, as outlined in equation 2.5 of the 2006 IPCC Guidelines (IPCC, 2006a).

To estimate growth after conversion to annual cropland, New Zealand uses the IPCC default biomass accumulation rate of 5.0 tonnes C ha^{-1} for the first year following conversion (table 5.9, IPCC, 2006a). After the first year, any increase in biomass stocks in annual cropland is assumed equal to biomass losses from harvest and mortality in that same year and, therefore, after the first year there is no net accumulation of biomass carbon stocks in *Annual cropland remaining annual cropland* (IPCC, 2006a, section 5.2.1).

To estimate growth after conversion to perennial cropland, New Zealand uses the biomass accumulation rate of 0.67 tonnes C ha^{-1} yr^{-1}. This value is based on the New Zealand-specific value of 18.76 tonnes C ha^{-1} (Davis and Wakelin, unpublished), sequestered over 28 years, which is the maturity period New Zealand uses for its lands to reach steady state.

Dead organic matter

New Zealand reports only losses in dead organic matter associated with the previous land use for this category. The losses are calculated based on the carbon in dead organic matter at the site prior to conversion to cropland. It is assumed that, immediately after conversion, dead organic

matter is zero (all carbon in dead organic matter prior to conversion is lost). There is insufficient information to estimate gain in carbon stock in dead organic matter pools after land is converted to cropland (IPCC, 2006a). Consequently, where there are no dead organic matter losses associated with the previous land use, the notation key NE (not estimated) is used in the CRF tables in accordance with Decision 24/CP.19 (UNFCCC, 2014).

Soil organic carbon

SOC stocks in land converted to annual and perennial cropland are estimated using a Tier 2 method for mineral soils and a Tier 1 method for organic soils, as described in section 6.3. In the absence of data on the rate of change specific to country and land use, the IPCC default of a linear change over a 20-year period is used to estimate the change in SOC stocks between the original and new land uses.

The IPCC default emission factors for organic soils under *Cropland* are also applied to *Land converted to cropland*.

Non-CO_2 emissions

Nitrous oxide emissions from disturbance associated with land-use conversion to cropland

Nitrous oxide emissions from disturbance associated with land-use conversion to cropland are described in section 6.11.3.

6.5.3   Uncertainties and time-series consistency

The uncertainty in mapping *Cropland* is ±8.0 per cent (see table 6.5.6). Further details are given in section 6.2.5 and Dymond et al. (2008).

New Zealand uses IPCC default values for biomass accumulation in annual cropland. For perennial cropland, a New Zealand-specific emission factor is used (Davis and Wakelin, unpublished). As the perennial and annual cropland emission factors are based on only a limited number of biomass studies, the uncertainty in these figures is estimated as ±75 per cent (table 5.9, IPCC, 2006a).

For mineral soils, the uncertainty is ±9.7 per cent for SOC in annual cropland and ±14.1 per cent for SOC in perennial cropland, as calculated from the Tier 2 method estimates of SOC (see table 6.5.6). For organic soils, New Zealand uses IPCC default values for annual and perennial cropland. The uncertainty associated with the IPCC default values is 95 per cent (based on table 2.3, IPCC, 2006a).

As shown in table 6.5.6, while uncertainty in activity data is low, the uncertainty in the IPCC default variables dominates the overall uncertainty in the estimate provided by New Zealand.

Table 6.5.6   Uncertainty in New Zealand's 2016 Cropland estimates (including land in transition)

	Uncertainty at a 95% confidence interval	
	Annual cropland (%)	Perennial cropland (%)
Activity data		
Uncertainty in land area	±8.0	±8.0
Emission factors		
Uncertainty in biomass carbon stocks	±75.0	±75.0
Uncertainty in soil carbon stocks	±9.7	±14.1
Uncertainty introduced into net emissions for LULUCF	**±1.0**	**±0.4**

6.5.4 Category-specific QA/QC and verification

In the preparation of this inventory, the data for CO_2 emissions from the conversion to *Cropland* category underwent Tier 1 quality checks. *Cropland remaining cropland* was a key category in 2016 (level assessment).

As part of verification of the New Zealand-specific above-ground biomass emission factor for perennial cropland, this factor has been compared with the IPCC default for temperate perennial cropland (table 5.1, IPCC, 2006a). The New Zealand value for above-ground biomass of 18.76 tonnes C ha^{-1} is much lower than the default value of 63 tonnes C ha^{-1} provided in 2006 IPCC Guidelines (IPCC, 2006a). Further research into the differences between the values has shown the IPCC default value is based on just four studies of agroforestry systems where crops are grown in rotation with trees, and none of these studies is New Zealand specific. While the country-specific emission factor used is based on a New Zealand study, it takes into account that New Zealand's main perennial crops are not grown in rotation with trees (i.e., are not part of an agroforestry system) and that a proportion of New Zealand's main perennial crops is vine fruit (i.e., kiwifruit and grapes). This means it has lower carbon content per area in living biomass at maturity than the cropland types included in the study on which the IPCC default value is based.

6.5.5 Category-specific recalculations

The impact of recalculations on net CO_2-e emission estimates for the *Cropland* category is shown in table 6.5.7. Recalculations of the entire time series were carried out for this category as a result of updated activity data on the land area of *Cropland* as part of land use mapping improvements.

Table 6.5.7   Recalculations of New Zealand's net emissions from the Cropland category in 1990 and 2015

Year	Net emissions (kt CO₂-e) 2017 submission	Net emissions (kt CO₂-e) 2018 submission	Change from the 2017 submission (kt CO₂-e)	Change from the 2017 submission (%)
1990	476.7	476.8	0.1	+0.02
2015	455.0	427.6	−27.4	−6.0

6.5.6 Category-specific planned improvements

Improvements to activity data following the creation of a new land use map will result in improved emissions estimates for *Cropland* in the 2019 submission.

6.6   Grassland (CRF 4C)

6.6.1 Description

In New Zealand, the *Grassland* category is used to describe a range of land-cover types. In this submission, three types of *Grassland* are used: high producing, low producing, and with woody biomass.

High producing grassland consists of intensively managed pasture land. Low producing grassland consists of low-fertility grasses on hill country, areas of native tussock and areas composed of low, shrubby vegetation, both above and below the timberline. Grassland with woody biomass consists of grassland areas where the cover of woody species is less than 30 per cent and/or does not meet, nor has the potential to meet, the New Zealand forest definition due to the current management regime (e.g., periodically cleared for grazing), characteristics of the vegetation, or environmental constraints (e.g., alpine shrubland) (see table 6.2.2 for further details). Grassland with woody biomass is therefore a diverse land use. To account for these differences, grassland with woody biomass is subcategorised into two types, permanent and

transitional, for modelling of land-use change effects on carbon. Separate emission factors for each type of grassland with woody biomass are derived from the LUCAS plot network (Wakelin and Beets, unpublished). Within the CRF Reporter, reporting on grassland with woody biomass is at the aggregate level.

Land use research indicates that under business-as-usual grassland farming operations, areas of woody shrublands (grassland with woody biomass – transitional) within farmland do not become forest over a 30- to 40-year timeframe (Trotter and MacKay, unpublished). This is the case as long as the farmer's intention is to manage the land as grassland for grazing animals. When it becomes evident that the farmer has modified land management in a way that encourages sustained growth of woody vegetation, such as by removing stock or planting, then these areas will be mapped as forest. A description of the land-management approaches that result in the sustained growth of woody vegetation is contained in the mapping interpretation guide (Ministry for the Environment, 2012).

In contrast, grassland with woody biomass – permanent consists of land covered by woody vegetation which does not meet the forest definition and which is not expected to do so under current ecological or environmental conditions. Such vegetation occurs where the abiotic conditions at a site are conducive to low-stature vegetation; for example, vegetation growing at high altitudes, on low fertility soil or on frost flats.

The net emissions from *Grassland* were 4,464.3 kt CO_2-e in 2016 (see table 6.6.1). These emissions comprise 4,377.2 kt CO_2 emissions from carbon stock change and 0.05 kt N_2O (14.7 kt CO_2-e) and 2.9 kt CH_4 (72.2 kt CO_2-e) emissions from *Biomass burning* and nitrogen mineralisation on *Land converted to grassland*.

The *Grassland remaining grassland* and *Land converted to grassland* categories were identified as key categories for the level and trend assessment in 2016.

Net emissions from *Grassland* have increased by 3,567.6 kt CO_2-e (397.8 per cent) from the 1990 level of 896.7 kt CO_2-e (see table 6.6.1). The majority of this change is in the category *Pre-1990 planted forest converted to high producing grassland* and is the effect of deforestation that involves large losses in the living biomass pool.

Table 6.6.1   **New Zealand's land-use change for the Grassland category, and associated CO_2-e emissions, from 1990 to 2016**

Grassland land use category	Area as at 1990 (ha)	Area as at 2016 (ha)	Net emissions (kt CO_2-e)		Change from 1990 (%)
			1990	2016	
Grassland remaining grassland	14,665,026	14,539,185	644.2	1,371.4	+112.9
Land converted to grassland	642,839	202,239	252.5	3,092.8	+1,124.9
Total	**15,307,865**	**14,741,425**	**896.7**	**4,464.3**	**+397.8**

Note: Net area in 1990 is as at 1 January 1990; net area in 2016 is as at 31 December. *Land converted to grassland* includes land converted up to 28 years prior. Net emission estimates are for the whole year indicated. Columns may not total due to rounding.

In 2016 there were 5,963,107 hectares of high producing grassland (22.1 per cent of total land area), 7,402,978 hectares of low producing grassland (27.5 per cent of total land area) and 1,375,339 hectares of grassland with woody biomass (5.1 per cent of total land area).

From 1990 to 2016 the net carbon stock change attributed to *Grassland* was a decrease of 38,301.5 kt C, equivalent to emissions of 140,438.8 kt CO_2 from *Grassland* since 1990 (see table 6.6.2). The majority of these emissions are due to the loss of living biomass carbon stock associated with *Forest land* conversion to *Grassland* (deforestation).

Table 6.6.2   New Zealand's carbon stock change by carbon pool for the Grassland category from 1990 to 2016

Grassland category	Net carbon stock change 1990–2016 (kt C)				Emissions 1990–2016 (kt CO$_2$)
	Living biomass	Dead organic matter	Soils	Total	
Grassland – high producing	−15,393.7	−1,384.6	−6,626.1	−23,404.4	85,816.1
Grassland – low producing	−11,746.4	−1,200.9	104.0	−12,843.3	47,092.1
Grassland – with woody biomass	−839.7	−187.6	−1,026.5	−2,053.8	7,530.6
Total	**−27,979.9**	**−2,773.1**	**−7,548.6**	**−38,301.5**	**140,438.8**

Note: Columns may not total due to rounding.

Grassland remaining grassland

There were 14,539,185 hectares of *Grassland remaining grassland* as at 2016, equivalent to 54.0 per cent of New Zealand's total land area. For estimating carbon stock change with land-use change, this category has been subcategorised into land use types: high producing, low producing and with woody biomass.

Land converted to grassland

Much of New Zealand's grassland is grazed, with agriculture being the main land use. The majority of New Zealand's agriculture is based on extensive pasture systems, with animals grazed outdoors year-round. Increased profitability of dairy farming relative to other land uses has seen a recent trend for conversion of planted forest to pasture (deforestation).

Between 2015 and 2016, 5,202 hectares of land was converted to *Grassland*, while 6,173 hectares of *Grassland* was converted to other land use categories.

The majority (94.6 per cent) of *Land converted to grassland* since 1 January 1990 is land that was previously *Forest land*. The 189,069 hectares of *Forest land* converted to *Grassland* since 1 January 1990 comprises an estimated 43,325 hectares of natural forest and 119,631 hectares of pre-1990 planted forest. A further 26,114 hectares of post-1989 forest (land that was not *Forest land* at the start of 1990) has also been converted to *Grassland* since 1 January 1990. (For more information on deforestation, see sections 6.2 and 6.4 and chapter 11.) Land-use change of *Forest land* to *Grassland* resulted in net emissions of 3,090.6 kt CO$_2$ in 2016.

6.6.2   Methodological issues

Emissions and removals from living biomass and dead organic matter have been calculated using a combination of IPCC Tier 1 emission factors and country-specific factors (see table 6.6.3). Emissions and removals from mineral soils are estimated using a Tier 2 method, whereas organic soils are estimated using a Tier 1 method (see section 6.3).

Table 6.6.3   Summary of New Zealand's biomass emission factors for Grassland

Land use	Carbon pool	Steady state carbon stock (t C ha^{-1})	Annual carbon accumulation (t C ha^{-1})	Years to reach steady state	Source
High producing	**Total biomass**	**6.345**	**6.345**	**1**	IPCC, 2006a, table 6.4
	Living biomass				
	AGB	1.269	1.269	1	
	BGB	5.076	5.076	1	
	Dead organic matter	NE	NA	NA	No IPCC guidelines

Land use	Carbon pool	Steady state carbon stock (t C ha^{-1})	Annual carbon accumulation (t C ha^{-1})	Years to reach steady state	Source
Low producing	**Total biomass**	**2.867**	**2.867**	**1**	IPCC, 2006a, table 6.4
	Living biomass				
	AGB	0.752	0.752	1	
	BGB	2.115	2.115	1	
	Dead organic matter	NE	NA	NA	No IPCC guidelines
With woody biomass – transitional	**Total biomass**	**13.05**	**0.47**	**28**	Wakelin and Beets, unpublished
	Living biomass				
	AGB	9.35	0.33	28	
	BGB	3.05	0.11	28	
	Dead organic matter				
	Dead wood	0.10	0.004	28	
	Litter	0.55	0.02	28	
With woody biomass – permanent	**Total biomass**	**60.57**	**NO**	**28**	Wakelin and Beets, unpublished
	Living biomass				
	AGB	45.18	NO	28	
	BGB	11.71	NO	28	
	Dead organic matter				
	Dead wood	3.68	NO	28	
	Litter	0.00	NO	28	

Note: AGB = above-ground biomass; BGB = below-ground biomass; NA = not applicable; NE = not estimated; NO = not occurring. Columns may not total due to rounding. The high producing grassland figure is based on the Warm temperate – wet figure from table 6.4 of the 2006 IPCC Guidelines, and the low producing grassland figure is based on the Warm temperate – dry figure from the same table (IPCC, 2006a).

Grassland remaining grassland (CRF 4.C.1)

For *Grassland remaining grassland*, the Tier 1 assumption is there is no change in carbon stocks (section 6.2.1.1, IPCC, 2006a). The rationale is that, where management practices are static, carbon stocks will be in an approximately steady state; that is, carbon accumulation through plant growth is roughly balanced by losses. New Zealand has reported NA (not applicable) in the CRF tables where there is no land-use change at the category level because no emissions or removals are assumed to have occurred. However, there is a significant area (328,780 hectares) in a state of conversion from one grassland type to another. The carbon stock changes for these land-use changes are reported under *Grassland remaining grassland*.

Living biomass

To calculate carbon change in living biomass on land converted from one category to another (e.g., high producing grassland converted to low producing grassland), it is assumed the carbon in living biomass immediately after conversion is zero; that is, the land is cleared of all vegetation. In the same year, carbon stocks in living biomass increase by the amount given in table 6.6.3 representing the annual growth in biomass for land converted to another land use. The values used for high producing and low producing grassland are Tier 1 defaults (table 6.6.3). The values given for grassland with woody biomass are country-specific factors based on the LUCAS national plot network (Wakelin and Beets, unpublished).

Dead organic matter

New Zealand does not report estimates of dead organic matter for high producing grassland or low producing grassland because the 2006 IPCC Guidelines state that there is insufficient information to develop default coefficients for estimating the dead organic matter pool (IPCC, 2006a). The notation key NE (not estimated) is used in the CRF tables in accordance with paragraph 37(b) of Decision 24/CP.19 (UNFCCC, 2014).

For grassland with woody biomass, an estimate of dead organic matter is derived from the LUCAS national plot network (Wakelin and Beets, unpublished), and estimates of changes in dead organic matter stocks with conversion to and from this land use are given in the CRF tables.

Soil carbon

SOC stocks in *Grassland remaining grassland* are estimated using a Tier 2 method for mineral soils (see table 6.6.4) and a Tier 1 method for organic soils (see section 6.3). The IPCC default emission factors for organic soils under *Grassland* are 0.25 tonnes and 2.5 tonnes C ha^{-1} per annum for cold temperate and warm temperate regimes respectively (IPCC, 2006a).

Table 6.6.4   New Zealand's soil carbon stock values by Grassland type: from table 6.3.2

Land use	Soil carbon stock density (t C ha^{-1})
High producing grassland	105.34
Low producing grassland	105.98
Grassland with woody biomass	98.23

Land converted to grassland (CRF 4.C.2)

Living biomass

New Zealand uses a Tier 1 method to calculate emissions for *Land converted to grassland*. The Tier 1 method multiplies the area of *Land converted to grassland* annually by the carbon stock change per area for that type of conversion.

The Tier 1 method assumes carbon in living biomass immediately after conversion is zero; that is, the land is cleared of all vegetation at conversion and is instantly oxidised. The emission factors for estimating the amount of biomass that is cleared when land at steady state is converted to another land use is shown in table 6.1.3. The Tier 1 method also includes changes in carbon stocks from one year of growth from the grassland category that land was converted to in the year conversion takes place, as outlined in equation 2.9 of the 2006 IPCC Guidelines (IPCC, 2006a).

Dead organic matter

For land conversion to high and low producing grassland, New Zealand reports only losses in dead organic matter. The losses are calculated based on the carbon in dead organic matter at the site prior to conversion to *Grassland*. It is assumed that, immediately after conversion, the carbon in the dead organic matter pool is zero (all carbon in dead organic matter prior to conversion is lost). New Zealand applies the Tier 1 default to high and low producing grassland land uses, which assumes there is no dead wood or litter accumulating in land converted to grassland (IPCC, 2006a). Therefore, where there are no dead organic matter losses associated with the previous land use, the notation key NE (not estimated) is used in the CRF tables in accordance with Decision 24/CP.19 (UNFCCC, 2014).

Where land is converted to grassland with woody biomass, dead organic matter accumulates to 0.65 tonnes C ha^{-1} (see table 6.6.3) over 28 years (the maturity period New Zealand has chosen for land to reach steady state).

Soil organic carbon

Soil carbon stocks in *Land converted to grassland* are estimated using a Tier 2 method for mineral soils and a Tier 1 method for organic soils (see section 6.3). In the absence of data on the rate of change specific to country and land use, the IPCC default of a linear change over a 20-year period is used to estimate the change in SOC stocks between the original land use and the new land use.

The IPCC default emission factors for organic soils under *Grassland* are also applied to *Land converted to grassland* (IPCC, 2006a).

6.6.3 Uncertainties and time-series consistency

The uncertainty in mapping *Grassland* is ±8.0 per cent for high and low producing grassland, and ±83 per cent for grassland with woody biomass. Further details are given in section 6.2.5.

New Zealand uses IPCC default values for biomass accumulation in high producing and low producing grassland. The uncertainty in these figures is given as ±75 per cent (table 6.4, IPCC, 2006a). A New Zealand-specific value derived from the LUCAS national plot network is used for biomass accumulation in grassland with woody biomass. Grassland with woody biomass is a diverse land use; therefore, the IPCC default uncertainty value is used (Wakelin and Beets, unpublished).

Of the *Grassland* land uses, low producing grassland has the greatest uncertainty in SOC stocks. Soil carbon stocks for low producing grassland are variable because this land use occurs across a wide range of environmental conditions due to its geographical extent.

Table 6.6.5   **Uncertainty in New Zealand's 2016 estimates for the Grassland category (including land in transition)**

Land use	Uncertainty at a 95% confidence interval		
	High producing (%)	Low producing (%)	With woody biomass (%)
Activity data			
Uncertainty in land area	±8.0	±8.0	±83.0
Emission factors			
Uncertainty in biomass carbon stocks	±75.0	±75.0	±75.0
Uncertainty in soil carbon stocks	±5.8	±7.3	±7.3
Uncertainty introduced into net emissions for LULUCF	**±4.6**	**±1.0**	**±0.5**

Note: Uncertainty in biomass carbon stocks for grassland with woody biomass is estimated using the IPCC default uncertainty value because an independent estimate of uncertainty for this category is not available.

6.6.4 Category-specific QA/QC and verification

Carbon dioxide emissions from the *Grassland remaining grassland* and *Land converted to grassland* categories are key categories (level and trend). In the preparation of this inventory, the data for these emissions underwent Tier 1 quality checks.

6.6.5 Category-specific recalculations

The impact of recalculations on net CO_2-e emission estimates for the *Grassland* category is shown in table 6.6.6.

Table 6.6.6   **Recalculations of New Zealand's net emissions from the Grassland category in 1990 and 2015**

Year	Net emissions (kt CO₂-e)		Change from the 2017 submission	
	2017 submission	2018 submission	(kt CO₂-e)	(%)
1990	878.5	896.87	18.2	+2.1
2015	4,652.1	5,150.0	497.9	+10.7

Recalculations of the entire time series were carried out for this category as a result of updated activity data on the land area of the *Grassland* categories as part of land use mapping improvements.

6.6.6   Category-specific planned improvements

Improvements to activity data following the creation of a new land use map will result in improved emissions estimates for *Grassland* in the 2019 submission.

6.7   Wetlands (CRF 4D)

6.7.1   Description

New Zealand has around 425,000 kilometres of rivers and streams, and almost 4,000 lakes that are larger than a hectare (Ministry for the Environment, 2006b). Damming, diverting and extracting water for power generation, irrigation and human consumption have modified the nature of these waterways and can deplete flows and reduce groundwater levels. Demand for accessible land has also led to the modification of a large proportion of New Zealand's vegetated wetland areas in order to provide pastoral land cover. Just over 10 per cent of wetlands present prior to European settlement remain across New Zealand (McGlone, 2009).

Section 3.2 of 2006 IPCC Guidelines defines *Wetlands* as "areas of peat extraction and land that is covered or saturated by water for all or part of the year (e.g., peatlands) and that does not fall into the *Forest Land*, *Cropland*, *Grassland* or *Settlements* categories" (IPCC, 2006a, p 3.6). The definition includes reservoirs as a managed subdivision (e.g., flooded lands), and natural rivers and lakes as unmanaged subdivisions. Flooded lands, a subcategory of *Wetlands*, are defined in the 2006 IPCC Guidelines (IPCC, 2006a, p 7.19) as:

> … water bodies where human activities have caused changes in the amount of surface area covered by water, typically through water level regulation. ... Regulated lakes and rivers that do not have substantial changes in water area in comparison with the pre-flooded ecosystem are not considered as Flooded Lands.

The majority of New Zealand's hydroelectric schemes are based on rivers and lakes where the main pre-flooded ecosystem was a natural lake or river; therefore, they are not defined as flooded lands.[51]

New Zealand's *Wetlands* are currently mapped into two types: open water, which includes artificially flooded lands, lakes and rivers; and vegetated wetland, which includes herbaceous vegetation that is periodically flooded, and estuarine and tidal areas. New Zealand has mapped its vegetated wetlands using existing LCDB data (see section 6.2 for more information). Areas of open water have been mapped using hydrological boundaries defined by Land Information New Zealand. The area of flooded land has not been mapped separately from other naturally occurring open water (natural lakes). Examples of flooded lands in New Zealand include

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[51]   An exception occurred in the creation of the Clyde Dam. The Clutha River in the South Island was dammed, creating Lake Dunstan. The area flooded was mostly low producing grassland.

irrigation reservoirs and the Clyde Dam hydroelectric dam. No methodologies are provided for *Flooded land remaining flooded land* (IPCC, 2006a), and New Zealand does not report emissions estimates for this category.

In 2016, there were 538,078 hectares of open water and 145,249 hectares of vegetated wetlands. Together these two land use types make up 2.5 per cent of the total New Zealand land area.

In 2016, there were 20.0 kt CO_2-e emissions from *Wetlands*, compared with emissions of –10.9 kt CO_2-e from *Wetlands* in 1990 (see table 6.7.1). This changing trend, from net remover in 1990 to net emitter in 2016 is due to the shift in land-use change patterns that have been observed since 1990, when compared with the changes that had occurred before 1990.

As at 2016, there were 8,313 hectares in a state of conversion to *Wetlands* (table 6.7.1). These lands have been converted to *Wetlands* during the previous 28 years but have not yet reached steady state to enter the *Wetlands remaining wetlands* category.

Table 6.7.1   **New Zealand's land-use change for the Wetlands category, and associated CO_2-e emissions, in 1990 and 2016**

	Net area (ha) as at		Net emissions (kt CO_2-e)		Change from 1990 (%)
Wetlands land use category	**1990**	**2016**	**1990**	**2016**	
Wetlands remaining wetlands	662,627	675,014	9.4	18.9	+100.7
Land converted to wetlands	14,386	8,313	–20.4	1.1	+105.3
Total	**677,013**	**683,327**	**–10.9**	**+20.0**	**+282.6**

Note: Net area in 1990 is as at 1 January 1990; net area in 2016 is as at 31 December. *Land converted to wetlands* includes land converted up to 28 years prior. *Land converted to wetlands* consists of land converted to hydro lakes prior to 1990. Net emission values are for the whole year indicated. Columns may not total due to rounding.

From 1990 to 2016, the net carbon stock in *Wetlands* increased by 25.1 kt C, equivalent to removals of 92.1 kt CO_2 in total since 1990 (see table 6.7.2). These carbon stock gains are mostly due to conversions to hydroelectric dams, which continue to have a lagged effect on SOC in the inventory period. Emissions from areas under peat extractions are reported for the first time in this submission.

Table 6.7.2   **New Zealand's carbon stock change by carbon pool for the Wetlands category from 1990 to 2016**

	Net carbon stock change 1990–2016 (kt C)				Emissions 1990–2016 (kt CO_2)
Land use	**Living biomass**	**Dead organic matter**	**Soils**	**Total**	
Wetlands – vegetated	–6.8	–1.0	2.4	–5.3	19.6
Wetlands – open water	–56.8	–2.4	89.7	30.5	–111.7
Total	**–63.6**	**–3.4**	**92.1**	**25.1**	**–92.1**

Note: Columns may not total due to rounding.

6.7.2   Methodological issues

Wetlands remaining wetlands (CRF 4.D.1)

Living biomass and dead organic matter

New Zealand applies Tier 1 methods for estimating CO_2 emissions in *Wetlands remaining wetlands* (following the guidance provided in section 7.1 of the 2006 IPCC Guidelines (IPCC, 2006a)). Chapter 7 (IPCC, 2006a) provides guidance for estimating emissions from flooded land and extraction from peat land. Recultivation of peat land is included under the Agriculture sector.

Due to the current lack of data on biomass carbon stock changes in *Wetlands remaining wetlands*, New Zealand has not prepared estimates for change in living biomass or dead organic matter for this category. New Zealand reports the notation key NE (not estimated) in the CRF table for this category.

Soil carbon

SOC stocks in *Wetlands remaining wetlands* are estimated using a Tier 2 method for mineral soils (see section 6.3) and Tier 1 methods for organic soils. The mineral soil steady state carbon stock for vegetated wetlands is estimated to be 136.06 tonnes C ha^{-1}, with an uncertainty of ±12.3 per cent (see table 6.3.2). For open water, the SOC stock at equilibrium is assumed to be the same value as that of low producing grassland (105.98 tonnes C ha^{-1}, with an uncertainty of ±7.3 per cent).

For mineral soils, as with living biomass and dead organic matter, there are no emissions for *Wetlands* in steady state so the notation key NE (not estimated) is used in accordance with Decision 24/CP.19 (UNFCCC, 2014).

For organic soils, IPCC good practice guidance is limited to the estimation of carbon emissions associated with peat extraction. In New Zealand, oligotrophic *Sphagnum* peat is mined for horticultural use (Clarkson, unpublished). Carbon dioxide emissions from the extraction of horticultural peat are estimated from two sources: on-site emissions from peat production; and off-site emissions from its subsequent use. Tier 1 default emission factors are applied. Non-CO_2 emissions are not estimated, as there is no method for estimating N_2O emissions from the extraction of nutrient poor peat, and no CH_4 emissions occur from this activity.

Land converted to wetlands (CRF 4.D.2)

Between 1990 and 2016, 7,831 hectares of land were converted to *Wetlands*, while 1,517 hectares of *Wetlands* were converted to other land uses (mainly *Grassland* at 866 hectares). This resulted in a net increase in total area reported under *Wetlands* of 6,314 hectares.

Land converted to peat extraction emissions are reported in the CRF tables as NO (not occurring) because the areas under peat extraction have remained static since 1990. For *Land converted to flooded land*, the area is included in the area mapped as *Land converted to open water* (this category includes naturally occurring open water (natural lakes) as well as intentionally flooded land). This means emissions for *Land converted to flooded land* are reported as IE (included elsewhere), and these emissions are captured under *Land converted to open water* instead.

Living biomass and dead organic matter

New Zealand uses a Tier 1 method to calculate emissions from *Land converted to wetlands* (equation 7.10, IPCC, 2006a). The Tier 1 method assumes carbon in living biomass and dead organic matter present before conversion is lost in the same year as the conversion takes place.

For open water wetlands, the carbon stocks in living biomass and dead organic matter following conversions are equal to zero. For vegetated wetlands, the carbon stocks in living biomass and dead organic matter are not estimated because there is no guidance in the 2006 IPCC Guidelines for estimating carbon stock following land-use change to *Wetlands*, and all emissions from land-use change to *Wetlands* from removal of the previous vegetation are instantly emitted.

If the land-use change does not occur, the notation key NO (not occurring) is reported within the CRF tables. If the estimate of gains in biomass is zero, then NA (not applicable) is reported instead because it is not possible to enter zero for biomass gains in the CRF reporting software.

Soil carbon

SOC stocks in *Land converted to wetlands* are estimated using a Tier 2 method, as described in section 6.3. In the absence of data on the rate of change specific to country and land use, the IPCC default method of a linear change over a 20-year period is used to estimate the change in SOC stocks between the original land use and *Wetlands* for any given period.

Non-CO₂ emissions

Non-CO₂ emissions from drainage of soils and wetlands

New Zealand has not prepared estimates for this category. The drainage of soils and *Wetlands* is a relatively minor activity in New Zealand, and there is insufficient information to reliably report on this. The notation key NE (not estimated) is used in the CRF tables where either no activity data are available to report on this activity or no Tier 1 methodology exists within the accepted guidelines for providing estimates. Use of these notation keys is in accordance with Decision 24/CP.19 (UNFCCC, 2014).

6.7.3   Uncertainties and time-series consistency

The uncertainty in mapping *Wetlands* is ±33.0 per cent (see table 6.7.3). Further details are given in section 6.2.5. The uncertainty for mineral SOC stocks in vegetated wetlands is ±12.3 per cent. The uncertainty in the emission factor for peat extracted for horticultural use is ±90 per cent, the default IPCC value provided in the 2006 IPCC Guidelines (IPCC, 2006a).

Because emissions from *Wetlands* are very small, the uncertainty introduced into net emissions for LULUCF is also very small.

Table 6.7.3   Uncertainty in New Zealand's 2016 estimates for the Wetlands category (including land in transition)

Variable	Uncertainty at a 95% confidence interval	
Land use	Wetlands – vegetated (%)	Wetlands – open water (%)
Activity data		
Uncertainty in land area	±33.0	±33.0
Emission factors		
Uncertainty in biomass carbon stocks	±75.0	NA
Uncertainty in mineral soil carbon stocks	±12.3	NA
Uncertainty in organic soil carbon stocks (on-site CO₂ emissions from peat extraction)	±90.0	NA
Uncertainty introduced into net emissions for LULUCF	**±0.1**	**±0.02**

Note: NA = not applicable. The activity data and combined emission factor uncertainty are weighted values and have been calculated using equation 3.2 from IPCC General Guidance and Reporting (IPCC, 2006b).

6.7.4   Category-specific QA/QC and verification

In the preparation of this inventory, the activity data and emission factor for carbon change underwent Tier 1 quality checks.

6.7.5 Category-specific recalculations

The impact of recalculations on net CO_2-e emission estimates for *Wetlands* is shown in table 6.7.4. Recalculations were carried out for this category as a result of reporting emissions estimates for areas under peat extraction for the first time and new activity data from the improved mapping process, as described in section 6.2 and under 'Soil carbon' in 'Wetlands remaining wetlands' in section 6.7.2.

Table 6.7.4   Recalculations for New Zealand's net emissions from the Wetlands category in 1990 and 2015

Year	Net emissions (kt CO_2-e)		Change from the 2017 submission	
	2017 submission	2018 submission	(kt CO_2-e)	(%)
1990	−20.3	−10.9	9.4	+46.2
2015	1.9	18.7	16.8	+890.6

6.7.6 Category-specific planned improvements

Improvements to activity data following the creation of a new land use map will result in improved emissions estimates for *Wetlands* in the 2019 submission.

6.8   Settlements (CRF 4E)

6.8.1 Description

The *Settlements* land use category, as described in chapter 3.2 of 2006 IPCC Guidelines, includes "all developed land, including transportation infrastructure and human settlements of any size, unless they are already included under other categories" (IPCC, 2006a, p 3.7). *Settlements* include trees grown along streets, in public and private gardens, and in parks associated with urban areas.

In 2016, there were 225,309 hectares of *Settlements* in New Zealand, an increase of 19,358 hectares since 1990. This category comprised 0.8 per cent of New Zealand's total land area in 2016. The largest area of change to *Settlements* between 1990 and 2016 was from high producing grassland, with 13,928 hectares of high producing grassland converted to *Settlements* between 1990 and 2016.

In 2016, the net emissions from *Settlements* were 78.9 kt CO_2-e, an increase of 16.4 per cent from net emissions in 1990 (see table 6.8.1). This change in emissions is mainly from the category of *Land converted to settlements* and results from the drainage of organic soils. *Settlements* was not a key category in 2016.

Table 6.8.1   New Zealand's land-use change for the Settlements category, and associated CO_2-e emissions, from 1990 to 2016

Settlements land use category	Net area (ha) as at		Net emissions (kt CO_2-e)		Change from 1990 (%)
	1990	2016	1990	2016	
Settlements remaining settlements	182,672	205,160	+64.5	+64.5	NA
Land converted to settlements	23,279	20,149	3.3	14.4	+340.4
Total	**205,951**	**225,309**	**67.7**	**78.9**	**+16.4**

Note: NA = not applicable. Net area in 1990 is as at 1 January 1990; net area in 2016 is as at 31 December. *Land converted to settlements* includes land converted up to 28 years prior. Net emission values are for the whole year indicated. Columns may not total due to rounding.

In 2016, there were 205,160 hectares in the category *Settlements remaining settlements* (see table 6.8.1). The emissions in this category are all from drainage of organic soils for establishment of settlements. Carbon in living biomass and dead organic matter for this land use category is estimated as zero but, because zero is not a valid entry for biomass gains in the CRF Reporter, the notation key NA (not applicable) is reported for biomass gains instead. The carbon stock in mineral soil for this land use is assumed to be in steady state so this is also reported as zero.

From 1990 to 2016, the net carbon stock change for *Settlements* decreased by 747.5 kt C, equivalent to emissions of 2,740.8 kt CO_2 in total since 1990 (see table 6.8.2). These carbon stock losses are predominantly due to the loss of carbon from organic soils associated with drainage when land is converted to *Settlements*.

Table 6.8.2   New Zealand's carbon stock change by carbon pool for the Settlements category from 1990 to 2016

Land use category	Net carbon stock change 1990–2016 (kt C)				Emissions 1990–2016 (kt CO_2)
	Living biomass	Dead organic matter	Soils	Total	
Settlements	−287.3	−17.0	−443.2	−747.5	2,740.8

6.8.2   Methodological issues

Settlements remaining settlements (CRF 4.E.1)

New Zealand applies Tier 1 methods for estimating emissions from the *Settlements remaining settlements* category. The assumptions are that there is no change in carbon stocks for living biomass, dead organic matter or mineral soils. The Tier 1 method for organic soils conversely assumes emissions are constant if they are drained. Where organic soils occur in this category, they are assumed to be drained. New Zealand reports emissions applying a factor of either 5.0 tonnes C ha^{-1} yr^{-1} or 10.0 tonnes C ha^{-1} yr^{-1}, depending on the climatic temperature regime of the area (sections 5.2.3.2 and 8.2.3.2, IPCC, 2006a).

Because this is not a key category, New Zealand is not investigating methods to move to a higher tier of reporting for this category.

Land converted to settlements (CRF 4.E.2)

Living biomass and dead organic matter

New Zealand has applied a Tier 1 method for estimating carbon stock change with land conversion to *Settlements* (equation 2.16, IPCC, 2006a). This is the same as that used for other areas of land-use conversion (e.g., *Land converted to cropland*). The default assumptions for a Tier 1 estimate are that all living biomass and dead organic matter present before conversion are lost in the same year as the conversion takes place. Furthermore, carbon stocks in living biomass and dead organic matter following conversion are equal to zero (sections 8.3.1 and 8.3.2, IPCC, 2006a).

Soil carbon

SOC stocks in mineral soil for *Land converted to settlements* are estimated using a Tier 2 method (see section 6.3). In the absence of data on the rate of change specific to either country or land use, the IPCC default of a linear change over a 20-year period is used to estimate the change in SOC stocks between the original land use and *Settlements* for any given period. For organic soils, loss of soil carbon is estimated using the Tier 1 method, using the same method as for *Settlements remaining settlements*.

6.8.3 Uncertainties and time-series consistency

The uncertainty in mapping *Settlements* is ±22.0 per cent (see table 6.8.3). Further details are given in section 6.2.5.

New Zealand uses the IPCC default values for biomass accumulation and biomass loss on conversion to *Settlements*. The uncertainty in these figures is ±75.0 per cent. For soils, the default uncertainty of ±95.0 per cent is applied here.

Table 6.8.3   **Uncertainty in New Zealand's 2016 estimates for the Settlements category (including land in transition)**

Variable	Uncertainty at a 95% confidence interval (%)
Activity data	
Uncertainty in land area	±22.0
Emission factors	
Uncertainty in biomass carbon stocks	±75.0
Uncertainty in soil carbon stocks	±95.0
Uncertainty introduced into net emissions for LULUCF	**±0.3**

Note: The activity data and combined emission factor uncertainty are weighted values and have been calculated using equation 3.2 from IPCC General Guidance and Reporting (IPCC, 2006b).

6.8.4 Category-specific QA/QC and verification

In the preparation of this inventory, the activity data for these emissions underwent Tier 1 quality checks.

6.8.5 Category-specific recalculations

Recalculations were carried out for this category as a result of new activity data from the improved mapping process, as described in section 6.2.

Table 6.8.4   **Recalculations for New Zealand's net emissions from the Settlements category in 1990 and 2015**

| Year | Net emissions (kt CO_2-e) | | Change from the 2017 submission | |
	2017 submission	2018 submission	(kt CO_2-e)	(%)
1990	67.7	67.7	0.0	+0.05
2015	85.8	78.8	−6.9	−8.1

6.8.6 Category-specific planned improvements

Improvements to activity data following the creation of a new land use map will result in improved emissions estimates for *Settlements* in the 2019 submission.

6.9 Other land (CRF 4F)

6.9.1 Description

Other land is defined in section 3.2 of the 2006 IPCC Guidelines (IPCC, 2006a) as including bare soil, rock, ice and all unmanaged land areas that do not fall into any of the other five land use categories. It consists mostly of steep, rocky terrain at high elevation, often covered in snow or ice. This category is 3.3 per cent of New Zealand's total land area.

In 2016, the net emissions from *Other land* were 36.6 kt CO_2-e (see table 6.9.1). They are 24.2 kt CO_2-e (195.2 per cent) higher than the 1990 level of 12.4 kt CO_2-e. The majority of these emissions occur in the *Land converted to other land* category. This is primarily because the area of land estimated as having been converted to *Other land* has been steadily increasing since 1990.

An analysis of change in area between 1990 and 2016 shows that, of the 7,060 hectares converted from *Other land* to different land use categories, 3,793 hectares were converted to post-1989 forest and 1,440 hectares were converted to grassland with woody biomass.

Between 1 January 1990 and 31 December 2016, there were 5,097 hectares of *Land converted to other land*; most (2,876 hectares) of this was from the *Grassland* categories. This is likely to be mainly due to conversion of *Grassland* to roads, mines and quarries.

In 2016 *Land converted to Other land* was not a key category.

Table 6.9.1   New Zealand's land-use change for the land use category Other land from 1990 to 2016

Land use category – Other land	Net area as at 1990 (ha)	Net area as at 2016 (ha)	Net emissions (kt CO_2-e) 1990	Net emissions (kt CO_2-e) 2016	Change from 1990 (%)
Other land remaining other land	895,986	889,113	0.1	2.6	+4,041.8
Land converted to other land	0	4,910	12.3	34.0	+175.8
Total	**895,986**	**894,023**	**12.4**	**36.6**	**+195.2**

Note: Net area in 1990 is as at 1 January 1990; net area in 2016 is as at 31 December. *Land converted to other land* includes land converted up to 28 years prior. Net emission values are for the whole year indicated. Net emissions for *Other land remaining other land* are not applicable (NA) because changes in carbon stocks and non-CO_2 emissions are not estimated (NE) for this category; see section 6.9.2 for details. Columns may not total due to rounding.

6.9.2   Methodological issues

Other land remaining other land (CRF 4.F.1)

The area of *Other land* has been estimated based on the Land Cover Database 2. The method used is described in more detail in section 6.2.

A summary of the New Zealand emission factors and other parameters used to estimate greenhouse gas emissions for *Other land* is provided in table 6.9.2.

Table 6.9.2   Summary of New Zealand emission factors for the land use category Other land

Other land greenhouse gas source category	Steady state carbon stock (t C ha^{-1})	Years to reach steady state	Carbon stock change on conversion to Other land (t C ha^{-1})	Reference
Biomass	NE	NA	Instantaneous loss of previous land use carbon stock	IPCC Tier 1 default assumption (section 9.3.1, IPCC, 2006a)
Soils (mineral)	58.37	20	Linear change over the conversion period between new and previous stock values	Section 6.3 of this submission
Biomass burning	NE	NA	NE	

Note: NA = not applicable; NE = not estimated.

Living biomass and dead organic matter

All of New Zealand's land area in the *Other land* category is classified as 'managed'. New Zealand considers all land to be managed, because all land is under some form of management plan, regardless of the intensity and/or type of land-management practices. Reporting for the category *Other land remaining other land* is not mandatory. New Zealand applies the Tier 1 approach to this category, which assumes carbon accumulation and loss for the biomass pool is zero in all years subsequent to the year of conversion (section 9.3.1, IPCC, 2006a).

Soil carbon

SOC stocks in *Other land remaining other land* are estimated using a Tier 2 method for mineral soils (see section 6.3). The steady state mineral SOC stock in *Other land* is estimated to be 58.37 tonnes C ha^{-1}. This is based on only three samples so has an associated uncertainty of ±70.7 per cent (McNeill and Barringer, unpublished).

Land converted to other land (CRF 4.F.2)

Living biomass and dead organic matter

New Zealand uses a Tier 1 method to calculate emissions for *Land converted to other land* (equation 2.16, IPCC, 2006a). This is the same as that used for other areas of land-use conversion (e.g., *Land converted to cropland*). The Tier 1 method assumes the carbon in living biomass and dead organic matter present before conversion is lost in the same year as the conversion takes place and that carbon stocks in living biomass and dead organic matter following conversion are equal to zero. There is no Tier 1 method for calculating carbon accumulation in living biomass or dead organic matter for *Land converted to other land*.

Soil carbon

SOC stocks in *Land converted to other land* prior to conversion are estimated using a Tier 2 method (see section 6.3). The IPCC default method of a linear change over a 20-year period is used to estimate the change in SOC stocks between the original land use and other land for any given period.

6.9.3   Uncertainties and time-series consistency

Uncertainty in the IPCC default variables dominates the overall uncertainty in the estimate provided by New Zealand. Uncertainty in *Other land* introduces ±0.0 per cent uncertainty into the LULUCF net carbon emissions (see table 6.9.3). This is low because the change in *Other land* and the emissions from *Other land* are low.

Table 6.9.3   Uncertainty in New Zealand's 2016 estimates for the land use category Other land (including land in transition)

Variable	Uncertainty at a 95% confidence interval (%)
Activity data	
Uncertainty in land area	±22.0
Emission factors	
Uncertainty in biomass carbon stocks	±75.0
Uncertainty in soil carbon stocks	±70.7
Uncertainty introduced into net emissions for LULUCF	**±0.04**

Note: The activity data and combined emission factor uncertainty are weighted values and have been calculated using equation 3.2 from IPCC General Guidance and Reporting (IPCC, 2006b).

6.9.4 Category-specific QA/QC and verification

In the preparation of this inventory, the data for these emissions underwent Tier 1 quality checks.

6.9.5 Category-specific recalculations

The impact of recalculations on net CO_2-e emission estimates for the *Other land* category is shown in table 6.9.4. Recalculations were carried out for this category as a result of new activity data from the improved mapping process, as described in section 6.2, and changes to the data and method used to estimate carbon stock change in soil organic matter, as explained in section 6.3.

Table 6.9.4   Recalculations for New Zealand's net emissions from the Other land category in 1990 and 2015

| | Net emissions (kt CO_2-e) | | Change from the 2017 submission | |
Year	2017 submission	2018 submission	(kt CO_2-e)	(%)
1990	10.9	12.4	1.5	+13.3
2015	147.5	35.8	−111.7	−75.7

6.9.6 Category-specific planned improvements

Improvements to activity data following the creation of a new land use map will result in improved emissions estimates for *Other land* in the 2019 submission.

6.10 Harvested wood products (CRF 4G)

6.10.1 Description

In 2016, the net emissions from *Harvested wood products* were –5,946.4 kt CO_2-e. This is –3,873.5 kt CO_2-e (186.9 per cent) lower than the 1990 level of –2,072.9 kt CO_2-e. The decrease in emissions in the *Harvested wood products* category is driven by the increased rate of harvest that has occurred since 1990, as shown in figure 6.10.1.

Figure 6.10.1   Volume of roundwood produced and exported between 1990 to 2016
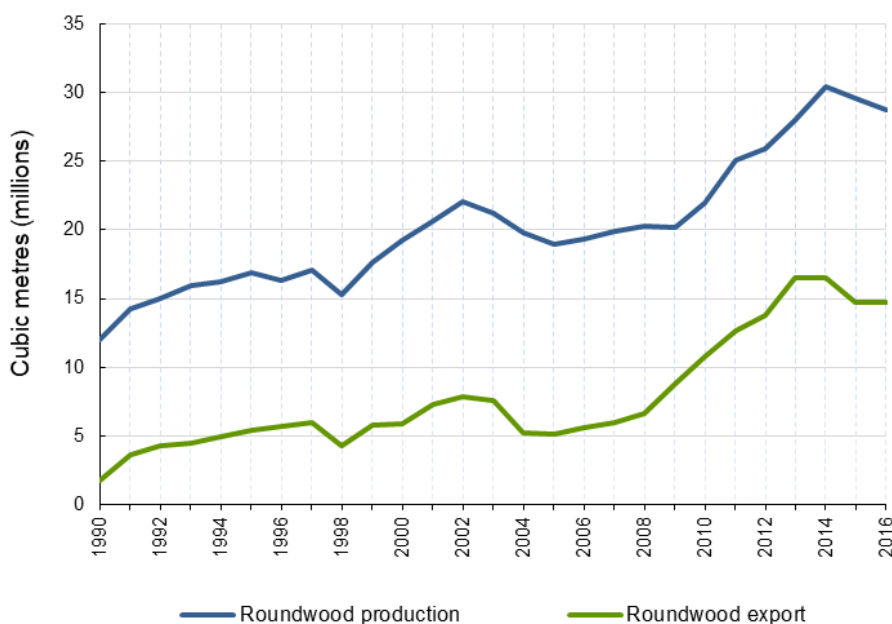
New Zealand has a large planted forest estate that provides the majority of wood products consumed domestically and exported in either product or raw material form. These forests were planted from the 1920s to supplement and eventually replace the harvesting of natural forests. Forest planting from the 1960s provides a resource specifically established to provide products to the export market. New Zealand currently processes under 50 per cent of its annual harvest. The remaining harvest is exported in raw material form. New Zealand is currently the second largest exporter of softwood logs after the Russian Federation (Wakelin, unpublished(d)). New Zealand's planted forests are dominated by radiata pine, which is used in a wide range of applications including timber-frame construction, packaging, plywood, medium density fibreboard (MDF), posts and poles and mechanical and chemical pulping (see CRF table 4.Gs2).

In 2016 *Harvested wood products* was a key category (trend and level assessment).

6.10.2 Methodological issues

New Zealand has selected the production approach to report *Harvested wood products* in the National Inventory Report. To do this, New Zealand has adapted the default *Harvested wood products* model and uses a Tier 2 method (section 12.2.1.2, IPCC, 2006a), which involves using country-specific activity data and parameters (Wakelin, unpublished(e)).

Activity data

Activity data are from the Food and Agriculture Organization statistical database (FAOSTAT) that is provided to the Food and Agriculture Organization by the Ministry for Primary Industries. Errors within the data sourced from FAOSTAT were corrected, including adding missing data and updating data that were not updated from the previous estimates. The data were corrected using data directly from the Ministry for Primary Industries.

Activity data for the period 1900–60 are populated using the IPCC model method, which assumes that consumption is correlated with population growth. The default value for Oceania for the annual rate of increase for the period 1900–60 was used by New Zealand. This information is used to initialise *Harvested wood products* stocks as at 1 January 1990.

A large proportion (over 50 per cent) of New Zealand's harvest was exported as raw materials in the form of logs or wood chips in 2016 (figure 6.10.1) (Ministry for Primary Industries, 2017). The FAOSTAT database provides data on the export quantity of raw materials but provides no information on the conversion of these materials to products or their expected half-lives. Research was completed in 2016 to provide information on harvested wood products from exported logs in New Zealand's three main export markets (China, South Korea and India). This research provides activity data for the conversion of New Zealand-produced raw materials to harvested wood products in export markets (Ministry for Primary Industries, 2016b). These data provide an improvement on the default assumption that exported raw materials were converted into products at the same rate as domestic production.

Emission factors

A wood carbon content value of 50 per cent is used in the harvested wood products model to maintain consistency with the planted forest model (table 4.3, IPCC, 2006a). A country-specific wood density value of 420 kilograms per square metre is used for sawnwood produced from coniferous species (Jones, 2005). This value is used to reflect coniferous species' contribution to New Zealand roundwood making up around 98 per cent of annual harvest. A country-specific wood density value of 500 kg/m^2 is used for sawnwood produced from non-coniferous species (Jones, 2005). Non-coniferous species (mainly *Eucalyptus* species) make up around 2 per cent of annual harvest. The default IPCC bark factor (11 per cent; annex 4A.1, IPCC, 2006a) is used for conifers and is considered appropriate for New Zealand. Wood-based panels and paper products all use IPCC defaults because no country-specific value is available (see table 6.10.1).

Table 6.10.1   **Country-specific conversion factors for Harvested wood products produced from New Zealand wood**

Category	Factor (t C/m^2 or t C/t*)	Source
Sawnwood, other industrial roundwood (coniferous)	0.210	Country specific (Jones, 2005)
Sawnwood, other industrial roundwood (non-coniferous)	0.250	Country specific (Jones, 2005)
Veneer sheets	0.210	Country specific (Jones, 2005)
Plywood	0.267	IPCC default (IPCC, 2014)
Particle board	0.269	IPCC default (IPCC, 2014)
Fibreboard (compressed)	0.315	IPCC default (IPCC, 2014)
Insulating board/other fibreboard	0.075	IPCC default (IPCC, 2014)
Paper products	0.450*	IPCC default (IPCC, 2014)

Note: * Indicates where factors are given in tonnes of carbon per tonne of product.

Half-lives

Half-lives determine the discard rate of products from service in the *Harvested wood products* category. New Zealand uses half-lives of 35 years for *Sawnwood,* 25 years for *Panels* and two years for *Paper and paperboard* from the Kyoto Protocol Supplement (IPCC, 2014) for domestic production. These half-lives are used to align with the method used in KP-LULUCF and to increase the accuracy of the estimates over the default categories (*Solid wood* and *Paper and paperboard*) (table 12.2, IPCC 2006a).

Research was completed in 2016 to provide information on harvested wood products from exported logs in New Zealand's three main export markets (China, South Korea and India). The study found that the majority of New Zealand wood is converted into construction and packaging materials. Weighted half-lives were found to be 6.6, 18 and 2.5 years for China, South Korea and India respectively (Ministry for Primary Industries, 2016b). The weighted half-lives for China and India are significantly lower than the IPCC default half-lives for *Sawnwood* and *Panels* (35 and 25 years respectively) (IPCC, 2014). These findings have now been included in New Zealand's *Harvested wood products* estimates and provide an improvement on the default assumption where exported raw materials were discarded at the same rate as domestic production.

6.10.3 Uncertainties and time-series consistency

Uncertainty in the *Harvested wood products* estimates is introduced by activity data, conversion factors and decay parameters. The *Harvested wood products* category provides the third-greatest contribution to uncertainty in the LULUCF sector. This is driven by large removals in this pool and high uncertainty associated with the end-use and discard rates of New Zealand wood. Uncertainty limits for *Harvested wood products* data and parameters are given in table 6.10.2. Uncertainty in New Zealand's 2016 estimates from emissions associated with *Harvested wood products* is provided in table 6.10.3.

Table 6.10.2   **Uncertainty in Harvested wood products data and parameters**

Parameter	Per cent uncertainty	Origin
Roundwood removals data	±20	Country specific (Wakelin, unpublished(e))
Harvested wood products production, import and export data	±15	IPCC default (table 12.6, IPCC, 2006a)
Product volume to weight factors	±10	Country specific (Wakelin, unpublished(e))
Oven dry product weight to carbon weight	±5	Country specific (Wakelin, unpublished(e))
Discard rate, domestic	±50	Country specific (Wakelin, unpublished(e))
Discard rate, export	±90	Country specific (Wakelin, unpublished(e))

Table 6.10.3 Uncertainty in New Zealand's 2016 estimates from emissions associated with Harvested wood products

Variable	Uncertainty at a 95% confidence interval (%)
Activity data	
Uncertainty in activity data	±15.0
Emission factors	
Domestic production	±51.2
Export raw materials	±90.7
Total domestic and export uncertainty	±67.4
Uncertainty introduced into net emissions for LULUCF	**±17.8**

6.10.4 Category-specific QA/QC and verification

New Zealand data from FAOSTAT were checked against data from the Ministry for Primary Industries (the agency responsible for the collection of these data). Missing totals in aggregate categories were filled by summing individual product categories, and incorrect estimates were replaced.

6.10.5 Category-specific recalculations

Table 6.10.4 Recalculations for New Zealand's net emissions from the Harvested wood products category in 1990 and 2015

Year	Net emissions (kt CO$_2$-e)		Change from the 2017 submission	
	2017 submission	2018 submission	(kt CO$_2$-e)	(%)
1990	−1,728.2	−2,072.9	−344.7	+19.9
2015	−5,769.7	−6,502.4	−732.7	−12.7

Recalculations in the 2018 submission were due to including the results of research carried out into the use of New Zealand raw materials in export markets.

6.10.6 Category-specific planned improvements

No category-specific improvements are planned for the next submission.

6.11 Non-CO$_2$ emissions (CRF 4(I–V))

6.11.1 Direct N$_2$O emissions from nitrogen fertilisation of forest land and other land (CRF 4(I))

New Zealand's activity data on nitrogen fertilisation are not currently disaggregated by land use and, therefore, all *Direct N$_2$O emissions from nitrogen fertilisation of forest land and other land* are reported in the Agriculture sector under the category *Direct N$_2$O emissions from managed soils* (CRF 3.D.a). The notation key IE (included elsewhere) is reported in the CRF tables for the LULUCF sector.

6.11.2 Emissions from drainage and rewetting of organic and mineral soils (CRF 4(II))

New Zealand has not prepared estimates for this category. Carbon dioxide emissions resulting from drainage of organic soils when land use is changed are reported within CRF tables 4.A to 4.F, and IE (included elsewhere) is reported in table CRF 4(II) in these cases. The drainage of soils and wetlands is a relatively minor activity in New Zealand and there is insufficient

information to reliably report on this activity where not associated with land-use change. This means the notation key NE (not estimated) is also reported in this CRF table within the LULUCF sector in accordance with paragraph 37(b) of Decision 24/CP.19 (UNFCCC, 2014).

6.11.3 Direct N₂O emissions from nitrogen mineralisation/ immobilisation (CRF 4(III))

Description

Nitrous oxide emissions result from the mineralisation of soil organic matter with land-use change. This mineralisation results in an associated conversion of nitrogen previously in the soil organic matter to ammonium and nitrate. Microbial activity in the soil converts some of the ammonium and nitrate present to N_2O. An increase in this microbial substrate caused by a net decrease in soil organic matter can therefore be expected to give an increase in net N_2O emissions (section 11, IPCC, 2006a).

Direct N_2O emissions from nitrogen mineralisation/immobilisation are minor in New Zealand, estimated at 0.3 kt N_2O in 2016 compared with 0.5 kt N_2O in 1990.

Methodological issues

To estimate N_2O emissions from disturbance associated with land-use change, New Zealand uses the method outlined in the 2006 IPCC Guidelines (equations 11.2 and 11.8, IPCC, 2006a). The inputs to these equations are:

- loss of carbon in mineral soils

- EF1 – the emission factor for calculating emissions of N_2O from nitrogen in the soil. New Zealand uses a country-specific value of 0.01 kg $N_2O – N$/kg N (Kelliher and de Klein, unpublished)

- C:N ratio – the IPCC default ratio of carbon to nitrogen in soil organic matter (1:15) is used (IPCC, 2006a, p 11.16).

Where an area of land is converted to a land use with a higher original mineral SOC stock than the category it is converted from, no N_2O emissions have been estimated as occurring because there is no associated loss of SOC. For instance, cropland converted to forest land is estimated not to result in net N_2O emissions because this land-use conversion is associated with a net gain in SOC in New Zealand (see table 6.3.1). In these situations, the notation key NO (not occurring) is reported in the CRF tables.

Uncertainties and time-series consistency

New Zealand uses a country-specific value for calculating N_2O emissions from nitrogen in soil. This value has a high level of uncertainty, which is estimated at 40.0 per cent (see table 6.11.1).

Table 6.11.1   Uncertainty in New Zealand's 2016 estimates for N₂O emissions from land-use change

Variable	Uncertainty at a 95% confidence interval (%)
Activity data	
Uncertainty in land area	±8.0
Emission factors	
Uncertainty in N₂O calculation	±40.0
Uncertainty in carbon calculation	±33.0
Uncertainty introduced into net emissions for LULUCF	**IE**

Source-specific planned improvements

No improvements are planned for this category at this time.

6.11.4 Indirect N₂O emissions from managed soils (CRF 4(IV))

Description

New Zealand cannot separate the sources of nitrogen between *Cropland*, *Grassland* and *Other land* uses. For this reason, it reports all *Indirect N₂O emissions from managed soils* within CRF table 3.D.b in the Agriculture sector and uses the notation key IE (included elsewhere) within CRF table 4(IV) of the LULUCF sector.

6.11.5 Biomass burning (CRF 4(V))

Description

Biomass burning may occur as a result of wildfires or controlled burning, and results in emissions of CO_2, CH_4, N_2O, CO and NO_x. The general approach for estimating greenhouse gas emissions from *Biomass burning* is the same, regardless of the specific land use type.

Biomass burning is not a significant source of emissions for New Zealand, because the practice of controlled burning is limited and wildfires are not common due to New Zealand's temperate climate and vegetation.

Emissions of CO_2 are reported as either IE (included elsewhere), where subsequent regrowth is not captured in the National Inventory Report, or NE (not estimated), where no data exist. The reason for this is explained below under 'Methodological issues'. Non-CO_2 emissions from *Biomass burning* in 2016 were 4.0 kt CH_4 (99.6 kt CO_2-e) and 0.03 kt N_2O (9.6 kt CO_2-e) (see table 6.11.2).

Table 6.11.2   Non-CO₂ emissions from Biomass burning

Emissions	1990	2016	Change since 1990 (%)
CH₄ emissions (kt CH₄)	4.7	4.0	−15.4
N₂O emissions (kt N₂O)	0.05	0.03	−38.8

Methodological issues

New Zealand reports on emissions from wildfire in *Forest land* and *Grassland* in the National Inventory Report. Controlled burning associated with the conversion of *Grassland* to *Forest land*, the clearing of vegetation (natural forest) prior to the establishment of exotic planted forest, the burning of post-harvest slash prior to restocking and controlled burning associated with deforestation, savanna (tussock) burning and controlled burning of *Grassland* are also included.

For all land uses, CO_2 emissions are captured in the general stock change calculation and, following the 2006 IPCC Guidelines (IPCC, 2006a), New Zealand reports IE (included elsewhere) where subsequent regrowth is not captured in the National Inventory Report.

New Zealand also reports IE for CH_4 and N_2O emissions for controlled burning of *Cropland remaining cropland*. This is because emissions from the burning of crop stubble associated with controlled burning of cropland is reported under the Agriculture sector (chapter 5) and reported within CRF table 3.F.

Tier 2 methodologies are employed to estimate emissions from *Biomass burning* in New Zealand. Country-specific emission factors are employed along with IPCC equations to derive emissions (sections 2.4 and 6.2.4.2, IPCC, 2006a). Activity data (area of land-use change) for grassland with woody biomass converted to forest are based on annual land-use changes, as estimated in section 6.2, and an estimate of area burned from a survey of forest owners. Wildfire activity data are sourced from the National Rural Fire Authority database, which has data from 1991/92 onwards. The April year data from the database are converted to calendar years for use in the National Inventory Report (Wakelin and Clifford, unpublished).

There has not been a significant change in total wildfire activity since 1990. However, there were significantly more wildfires in planted forests during 2016 than previous years, likely caused by summer droughts and one of the strongest El Niño weather patterns on record. Wildfires induced by natural disturbances (lightning) are estimated to account for only 0.1 per cent of burning in *Grassland* and *Forest land* in New Zealand (Doherty et al., unpublished; Wakelin, unpublished(f)). Non-CO_2 emissions from wildfires induced by natural disturbances are reported in the National Inventory Report, using data collected by the National Rural Fire Authority (NRFA). The NRFA does not distinguish between anthropogenic and natural wildfire events. Given the small incidence of natural-disturbance-induced wildfires in New Zealand, this is not regarded as a significant source of error.

Emissions of CO_2 from wildfires in *Forest land remaining forest land* are included in the general stock change calculation. In *Forest land remaining forest land*, burned stands are either harvested (so emissions are included with the harvesting emissions) or left to grow on at reduced stocking. Carbon dioxide emissions are reported when the stand is harvested or deforested (with no reduction in stock when compared with an unburned stand). For both natural and planted forests, emissions from areas burned are captured within the forest plot networks that New Zealand uses to estimate carbon stock change. In these cases, to avoid double counting of CO_2 emissions, the notation key IE (included elsewhere) is used. *Biomass burning* is not a key category for New Zealand.

A single weighted biomass density is used to estimate non-CO_2 emissions from wildfire in the *Forest land remaining forest land* category. Wildfire activity data are attributed to each category by proportion of forest type estimated to be burned over the time series. They are therefore split between 87.5 per cent to planted forest and the remainder to natural forest (Wakelin, unpublished(a)). The planted forest activity data are further split into pre-1990 forest and post-1989 forest by the proportion of area each forest type makes up of the total planted forest area. In planted forest, it is assumed that the carbon stock affected by wildfire is equivalent to the carbon stock at the average stand age in each forest type (Wakelin, unpublished(a)). The individual forest type estimates that make up the single weighted figure are derived from the national plot network described in section 6.4.

An estimate for wildfire in *Land converted to grassland* is provided in this submission. The activity data for wildfire in *Grassland* are attributed to the *Land converted to* and *Land remaining* categories by the proportion each category makes up of the total area.

A survey of controlled burning in planted forest was carried out in 2011 to estimate controlled burning activity on *Forest land* in New Zealand. Estimates were provided for burning associated with the clearing of vegetation (i.e., pre-1990 natural forest and grassland with woody biomass) prior to the establishment of exotic planted forest. The survey indicated that 5 per cent of conversions to planted forest involved burning to clear vegetation. This was allocated to pre-1990 planted forest (conversions from pre-1990 natural forest) and post-1989 forest (conversions from grassland with woody biomass) on a pro rata basis (Wakelin, unpublished(c)).

Activity data are combined with emission factors derived from the national plot network (see table 6.1.3) to estimate non-CO_2 emissions from burning associated with the clearing of

vegetation prior to the establishment of exotic planted forest. Below-ground biomass is assumed not to burn. The IPCC default combustion proportion for the burning of non-eucalypt temperate forest in land clearing fires (0.51) (for pre-1990 natural forest) and the burning of shrublands (0.72) (for grassland with woody biomass) is then applied to estimate emissions from this activity (table 2.6, IPCC, 2006a).

The survey also provided data on the burning of post-harvest slash prior to restocking. This activity was found to occur mainly as a training exercise for wildfire control or for the clearing of slash heaps on skid sites. The data indicated that 0.8 per cent of restocked area was burned each year in recent years. This estimate was combined with two earlier estimates of controlled burning in planted forest (Forest Industry Training and Education Council, 2005; Robertson, 1998) to provide activity data throughout the time series. It is assumed that 1.6 per cent of restocked area was burned from 1990 to 1997. From 1997, the area burned declines linearly to 0.8 per cent, which is used from 2005 onwards (Wakelin, unpublished(c)).

Activity data are combined with an emission factor derived from the pre-1990 planted forest carbon-yield table to estimate emissions from the burning of post-harvest slash (harvest residue) on *Forest land*. The harvest residue is calculated by subtracting the amount of above-ground biomass that is taken off site as logs (70 per cent) from the total above-ground biomass predicted at the age of 28 years (the average harvest age in New Zealand). Below-ground biomass is assumed not to burn. The IPCC default combustion proportion for the burning of harvest residue in non-eucalypt temperate forest (0.62) is applied to estimate emissions from this activity (table 2.6, IPCC, 2006a).

An estimate is provided for burning of post-harvest residues associated with deforestation in the National Inventory Report. No information is available on the extent of burning associated with deforestation in New Zealand. Therefore, it is assumed that 30 per cent of conversions involve burning to clear residues. The IPCC default combustion proportion for the burning of harvest residue in non-eucalypt temperate forest (0.62) is applied to category-specific emission factors to estimate emissions from this activity. The emission factor excludes the proportion of logs taken off site (70 per cent of above-ground biomass) and is taken from the plot-network-derived yield tables by forest type at the average age of harvest in New Zealand.

Carbon dioxide emissions from controlled burning in planted forests in the National Inventory Report are captured at the time of conversion or harvest.

The National Inventory Report includes burning of tussock (*Chionochloa*) grassland in the South Island of New Zealand for pasture renewal and weed control. The amount of burning has been decreasing steadily over the past 50 years as a result of changes in lease tenure and a reduction in grazing pressure. The tussock burning data are sourced from consents under the Resource Management Act 1991 for activities that occurred between 1990 and 2004. Statistics New Zealand provides these data from 2005 because burning became a permitted activity under the Act in some regions (Thomas et al., 2011).

Current practice in New Zealand is to burn in damp spring conditions, reducing the amount of biomass consumed by fire. To reflect this, a country-specific burning fraction of 0.356 is applied to a country-specific biomass density of 28 tonnes of dry matter. The ratio of biomass density to carbon lost upon burning is 0.45 (as cited in Thomas et al., 2011).

An estimate for controlled burning in *Grassland remaining grassland* (grassland with woody biomass) is provided for the first time in this submission. The activity data are sourced from Statistics New Zealand's Agricultural Production Survey. The activity data are combined with an emission factor derived from the national plot network (see table 6.1.3) to estimate non-CO_2 emissions from burning associated with the clearing of vegetation for pasture regeneration. Below-ground biomass is assumed not to burn. The IPCC default combustion

proportion for the burning of shrublands (0.72) is then applied to estimate emissions from this activity (table 2.6, IPCC, 2006a).

Different emission factors derived from the LUCAS plot network are used for wildfire and controlled burning on grassland with woody biomass in the inventory. The differences are due to the vegetation that is typically converted to forest, which is generally of a lesser stature when compared with other shrubland (Wakelin and Beets, unpublished).

Uncertainties and time-series consistency

Uncertainties arise from relatively coarse activity data for wildfires and controlled burning activities in New Zealand (see table 6.11.3). The biomass burning statistics have gaps in the time series where data collection did not occur or survey methodologies changed. Assumptions are made for some activity data, emission factors and burning fractions where insufficient data exist.

Table 6.11.3   Uncertainty in New Zealand's 2016 estimates for CH$_4$ and N$_2$O emissions from Biomass burning

Variable	Uncertainty at a 95% confidence interval (%)
Activity data	
Uncertainty in activity data	±30.0
Emission factors	
Uncertainty in emission factors	±41.6
Uncertainty introduced into net emissions for LULUCF	**±0.3**

Source-specific QA/QC and verification

Quality-control and quality-assurance measures are applied to the biomass burning activity data and emission factors. The biomass burning data set is verified whenever new data are supplied. The *Biomass burning* parameters (burning and emission factors), assumptions and data set have been reviewed (Payton and Pearce, 2009; Thomas et al., 2011; Wakelin, unpublished(a), (c), (f); Wakelin et al., unpublished).

Source-specific recalculations

The post-1989 planted forest yield table used in the controlled burning calculations following harvest and deforestation has been updated in this submission (see section 6.4.5 for further details). Activity data have also been updated between the 2017 and 2018 submissions. New estimates for controlled burning in *Grassland remaining grassland* have required recalculations across the time series.

Source-specific planned improvements

No improvements are planned for this category at this time.

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Chapter 7: Waste

7.1 Sector overview

7.1.1 The Waste sector in New Zealand

In New Zealand, virtually all solid waste is disposed to land. Most of the country's household, commercial and industrial waste is placed in managed municipal landfills. Before 2010, some municipal waste was also disposed to unmanaged or uncategorised sites. In addition, there are many small unmanaged disposal sites such as those on farms and in industry that are still in operation for other waste types.

There is no incineration of municipal waste in New Zealand. Incineration is used only on a very small scale, mainly for hazardous and clinical waste, and has declined over time due to environmental regulation and the availability of other disposal options.

Most wastewater treatment in New Zealand is aerobic, including domestic, commercial and industrial wastewater. Methane (CH_4) emissions from domestic wastewater are mainly from rural septic tank usage. Wastewater emissions are also from some municipal treatment plants that use semi-aerobic processes, and from industries in New Zealand, in particular the meat and the pulp and paper industries.

Emissions from biological treatment of solid waste, namely household composting are considered insignificant and are not estimated. No other emission sources for direct greenhouse gases are applicable to New Zealand and no other activity data are available.

7.1.2 Emissions summary

The Waste sector in New Zealand produces mainly CH_4 emissions (96.5 per cent) followed by N_2O emissions (3.4 per cent) and carbon dioxide (CO_2) emissions (0.03 per cent). There are also emissions of CO_2 from the disposal of solid waste, but these are of biogenic origin and are not reported.

2016

In 2016, emissions from the Waste sector contributed 3,838.2 kilotonnes of carbon dioxide equivalent (kt CO_2-e) or 4.9 per cent of New Zealand's gross greenhouse gas emissions. The largest source category is the *Solid waste disposal* category, as shown in table 7.1.1 (emissions by source category).

1990–2016

Total Waste sector emissions in 2016 were 24.4 kt CO_2-e (0.6 per cent) below 1990 emissions of 3,862.6 kt CO_2-e. Annual emissions increased between 1990 and 2002, peaking at about 4,500 kt CO_2-e in 2002, and have decreased since that time. The increase between 1990 and 2002 was the result of ongoing growth in population and economic activity. This has resulted in increasing volumes of solid waste and wastewater for the whole of the time series. Ongoing improvements in the management of solid waste disposal at municipal landfills, particularly increased CH_4 recovery has meant total Waste sector emissions have been trending down since 2005 in spite of increasing volumes of solid waste and wastewater. The trends are shown in figures 7.1.1 and 7.1.2.

2015–2016

Total Waste sector emissions in 2016 were 26.3 kt CO_2-e (0.7 per cent) lower than emissions in 2015. This decrease is the result of reductions in CH_4 emissions in the *Solid waste disposal* category, largely due to ongoing improvements in municipal solid waste management and the continuation of the gradual reduction in the total waste disposed in farm fills.

Table 7.1.1   New Zealand's greenhouse gas emissions for the Waste sector by source category 1990 and 2016

Source category	Emissions (kt CO_2-e) 1990	Emissions (kt CO_2-e) 2016	Difference (kt CO_2-e) 1990–2016	Change (%) 1990–2016	Share (%) 1990	Share (%) 2016
Solid waste disposal (5.A)	3,510.9	3,439.0	–71.9	–2.0	90.9	89.6
Biological treatment of solid waste (5.B)	NO, NE	NO, NE	–	–	–	–
Incineration and open burning of waste (5.C)	14.8	2.4	–12.3	–83.5	0.4	0.1
Wastewater treatment and discharge (5.D)	337.0	396.8	59.8	17.7	8.7	10.3
Total	**3,862.6**	**3,838.2**	**–24.4**	**–0.6**	**–**	**–**

Note: Emissions from biological treatment of solid waste are insignificant and not estimated (NE) or not occurring (NO) in New Zealand. Percentages presented are calculated from unrounded values.

Figure 7.1.1   Profile of emissions from New Zealand's Waste sector, by source from 1990 to 2016
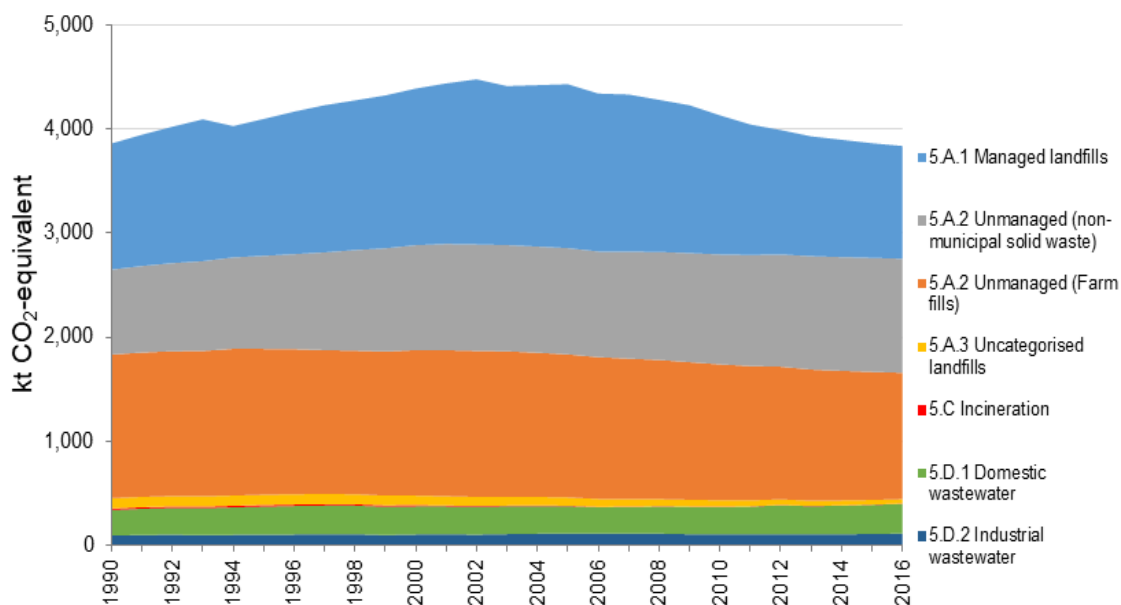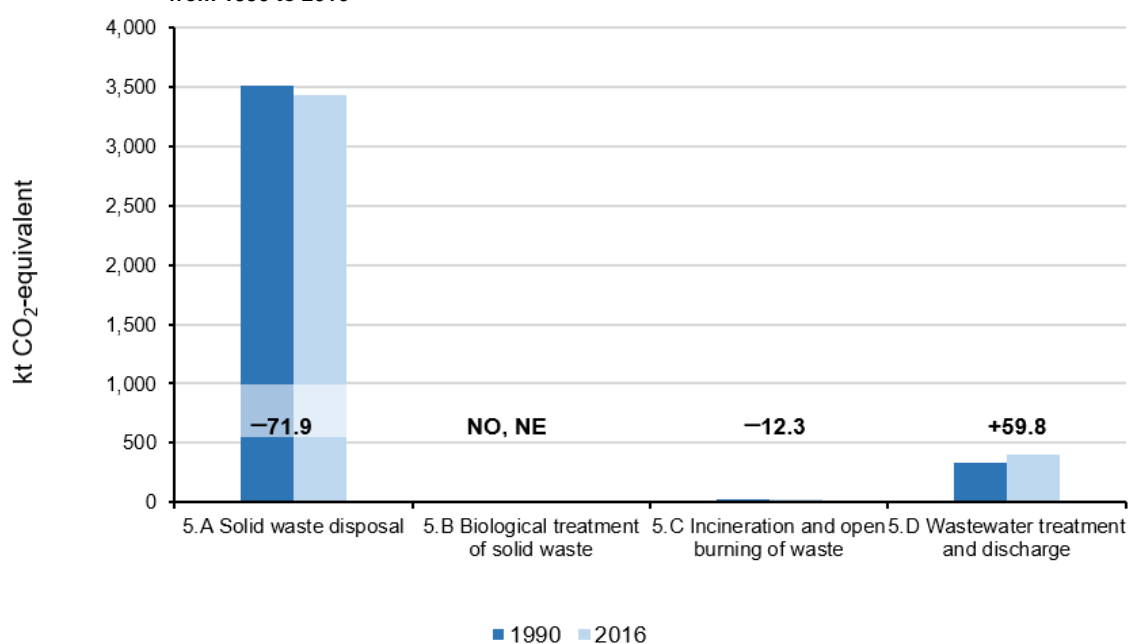
Note: NO = not occurring; NE = not estimated.

7.1.3   Key categories for Waste sector emissions

Details of New Zealand's key category analysis are in chapter 1, section 1.5. The key categories in the Waste sector are listed in table 7.1.2.

Table 7.1.2   **Key categories in the Waste sector**

CRF category code	IPCC categories	Gas	Criteria for identification
5.A	Solid waste disposal	CH_4	L1, T1
5.D	Wastewater treatment and discharge	CH_4	L1

Note: L1 means a key category is identified under the level analysis – approach 1 and T1 is trend analysis – approach 1. See chapter 1 for more information.

7.1.4   Methodological issues for the Waste sector

Activity data have come from a variety of sources. Municipal solid waste disposal data, from mandatory reporting under the Waste Minimisation Act 2008 and from the New Zealand Emissions Trading Scheme (NZ ETS), were used for the years for which they are available (2010 onwards). Activity data for all other sources were based on specific surveys. Interpolation based on gross domestic product (GDP) or population is used for other years.

New Zealand uses Tier 2 methodologies for estimating emissions from the *Solid waste disposal* source category, which is a key category, and for some wastewater emissions. Tier 1 methods are used to estimate other emissions in the Waste sector.

Country-specific emission factors have been used where available, including parameters for municipal waste and for treatment of some types of industrial wastewater (Cardno, unpublished).

Methodological issues are discussed under each source category in this chapter.

7.1.5 Uncertainties

The uncertainties for emission estimates are discussed under each category in this chapter. For most sources, they conform to default uncertainties in the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines (IPCC, 2006a). Much higher uncertainties are reported for waste disposed to land by farmers, due to uncertainty in the activity data, and for indirect N_2O emissions from wastewater going into rivers and sea water (for which the emission factors are highly uncertain).

7.1.6 Verification

Where available, data from different sources were used for verification. Municipal landfills report their activity data annually under the requirements of the Waste Minimisation Act 2008 and, in addition, most now report activity data and estimated emissions as part of the NZ ETS. These data sources are used as primary sources or for verification, as appropriate.

Data on wastewater treatment have been obtained from surveys.

7.1.7 Recalculations and improvements

There have been numerous changes and improvements in the Waste sector resulting in recalculations for several categories. These improvements are a combination of planned improvements and also responses to issues found during reviews of previous submissions. In addition, this chapter has been revised to improve the transparency of how emissions are calculated.

The most significant improvements have been made to the *Unmanaged waste disposal sites* source category and have resulted in the largest recalculation for the waste sector, reducing emissions on average by about 240 kt CO_2-e per year across the time series. The inclusion of an additional survey of farm wastes resulted in the downward revision of emissions from farm fills, and this change had the largest impact on emissions for the sector. Other changes in this category include revising methods for scaling data to a national level and revised waste composition.

In addition, several other corrections have been made to other categories in the Waste sector, including small improvements in activity data for the *Wastewater* category.

Further details can be found under methodological issues for each source and also in chapter 10.

7.1.8 Quality-assurance/quality-control (QA/QC) processes

Figure 7.1.3 shows a flow diagram for data in the Waste sector, including QA/QC processes. Tier 1 quality checks were carried out on all data for key categories in this sector.

Figure 7.1.3   Tier 1 quality checks for the Waste sector
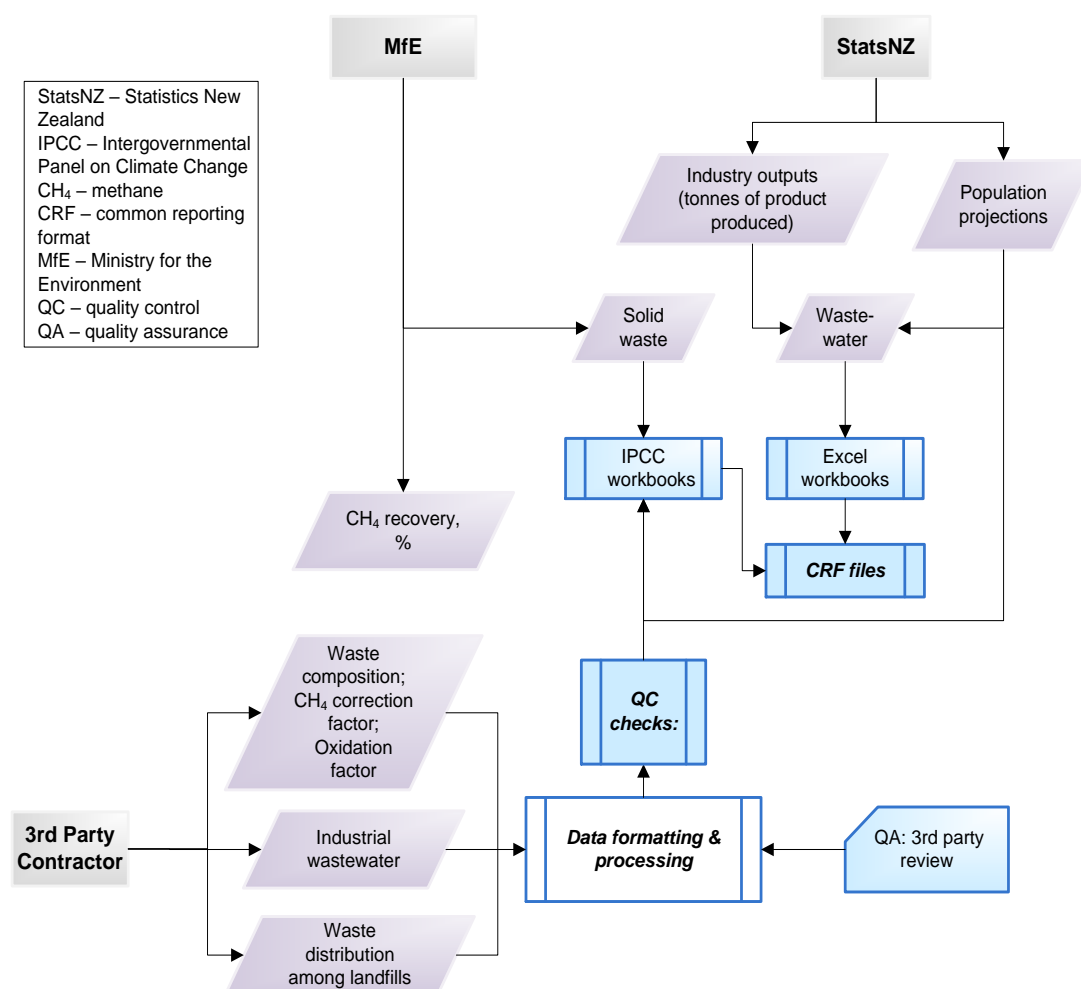
7.2   Solid waste disposal (5.A)

7.2.1   Description

Household and industrial solid waste in New Zealand is disposed of almost exclusively to landfills. The three broad types of landfill sites in New Zealand are:

1. municipal landfills, which are used for disposal of household waste but may also accept industrial waste or other types of solid waste

2. non-municipal landfills or significant landfill sites that do not accept household waste. These include cleanfills (sites disposing of largely inert waste), industrial fills and sites that dispose of construction and demolition waste

3. farm fills, which are used for disposal of household and other on-farm waste to land; disposal of waste to land is prevalent on farms in New Zealand.

These types of landfill sites map on to the common reporting format (CRF) tables, as shown in table 7.2.1. All currently operational municipal landfill sites are managed sites (IPCC, 2006a) but some emissions also come from uncategorised municipal landfill sites, which were in operation before 2010.

Table 7.2.1   Landfill emissions in the common reporting format table

CRF category code	Landfill type	Comment
5.A.1.a (Anaerobic)	Managed municipal landfills	Includes all currently operational municipal landfill sites and all sites with gas recovery
5.A.1.b (Semi-aerobic)	–	No semi-aerobic landfill sites identified in New Zealand
5.A.2 (Unmanaged)	Non-municipal landfills	Includes industrial landfills
5.A.2 (Unmanaged)	Farm fills	Disposal of waste on farms
5.A.3 (Uncategorised)	Other municipal landfills	Prior to 2010 only

Since 1990, there have been a number of initiatives to improve solid waste management practices in New Zealand. These include:

- requirements for all landfills to meet resource consent conditions set under the Resource Management Act 1991

- guidance and direction to local government and the Waste sector through *The New Zealand Waste Strategy* (Ministry for the Environment, 2002a) and its revision in 2010 (Ministry for the Environment, 2010)

- development of the *Solid Waste Analysis Protocol*, which provides a consistent classification system, sampling regimes and survey procedures to estimate the composition of solid waste (Ministry for the Environment, 2002b)

- the Waste Minimisation Act 2008, which imposes a levy of NZ$10 per tonne of municipal solid waste and enables regulations to establish product stewardship requirements and for information reporting.

In addition, most municipal landfills are now mandatory participants in the NZ ETS with obligations to report and surrender emission units for their CH_4 emissions.

These initiatives have contributed to substantial improvements in waste management since 1990. A large number of small, often poorly located and substandard municipal landfills have been closed, and most communities are now using larger, more modern regional facilities for disposal of their waste. There are now 39 significant municipal landfill sites, in comparison with 327 in 1995 and 563 in 1971.

Non-municipal landfills and farm fills are also required to comply with regional policies and plans made under the Resource Management Act 1991. However, these facilities are not currently required to monitor and report the waste they accept, to pay the waste levy, or to participate in the NZ ETS.

In 2016 the *Solid waste disposal* source category contributed 3,439.0 kt CO_2-e (89.6 per cent) of total emissions from the Waste sector. Emissions from *Solid waste disposal* in 2016 were 71.9 kt CO_2-e (2.0 per cent) below the 1990 level of 3,510.9 kt CO_2-e. This net decrease is the result of two contrary trends. First, population and economic growth have driven ongoing increases in the amount of municipal waste generated but, secondly, improved landfill management practices, particularly landfill gas (LFG) recovery, have offset this increase, resulting in emissions peaking in 2002. There is also some year-to-year variation.

Methane emissions from *Solid waste disposal* were identified as a key category in the 2016 level assessment and trend assessment.

7.2.2 Methodological issues

Choice of activity data

Municipal landfills (5.A.1.a and 5.A.3)

Annual total waste placement to all municipal landfills has been estimated based on:

- back-casting from a 1982 national survey, using real (inflation-adjusted) GDP, for the years before 1982

- national surveys carried out for the years 1982, 1995, 1998, 2002 and 2006

- linear interpolation for the years between these surveys

- linear interpolation for the years 2007 to 2009

- data collected annually under the requirements of the Waste Minimisation Act 2008 for the years since 2010.

A regression analysis established that there was a correlation between real GDP and the amount of waste landfilled up to 2002. The transition from national surveys to using Waste Minimisation Act 2008 information uses a linear interpolation. Other methods were explored, but this approach gave the most robust estimates (Eunomia and Waste Not, unpublished).

Activity data are also available from individual landfill sites. This information was collected from landfill operators by a survey in 2009 (SKM, unpublished(b)). The 24 landfills that were operating at that time and that either had LFG recovery systems, or were planning to install LFG recovery systems by 2012, all provided data. These data included their annual waste placement history and intentions. Some of these sites have since closed and are no longer accepting waste, but they all still have CH_4 emissions. No new large landfill sites have opened in New Zealand since 2009.

The municipal landfill sites that were operational from 2013 to 2016, with some minor exceptions, have also submitted NZ ETS returns for those years specifying their monitored annual waste placement. For each of the sites that were also covered by the 2009 survey, the time series has been updated using the NZ ETS data, with linear interpolation as necessary between 2009 and 2012.

For each year in the time series, the total waste placement to all sites without LFG recovery systems and to uncategorised sites is the difference between the national total, estimated as above, and the total of the individual estimates made for the sites with LFG recovery. The waste placement for the uncategorised category (5.A.3) is estimated as a fixed fraction of this amount up until 1995, before declining to zero in 2010. Table 7.2.2 shows waste placement for 1990 to 2016.

Table 7.2.2   **Solid waste deposited to municipal and uncategorised landfills from 1990 to 2016**

Year	Sites with LFG recovery (kt)	Sites without LFG recovery (kt)	Uncategorised sites (kt)	National total (kt)
1990	1,432.6	1,174.7	130.5	2,737.8
1991	1,432.6	1,254.7	139.4	2,826.6
1992	1,432.6	1,334.7	148.3	2,915.5
1993	1,650.5	1,218.5	135.4	3,004.4
1994	1,687.5	1,265.2	140.6	3,093.2
1995	1,687.5	1,345.2	149.5	3,182.1
1996	1,735.0	1,186.0	122.1	3,043.1
1997	1,671.2	1,126.0	106.8	2,904.1
1998	1,575.0	1,094.8	95.2	2,765.0
1999	1,575.0	1,162.3	92.0	2,829.3

Year	Sites with LFG recovery (kt)	Sites without LFG recovery (kt)	Uncategorised sites (kt)	National total (kt)
2000	1,575.0	1,230.6	87.9	2,893.5
2001	1,718.3	1,165.1	74.4	2,957.8
2002	1,714.2	1,238.0	69.7	3,022.0
2003	1,626.8	1,362.0	66.7	3,055.5
2004	1,676.5	1,356.0	56.5	3,089.0
2005	1,881.2	1,199.9	41.4	3,122.5
2006	2,305.4	827.9	22.7	3,156.0
2007	2,158.8	824.2	16.8	2,999.8
2008	2,097.4	736.2	9.9	2,843.5
2009	2,051.7	631.4	4.2	2,687.3
2010	2,146.7	384.3	0.0	2,531.0
2011	2,216.6	244.4	0.0	2,461.0
2012	2,286.4	227.5	0.0	2,513.9
2013	2,359.0	439.4	0.0	2,798.4
2014	2,610.0	324.2	0.0	2,934.2
2015	2,872.5	351.2	0.0	3,223.7
2016	3,044.4	361.4	0.0	3,405.8

Note: LFG = landfill gas. Columns may not total due to rounding.

Non-municipal landfills and farm fills (5.A.2)

The available information on historical and current disposal rates to non-municipal landfills is derived from direct contact with landfill operators and from regional councils, who regulate these activities under the Resource Management Act 1991. There are substantial gaps, which were filled by correlating waste quantities with regional GDP (Tonkin and Taylor Ltd, unpublished(b)). Waste quantities are determined for each region and then combined to provide a national total (Tonkin and Taylor Ltd, unpublished (b)).

Farm fills are used to dispose of various types of farming waste such as scrap metal, timber used for fencing, plastic wraps and ties, batteries and demolition waste. Farmers also use them to dispose of organic and general household waste.

The information used to estimate activity data and emissions from farm fills has come from surveys carried out in the Canterbury region in 2012 and 2013, and the Waikato and Bay of Plenty regions in 2014 (GHD, 2013, 2014; Tonkin and Taylor Ltd, unpublished(b)). The results from these surveys are extrapolated to the rest of the country. Farming practices regarding farm fill sites are quite similar around the country, so the extrapolation is unlikely to introduce a systematic bias. However, the sample size is small in relation to the number of farms in New Zealand.

Waste quantities were determined for the farm types surveyed: dairy, livestock, arable, viticulture and other horticulture. These survey results have been applied regionally and then combined to provide a national total, with adjustments to account for the differences in the prevalence of these five farm types across all regions (Tonkin and Taylor Ltd, unpublished (b)).

Table 7.2.3   Solid waste deposited to unmanaged landfills from 1990 to 2016

Year	Farm fills (kt)	Non-municipal landfills (kt)	Total waste disposed (kt)
1990	1,421.3	2,631.4	4,052.7
1991	1,412.5	2,635.4	4,047.9
1992	1,397.9	2,606.7	4,004.6

Year	Farm fills (kt)	Non-municipal landfills (kt)	Total waste disposed (kt)
1993	1,508.7	2,635.6	4,144.4
1994	1,288.7	2,804.2	4,092.9
1995	1,276.3	2,948.2	4,224.5
1996	1,225.9	3,087.8	4,313.8
1997	1,318.2	3,199.8	4,518.0
1998	1,410.4	3,265.0	4,675.3
1999	1,502.6	3,291.5	4,794.1
2000	1,436.7	3,471.0	4,907.8
2001	1,370.9	3,571.8	4,942.7
2002	1,305.0	3,694.9	5,000.0
2003	1,226.1	3,867.5	5,093.6
2004	1,235.9	4,043.7	5,279.6
2005	1,196.9	4,203.4	5,400.3
2006	1,200.5	4,342.1	5,542.6
2007	1,178.1	4,463.9	5,642.0
2008	1,126.5	4,592.8	5,719.3
2009	1,103.4	4,541.4	5,644.8
2010	1,114.2	4,527.6	5,641.7
2011	1078.8	4,596.7	5,675.5
2012	1,081.5	4,701.1	5,782.6
2013	1,054.4	4,806.6	5,861.0
2014	1,054.6	4,924.4	5,979.0
2015	1,027.5	5,092.4	6,120.0
2016	1,032.3	5,215.4	6,247.7

Note: Columns may not total due to rounding.

Choice of methods

Estimations of CH_4 emissions from solid waste disposal to land were calculated by using the First Order Decay (FOD) model. This is the Tier 2 method from the 2006 IPCC Guidelines (IPCC, 2006a).

Municipal landfills (5.A.1.a)

For each of the 24 landfill sites covered by the 2009 survey (above), the FOD model (IPCC, 2006a) has been applied to develop estimates of CH_4 emissions, with site-specific data on waste placement, k-value and other parameters applied where available, and uses a single-phase bulk waste approach. These sites that are still operational account for approximately 90 per cent of waste disposed to municipal landfills.

Municipal waste outside of these 24 sites is disposed to smaller landfills that have never had gas recovery. In 1990 there were more than 300 of these sites and in 2016 there were approximately 25 still in operation. This number includes some very small sites serving small and remote communities. The FOD model has also been applied to estimate the total CH_4 emissions from these landfills, using a multi-phase waste composition approach.

Non-municipal landfills and farm fills (5.A.2)

Non-municipal landfills include privately owned industrial landfills, and a large number of landfill sites (cleanfills, and construction and demolition fills) that are consented for largely inert waste

and accept a maximum of 5 per cent municipal waste. Only limited information is available on these sites and their management practices, with a lack of historical information in particular. The FOD model has been applied to estimate total CH_4 emissions from non-municipal landfills.

For on-farm disposal to land, the FOD model has been applied to estimate the total CH_4 emissions. Farm waste comprises a mix of household and other wastes. Survey data on waste composition are used to determine weighted average values for degradable organic carbon (DOC) content of waste from dairy farms, livestock farms, arable and viticulture farms (GHD, 2013, 2014). Survey data on waste composition from viticulture and arable farms are used to determine a weighted average DOC value for other remaining horticultural farms.

Choice of emission factors and parameters

Municipal landfills (5.A.1.a)

Waste composition

Many municipal landfills in New Zealand accept locally produced industrial waste as well as municipal waste. New Zealand has insufficient data to determine how much of the waste disposed to municipal landfills comes from industrial sources. Where surveys of composition data have occurred at sites that take industrial waste, this is included as part of the overall composition estimates.

Waste composition has been estimated from national surveys carried out in 1995 and 2004 (Ministry for the Environment, 1997; Waste Not Consulting, unpublished(a)). In addition, estimates have been made for 2008 and 2012 based on individual landfill surveys (Waste Not Consulting, unpublished(b)). The waste surveys have been based on the *Solid Waste Analysis Protocol* (Ministry for the Environment, 2002b) to ensure a consistent methodology for sampling and analysis.

No usable waste composition data are available for the period before 1995. For the years 1950 to 1994, data from the 1995 survey have been used, with an adjustment to account for the fact that disposable nappies came into use in the 1960s (Eunomia Research and Consulting and Waste Not Consulting, unpublished). Linear interpolation was used for years between the survey years, and the years since 2012 are assumed to be the same as 2012. This will be revised when more survey data are collected in the future.

Table 7.2.4 shows the resulting estimated composition data from 1950 to 2016. These have been used for the waste disposed to all municipal landfills.

Table 7.2.4   Estimated composition of waste to municipal landfills from 1950 to 2016

Year	Food (%)	Garden (%)	Paper (%)	Wood (%)	Textile (%)	Nappies (%)	Inert (%)	Notes
1950–60	17	11	16	7	1	0	48	No nappies
1961–69	17	11	16	7	1	1	47	Interpolation
1970–79	17	11	16	7	1	2	46	Interpolation
1980–94	17	11	16	7	1	3	45	As for 1995
1995	17	11	16	7	1	3	45	National survey
1996	17	11	16	8	1	3	45	Interpolation
1997	17	11	16	9	1	3	44	Interpolation
1998	16	10	16	9	2	3	44	Interpolation
1999	16	10	16	10	2	3	43	Interpolation
2000	16	10	16	11	2	3	43	Interpolation
2001	15	10	15	12	3	3	43	Interpolation

Year	Food (%)	Garden (%)	Paper (%)	Wood (%)	Textile (%)	Nappies (%)	Inert (%)	Notes
2002	15	10	15	12	3	3	42	Interpolation
2003	15	9	15	13	4	3	42	Interpolation
2004	14	9	15	14	4	3	41	National survey
2005	15	9	13	13	4	3	42	Interpolation
2006	16	9	12	13	4	3	43	Interpolation
2007	16	9	10	12	4	3	44	Interpolation
2008	17	9	9	12	4	3	45	Survey
2009	17	9	9	12	4	3	45	Interpolation
2010	17	9	10	12	5	3	44	Interpolation
2011	17	9	10	12	5	3	44	Interpolation
2012	17	8	11	12	6	3	44	Survey
2013–16	17	8	11	12	6	3	44	Assumed same as 2012

The resulting estimates of DOC content in the waste, with the IPCC default DOC fraction for each component, track these changes in composition. The overall average DOC fraction (including individual sites with different composition) has changed through the time series, increasing from 0.145 in the 1950s to peak at 0.175 in 2004, and then back down to 0.156 in 2012.

Methane correction factor and oxidation factor

The methane correction factor used is 1.0 for all managed landfill sites, both landfills with LFG recovery and those without. An oxidation factor of 10 per cent is used for waste disposed to these sites.

For all sites other than managed landfills, there was an unknown mix of shallow and deep disposal areas. A survey carried out in 1971 revealed that larger sites in operation were assessed at that time to be roughly half deep (more than 5 metres) and half shallow. The use of cover material was variable. Therefore, for uncategorised sites, the methane correction factor of 0.6 and an oxidation factor of zero have been used.

Methane generation rates

For the landfills with LFG recovery, k-values for waste were estimated based on those used for municipal solid waste in the United States inventory as at 2007, which were considered more appropriate than IPCC defaults because the waste composition is more closely comparable with that of the United States of America. Figure 7.2.1 shows the similarity in composition of municipal solid waste to landfills between the United States of America and New Zealand (United States Environmental Protection Agency, 2014).
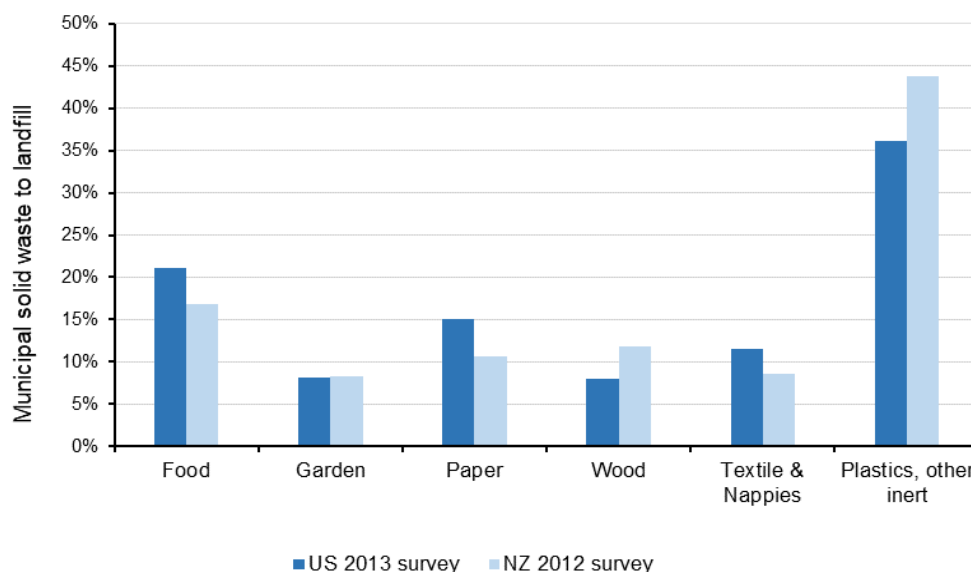
Note: Nappies were not specified for the US survey, so for New Zealand, nappies (3.0 per cent) have
been included with textiles (5.6 per cent) as they use the same DOC value.

In addition, the k-values for some managed landfills with LFG recovery were increased by 5 per
cent to 25 per cent to account for the conditions of sites that do not collect leachate, sites that
recirculate leachate and sites that were assessed to be using poor-quality capping materials or
practices (SKM, unpublished(b)). The k-values for managed landfills with LFG recovery are
shown in table 7.2.5, along with data on the proportion of placement managed by each group of
landfills with common k-values.

Table 7.2.5   Methane generation rates used for landfills with landfill gas recovery 1990 and 2016

k-value	Number of sites applying this k-value	Comment	Percentage of waste disposed to site group	
			1990	2016
0.038	8	US default for sites with 500–1,000mm of annual rainfall	30.5	20.8
0.0418	1	k-value modified for site-specific conditions	–	0.9
0.0475	1	k-value modified for site-specific conditions	6.3	2.7
0.057	11	US default for sites with more than 1,000mm of annual rainfall	57.1	41.3
0.05985	2	k-value modified for site-specific conditions	6.2	32.8
0.0627	1	k-value modified for site-specific conditions	–	1.7

For sites without LFG recovery, the IPCC default k-values for a wet temperate climate have
been used on a waste composition basis. The wet temperate climate is the best overall match for
New Zealand's climate as site-specific data are not known for those sites.

Gas recovery

For each of the landfill sites that have gas recovery, the recovery rate was estimated based on
research into the local conditions at that site, taking into consideration the landfill capping type
and quality, landfill lining, well placement, active or passive gas control in use and whether
wells were original or retrofitted (SKM, unpublished(b)). In some cases, gas-flow data or other
evidence of gas flow such as energy generation data were collected in the research done in 2009
and have been used to estimate recovery rates in addition to the local conditions at the site
(SKM, unpublished(b)). Table 7.2.6 shows the range of recovery rates applied for each method
of estimating the recovery rate and the total amounts recovered.

Table 7.2.6   Methane recovery rates and amounts for landfill sites with landfill gas recovery 2016

Method for determining recovery rate	Number of sites	Recovery rate applied for 2016 (%)	Methane recovered in 2016 (kt CH$_4$)		
			Energy generation	Flaring	Total
Direct evidence of gas-flow rate in 2009	4	33–90	22.9	1.3	24.2
Evidence of energy generation in 2009	1	47	1.0	–	1.0
Indirect methods based on site conditions	19	25–90	28.1	7.5	35.6
Total	**24**	**N/A**	**52.0**	**8.8**	**60.8**

The key driver of the amount of CH$_4$ recovered at each site is the annual waste placement as only historical gas-flow data are available from the research conducted on the recovery rates in 2009 (SKM, unpublished(b)). New Zealand is investigating the use of data from the energy sector on the energy generated from landfills to further inform methane recovery rates.

Based on reviews of previous submissions, New Zealand was recommended to use a recovery rate of 20 per cent. The IPCC guidelines state that when CH$_4$ recovery is estimated on the basis of the number of solid waste disposal sites with LFG recovery, a default estimate of recovery would be 20 per cent (IPCC, 2006a). However, it is known that the collection efficiency varies greatly depending on the technology used. New Zealand has detailed information about each site, as well as evidence of actual recovery rates. This information provides assurance that the site-specific recovery rates used are appropriate. Using the suggested recovery rate of 20 per cent has the effect of substantially underestimating recovery and therefore overestimating emissions for landfills with LFG recovery. Figure 7.2.3 demonstrates the effect on CH$_4$ emissions from landfills with LFG recovery for the entire time series when the default recovery rate of 20 per cent is used.

Recovery rates vary across the time series as the LFG recovery technology has been progressively installed and upgraded. In the emissions estimates, the methane recovery rate is specified for each site by year based on the gas-flow data or site-specific factors described above, taking into account when methane recovery began for each site. One site ceased methane recovery in 2006 and this is taken into account also. In 2016 recovery efficiencies varied from 25 per cent to 90 per cent over the landfills with recovery technology, excluding the site that no longer recovers CH$_4$.

When the varying amounts of CH$_4$ generated at each site are taken into account, the total recovery rate for all 24 landfills can be determined and in 2016, 68 per cent of the CH$_4$ generated was recovered. Figure 7.2.2 shows how the site-specific recovery efficiency has increased over time as recovery technology has been progressively deployed across municipal landfills. In addition, it shows the effect on the overall recovery rate of using a rate of 20 per cent for the duration each site is known to have been undertaking recovery.

Figure 7.2.2   Total methane recovery rate as applied for landfills with landfill gas recovery from 1990 to 2016
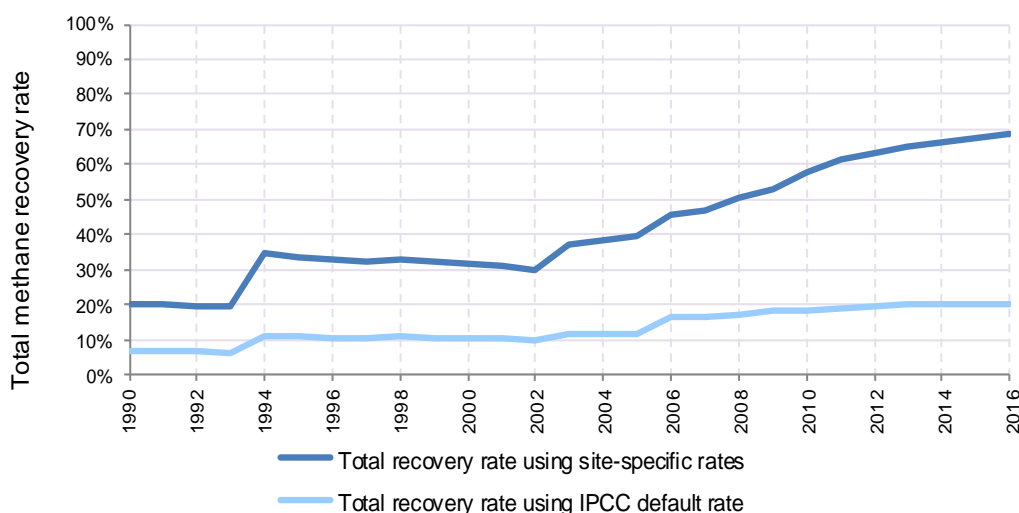
As LFG recovery technology has been installed and upgraded and the overall rate of recovery increases, it recovers increasing quantities of CH_4 generated in landfills, even as placement has increased across the time series. Figure 7.2.3 shows the difference in emissions between applying the IPCC default recovery rate based on the number of sites with recovery compared with using the site-specific recovery rates.

Figure 7.2.3   Effect on emissions from landfills with landfill gas (LFG) recovery when using default methane recovery rate from 1990 to 2016
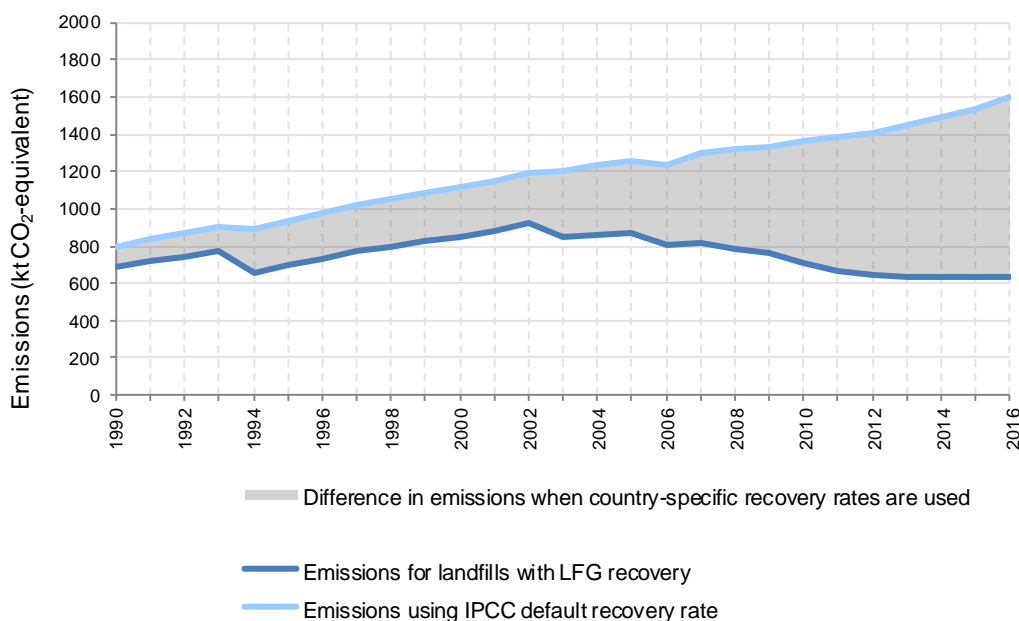
Summary of parameters used

Table 7.2.7 gives a summary of the parameter values that have been applied for estimating CH_4 emissions for solid waste disposed to municipal landfills.

Table 7.2.7   Summary of parameters for municipal landfills

Parameter	Values	Source	Reference
Managed landfills with CH$_4$ recovery			
k-value	0.038–0.0627	Country specific	SKM (unpublished(b))
Methane correction factor	1.0	IPCC default	IPCC (2006a)
Oxidation factor	10%	IPCC default	IPCC (2006a)
Recovery efficiency	25–90%	Site specific	SKM (unpublished(b))
Managed landfills without CH$_4$ recovery			
k-value	0.030–0.185	IPCC default	IPCC (2006a)
Oxidation factor	10%	IPCC default	IPCC (2006a)
Uncategorised landfills			
k-value	0.030–0.185	IPCC default	IPCC (2006a)
Methane correction factor	0.6	IPCC default	IPCC (2006a)
Oxidation factor	0	IPCC default	IPCC (2006a)
All landfill sites			
Starting year	1950	IPCC default	IPCC (2006a)
Delay time	6 months	IPCC default	IPCC (2006a)
Fraction of degradable organic carbon (DOC) that decomposes	0.5	IPCC default	IPCC (2006a)
Fraction of CH$_4$ in gas	0.5	IPCC default	IPCC (2006a)
DOC (kt C/kt waste)	0.145–0.175	Country specific	Waste Not Consulting (unpublished(b)); Eunomia Research and Consulting and Waste Not Consulting, (unpublished)

Non-municipal landfills and farm fills (5.A.2)

Waste composition

The main waste types disposed to non-municipal landfills are described in survey data as cleanfill, construction and demolition waste, green waste and wood. These were mapped to the IPCC waste types (IPCC, 2006a) and the IPCC default DOC values were applied. Most sites provided data on which types of waste are accepted, but only a few could quantify the amounts. To fill this data gap, an assumption is made that the quantities of waste produced in each region could be determined from the proportion of waste types reported for each region (Tonkin and Taylor Ltd, unpublished(b)). Updated site data on waste composition from non-municipal landfills have been included for the 2016 year (MWH, 2017).

Other parameters

The majority of non-municipal landfills and farm fills are shallow, with less than 5 metres depth of waste. These are estimated to account for 90 per cent of the waste disposed with a methane correction factor value of 0.4. The other 10 per cent (approximately) goes to fills that are assumed to be:

- for non-municipal landfills, an unknown mix that would have an average methane correction factor value of 0.6; this gives an overall average for these sites of 0.42

- for farm fills, deeper pits with an average depth greater than 5 metres, so the methane correction factor value is 0.8 and the average for all farm fills is 0.44.

Default k-values for a wet temperate climate are used. No oxidation is assumed to occur in the cover for these unmanaged sites.

Summary of parameters used

Table 7.2.8 gives a summary of the parameter values that have been applied for estimating CH_4 emissions for solid waste disposed to non-municipal landfills and farm fills.

Table 7.2.8   Summary of parameters for non-municipal landfills and farm fills

Parameter	Values	Source	Reference
Non-municipal landfills			
k-value	0.030–0.185	IPCC default	IPCC (2006a)
Methane correction factor	0.42	Country specific	Tonkin and Taylor Ltd (unpublished(b))
Degradable organic carbon (DOC) (kt C/kt waste)	0.040–0.043	Country specific	Waste Not Consulting (unpublished(b))
Farm fills			
k-value	0.09	IPCC default	IPCC (2006a)
Methane correction factor	0.44	Country specific	Tonkin and Taylor Ltd (unpublished(b))
DOC (Gg C/Gg waste)	0.184-0.331	Country specific	GHD (2013, 2014)
All sites			
Oxidation factor	0	IPCC default	IPCC (2006a)
Starting year	1950	IPCC default	IPCC (2006a)
Delay time	6 months	IPCC default	IPCC (2006a)
Fraction of DOC that decomposes	0.5	IPCC default	IPCC (2006a)
Fraction of CH_4 in gas	0.5	IPCC default	IPCC (2006a)

7.2.3   Uncertainties and time-series consistency

Uncertainties

For emission factors used in CH_4 emissions from managed municipal landfills, the uncertainty estimate is ±40 per cent (table 7.2.9). This is consistent with the estimates provided in the IPCC Guidelines (IPCC, 2006a). It is set at this level because some, but not all, of the estimates for CH_4 recovery are based on metered gas-flow data.

For non-municipal landfills and farm fills, the uncertainty in activity data is estimated to be ±140 per cent. Historical information on the amount of waste placed in these sites is very limited, given the nature of the management of such fills.

Table 7.2.9   Uncertainty in emissions from Solid waste disposal

Emissions category	Uncertainty in activity data (%)	Uncertainty in emission factors (%)
Managed landfills	±40	±40
Unmanaged landfills	±140	±40
Uncategorised landfills	±40	±40
Overall uncertainty in CH_4 emissions	±97	±40

Time-series consistency

As a result of substantial changes in waste disposal practices over time (including closure of the majority of landfill sites that were operating in 1990), the move to Waste Levy and NZ ETS reporting and ongoing improvement in the quality and completeness of activity data for *Solid waste disposal*, the basis for calculating emissions has changed significantly. However, these changes have had little effect on the apparent consistency of data or the implied emission factors, because they have occurred gradually and they affect CH_4 emissions over a long period.

7.2.4 Source-specific quality assurance and quality control and verification

Solid waste disposal is a key category. In the preparation of this submission, the data for this category underwent Tier 1 quality checks.

7.2.5 Source-specific recalculations

Several corrections and improvements have been made within the *Solid waste disposal* category, leading to recalculations of estimates for the full time series in the 2018 submission. The main changes are:

- correction of several errors in the calculation of emissions from the *Managed waste disposal sites* category (5.A.1). When compared with the previous submission, the effect of the change on emissions from the *Managed waste disposal sites* category over the time series is to decrease emissions in 1990 by 14.5 kt CO_2-e and increase emissions in 2015 by 31.1 kt CO_2-e

- a number of improvements and corrections in the calculation of emissions from the *Unmanaged waste disposal sites* category (5.A.2) for non-municipal landfills and farm fills. These represent the largest recalculations in the Waste sector. When compared with the previous submission, the effect of the change on emissions from the *Unmanaged waste disposal sites* category over the time series is to decrease emissions in 1990 by 243.0 kt CO_2-e and to decrease emissions in 2015 by 181.9 kt CO_2-e.

Recalculations are listed in greater detail in Chapter 10 of this submission. There have been no recalculations to the *Uncategorised waste disposal sites* category (5.A.3).

7.2.6 Source-specific planned improvements

Several areas in the *Solid waste disposal* category are being considered for improvements, depending on the availability of resourcing.

For improvements to estimates of methane recovery, New Zealand is investigating the use of data from the energy sector on energy generation from landfills to improve the accuracy of methane recovery rates.

Landfill operators who are mandatory NZ ETS participants have the option of applying for a unique emissions factor (UEF) to account either for gas recovery or for a different waste composition from that assumed otherwise. The inventory agency will consider using data sourced from approved UEF applications to improve site-specific estimates of gas recovery, waste composition and other parameters for future submissions.

Regional councils in Canterbury, Waikato and other regions are likely to continue to carry out surveys and other research on farm waste disposal over time. As and when better activity data become available, they will be used to improve the estimates of waste disposal on farms, which is the largest source of emissions in the Waste sector.

Emissions of carbon monoxide, oxides of nitrogen and non-methane volatile organic compounds for landfills have not been estimated for this submission. These emissions are considered likely to be immaterial, but the inventory agency will consider estimating them for future submissions.

7.3 Biological treatment of solid waste (5.B)

New Zealand has no large-scale biological treatment of solid waste. There is likely to be a relatively small amount of composting of solid waste, mainly on a household scale. Emissions from this source are likely to be immaterial and are not estimated. However, the inventory agency will monitor the scale of this activity and the scope for estimation of emissions in future submissions.

An order of magnitude calculation has been prepared that justifies the use of 'NE' (not estimated) for emissions in this category. In the absence of any activity data, the conservative assumption is made that the amount of waste composted is the equivalent of 1 per cent of municipal solid waste (municipal solid waste is reported in table 7.2.2). Applying default emission factors for composting on a wet basis (IPCC, 2006a) to these activity data give emissions of 5.8 kt CO_2-e in 2016. See annex 6.2 for more detail about this and other categories that are 'NE' (not estimated).

7.4 Incineration and open burning of waste (5.C)

7.4.1 Description

There is no incineration of municipal waste in New Zealand, for energy production or otherwise. Incineration is used on a small scale for disposal of medical, quarantine and hazardous wastes and sewage sludge. The practice of incinerating these wastes has declined through the time series, due to more stringent environmental regulation and the use of alternative technologies such as sterilisation.

Waste incineration is regulated under the Resource Management Act 1991. In addition, in 2004 a National Environmental Standard was introduced, which required consents for all existing low-temperature incinerators, such as those historically used in schools and sometimes in hospitals.

There is no open burning of waste at municipal or non-municipal landfill facilities in New Zealand. It is possible that farmers may burn some waste (Tonkin and Taylor Ltd, unpublished(b)) but no information is available to confirm whether this occurs or the extent of the practice. Since the total emissions from field burning in the Agriculture sector (3.F) are relatively small, any such emissions are likely to be insignificant. Farm waste disposal is considered to be to pits rather than open burning, and the emissions are reported in *Solid waste disposal* (CRF 5.A).

Waste oil is used in the cement industry for firing a cement kiln. All emissions from this source are reported in the Energy sector.

In 2016 *Incineration and open burning of waste* accounted for 2.4 kt CO_2-e (0.1 per cent) of Waste sector emissions. This was a decrease of 12.3 kt CO_2-e below the 1990 level of 14.8 kt CO_2-e, with no change estimated from 2015.

7.4.2 Methodological issues

Choice of activity data

Limited information was available from individual site operators on the amount of waste that they burned between 1990 and 2007. For most sites, these activity data needed to be assessed because the only evidence available was the capacity of equipment and the amounts allowed by consent conditions. For the years after 2007, it has generally been assumed that facilities are continuing in operation at the same rates, in the absence of better information.

Choice of methods

Estimates of direct emissions from the incineration of waste are made using the default Tier 1 methodology (IPCC, 2006a). The data used were collected and collated in 2007 and the sources used included information previously collected for purposes of air quality regulation, and consent data from regional councils and from site operators (SKM, unpublished(a)).

Choice of emission factors

IPCC default parameters are used as detailed in table 7.4.1.

Table 7.4.1   Parameter values applied to estimate emissions from incineration

Parameter	Hazardous waste	Clinical waste	Sewage sludge
Dry-matter content in waste (%)	50	65	10
Fraction of carbon in dry matter	NA	0.6	0.45
Fraction of fossil carbon in total carbon	0.275	0.4	0.0
Oxidation factor	1.0	1.0	1.0
Methane emission factor (kg/kt)	2.34	17.86	9.7
Nitrous oxide emission factor (kg/kt)	100	60	900

Source: IPCC (2006a, 2006b)

Note: NA = Not applicable.

These parameters are as given in the IPCC Guidelines (IPCC, 2006a, 2006b), except that:

- where a range is given, the mid-point is used

- CH_4 emission factors for hazardous and clinical waste (IPCC, 2006b) have been converted from a terajoule (TJ) basis to a kt basis.

Quarantine waste is a significant proportion of the material incinerated in New Zealand. There is no IPCC default category that specifies quarantine waste. The composition is closest to clinical waste, so the emission factors for clinical waste have been used.

7.4.3   Uncertainties and time-series consistency

Uncertainties

As per the IPCC recommendation for uncertainties relating to activity data (IPCC, 2006a), estimated uncertainty for the amount of wet waste incinerated ranges from ±10 per cent to ±50 per cent and uncertainty of ±50 per cent is applied (table 7.4.2).

The data collected for the composition of waste are not detailed. Therefore, as per the recommendation for uncertainties relating to emission factors (IPCC, 2006a), the estimated uncertainty for default CO_2 factors is ±40 per cent. Default factors used in the calculation of CH_4 and N_2O emissions have a much higher uncertainty (IPCC, 2006a); hence, the estimated uncertainty for default CH_4 and N_2O factors is ±100 per cent (SKM, unpublished(a)).

Table 7.4.2   Uncertainty in emissions from incineration

Emissions category	Uncertainty in activity data (%)	Uncertainty in emission factors (%)
Waste incineration (CO_2)	±50	±40
Waste incineration (CH_4)	±50	±100
Waste incineration (N_2O)	±50	±100

Time-series consistency

Time-series consistency is ensured by the use of consistent models and parameters across the period. Where changes to methodologies or emission factors have occurred, a full time-series recalculation is conducted.

7.4.4 Source-specific QA/QC and verification

These emissions are very small, and basic QA/QC checks are carried out where possible. Detailed QA/QC efforts for the Waste sector focus on the disposal to land and wastewater categories.

7.4.5 Source-specific recalculations

An error was identified where emissions for incineration were reported a year later than they actually occurred. This has been corrected in this submission, resulting in a recalculation to the time-series for incineration.

7.4.6 Source-specific planned improvements

No specific improvements are planned for this category. Over time, surveys by local authorities on disposal of waste in the farm sector are expected to provide a better understanding of any open burning that may occur in New Zealand, particularly in the farm sector.

7.5 Wastewater treatment and discharge (5.D)

7.5.1 Description

In 2016 *Wastewater treatment and discharge* contributed 396.8 kt CO_2-e (10.3 per cent) of emissions from the Waste sector. This was an increase of 59.8 kt CO_2-e (17.7 per cent) from the 1990 level of 337.0 kt CO_2-e and is due to increases in emissions from the volume of industrial and domestic wastewater handled over this period.

Small amounts of industrial wastewater are applied as organic amendments to agricultural soils, as well as an extremely small amount of sewage sludge (van der Weerden et al., 2014). Any emissions from this practice are likely to be insignificant (see chapter 5, section 5.5.2).

Methane emissions from the *Wastewater treatment and discharge* source category were identified as a key category in the 2016 level assessment.

Domestic wastewater (5.D.1)

Wastewater from almost every town in New Zealand with a population over 1,000 is collected and treated in community wastewater treatment plants. There are approximately 317 municipal wastewater treatment plants in New Zealand and approximately a further 50 government or privately owned treatment plants serving populations of more than 100 people (SCS Wetherill Environmental, unpublished).

Although most of the wastewater treatment processes are aerobic, a significant number of wastewater treatment plants use partially anaerobic processes such as oxidation ponds or septic tanks. Small communities and individual rural dwellings are served mainly by simple septic tanks. While the part of the population using septic tanks is small compared with the national population, this treatment type is the largest source of CH_4 emissions for domestic wastewater, because emissions from other treatment types are either small or the CH_4 is destroyed.

Most of the sludge removed from domestic wastewater treatment is sent to landfills, and emissions from its disposal are reported in the *Solid waste disposal* source category (Tonkin and Taylor Ltd, unpublished(a)).

Industrial wastewater (5.D.2)

The major sources of industrial wastewater in New Zealand are the meat and the pulp and paper industries. Most of the industrial wastewater treatment is aerobic, and most of the CH_4 generated from anaerobic treatment is flared.

In June 2015 the methodologies and input data used to calculate the industrial wastewater emissions were reviewed, in order to capture any changes in industry activity and to ensure current best practice and knowledge were reflected (Cardno, unpublished). This is discussed further under section 7.5.2.

7.5.2   Methodological issues

Choice of activity data

Domestic wastewater (5.D.1)

Estimates for CH_4 emissions are derived from combining the population connected to each treatment plant in New Zealand with the treatment methods for each plant (Beca Infrastructure Ltd, unpublished).

The population using each municipal treatment plant and an estimation of the population using septic tanks were determined (Beca Infrastructure Ltd, unpublished; SCS Wetherill Environmental, unpublished). The population treated by each plant is updated each year based on the population growth rate of the district in which the plant is located. This information is obtained from Statistics New Zealand. In 2016 the total population connected to treatment plants was estimated to be 3.8 million. The connected population excludes both people connected to rural septic tanks, estimated at 461,500 people in 2016, and approximately 51,000 people using other aerobic plants.

A remaining population of 0.5 million people is not accounted for, which is a result of incomplete data on the wastewater treatment plants in New Zealand and the populations connected to each of these wastewater treatment plants. To account for domestic wastewater emissions from this population, CH_4 emissions for the *Domestic wastewater* source category have been increased by a fraction determined by the missing population as a proportion of the population for which emissions are known. An assumption is made to apply the average wastewater treatment method for this otherwise unaccounted for population.

Indirect N_2O emissions from the disposal of treated domestic wastewater are estimated using per capita protein consumption and national population estimates. Activity data for domestic wastewater are reported in table 7.5.1. Also included in table 7.5.1 is an aggregate CH_4 correction factor that is determined by the sum of the methane correction factor for various treatment types, weighted by the population served by each type.

Table 7.5.1   **Activity data and key factors for domestic wastewater from 1990 to 2016**

Year	National population	Aggregate methane correction factor	Domestic wastewater total organic product (kt)
1990	3,410,400	0.048	137.4
1991	3,516,000	0.048	142.2
1992	3,552,200	0.048	144.2
1993	3,597,800	0.048	146.6

Year	National population	Aggregate methane correction factor	Domestic wastewater total organic product (kt)
1994	3,648,300	0.048	149.2
1995	3,706,700	0.048	152.1
1996	3,762,300	0.048	155.0
1997	3,802,700	0.048	157.2
1998	3,829,200	0.047	156.1
1999	3,851,100	0.047	155.0
2000	3,873,100	0.047	153.8
2001	3,916,200	0.046	152.6
2002	3,989,500	0.044	158.3
2003	4,061,600	0.042	164.0
2004	4,114,300	0.040	169.7
2005	4,161,000	0.038	175.5
2006	4,209,100	0.036	174.8
2007	4,245,700	0.036	176.9
2008	4,280,300	0.036	179.1
2009	4,332,100	0.036	181.1
2010	4,373,900	0.035	183.5
2011	4,399,400	0.035	185.3
2012	4,425,900	0.038	186.7
2013	4,475,800	0.035	184.8
2014	4,554,600	0.036	187.8
2015	4,647,300	0.036	191.3
2016	4,747,200	0.036	195.0

Industrial wastewater (5.D.2)

The following industries are identified as having organic-rich wastewaters that are treated anaerobically (in order of significance): meat processing, pulp and paper, and other industries described below. Table 7.5.2 reports the activity data for the amount of total organics in wastewater (TOW) across the main industries.

Table 7.5.2   Activity data for industrial wastewater calculations from 1990 to 2016

Year	Meat industries TOW (kt)	Pulp and paper industry TOW (kt)	All other industries TOW (kt)	Total industrial TOW (kt)
1990	55.6	71.7	20.7	148.0
1991	59.2	78.2	21.0	158.3
1992	64.1	76.4	21.5	162.1
1993	59.3	73.0	21.6	153.9
1994	62.1	79.4	23.7	165.3
1995	64.5	80.5	23.9	168.9
1996	65.7	82.7	25.3	173.7
1997	66.6	81.2	27.1	174.9
1998	68.7	82.5	27.9	179.1
1999	61.4	79.7	27.0	168.1
2000	65.8	84.9	29.1	179.8
2001	67.7	88.0	31.6	187.2
2002	65.0	85.3	33.6	183.9
2003	70.1	85.1	33.7	188.9
2004	73.8	83.1	36.3	193.2
2005	72.6	90.3	34.9	197.9

Year	Meat industries TOW (kt)	Pulp and paper industry TOW (kt)	All other industries TOW (kt)	Total industrial TOW (kt)
2006	71.3	90.1	36.8	198.2
2007	72.5	86.4	37.8	196.8
2008	72.8	87.0	38.1	197.9
2009	68.3	85.7	40.8	194.8
2010	66.6	87.6	41.5	195.8
2011	65.6	90.7	44.0	200.4
2012	65.7	86.9	47.0	199.6
2013	67.9	83.5	47.5	198.9
2014	68.7	79.2	52.4	200.4
2015	71.7	77.7	52.2	201.6
2016	71.9	89.0	52.9	213.7

Note: TOW = Total organics in wastewater. Columns may not total due to rounding.

Meat industry

Methane emissions from the meat industry are calculated from an estimate of the wastewater output from meat processing. This estimate is based on the total production (kills) from the different producers in the meat industry, and uses data as far as possible consistent with the data for kills used in the Agriculture sector.

Poultry processing is calculated separately from other meat processing because its fraction of waste treated in anaerobic ponds and the unit chemical oxygen demand (COD) load are higher than other meat processing (Cardno, unpublished).

Rendering loads are not separated out in order to simplify the inventory calculations, as there are only a few standalone rendering plants in New Zealand and the rest are combined with meat processing plants. So the unit COD load includes rendering operations (Cardno, unpublished).

Nitrous oxide emissions from the meat industry are calculated using the same activity data as for CH_4 emissions.

Pulp and paper industry

Estimated pulp and paper wastewater output is based on paper, paperboard and pulp production. This information is obtained from the Ministry for Primary Industries.

Wine industry

Methane emissions from wastewater for the wine industry are based on the outputs obtained from the national organisation for New Zealand's grape and wine sector. For the purposes of this assessment, an average industry wastewater discharge metric of 2.7 cubic metres of water per tonne of grapes processed is assumed. This value is derived from national data. It is noted that this value is significantly lower than IPCC default values (Beca Ltd, unpublished).

Wool scouring industry

Methane emissions from wastewater for the wool scouring industry are based on the outputs obtained by SCS Wetherill Environmental (unpublished) for the years up to 2000. From 2001 to 2012, the SCS estimates have been prorated against the industry's output data and applied to the output data for these years. After 2012, the wool scouring industry used only aerobic treatment of wastewater and, consequently, no emissions are reported for 2013 onwards (Beca Ltd, unpublished).

Dairy processing industry

The dairy processing industry predominantly uses aerobic treatment. There is only one factory that uses anaerobic treatment. The emissions from the wastewater treatment process are recovered and most of the captured biogas (consisting of 55 per cent CH_4) is used in boilers. The remainder is flared. Consequently, no CH_4 emissions are reported from this industry (Beca Infrastructure Ltd, unpublished).

Nitrous oxide emissions from dairy industry wastewater are included, based on the review of methods for industrial wastewater by Cardno (unpublished). Emission estimates are based on the total litres of milk processed, consistent with data reported in the Agriculture sector. The production data are then converted from litres to kilograms by multiplying by 1.031 (the weight of 1 litre of milk) for the activity data used in the emissions calculations.

Leather and skins industry

Methane emissions from wastewater for the leather and skins industry, also known as tanneries, are based on the outputs obtained by SCS Wetherill Environmental (unpublished) for the years up to 2001. From 2002, all wastewater from the leather and skins industry is accounted for in domestic wastewater because all tanneries now discharge to the municipal wastewater system (Cardno, unpublished).

Nitrous oxide emissions from wastewater for the leather and skins industry are based on the outputs obtained by SCS Wetherill Environmental (unpublished).

Choice of methods

Methods used to calculate emissions from wastewater handling are summarised in table 7.5.3. For domestic wastewater, the total organics in wastewater is estimated for each individual treatment plant based on the population in the district served by the plant.

Table 7.5.3   Methods used for calculating emissions from wastewater treatment

Emissions category	Gas	Comment	Method	Source
Domestic wastewater (5.D.1)	CH_4		Tier 1	IPCC (2006a)
Domestic wastewater (5.D.1)	N_2O	Based on average per-capita protein intake	Tier 1	IPCC (2006a)
Industrial wastewater (5.D.2) – Meat industry	CH_4		Tier 1	IPCC (2006a)
Industrial wastewater (5.D.2) – Pulp and paper industry	CH_4		Tier 1	IPCC (2006a)
Industrial wastewater (5.D.2) – Wine industry	CH_4		Tier 2	Beca Ltd (unpublished)
Industrial wastewater (5.D.2) – Wool scouring industry	CH_4		Tier 1	IPCC (2006a)
Industrial wastewater (5.D.2)	N_2O	Based on chemical oxygen demand from CH_4 emissions	Tier 2	Cardno (unpublished)

Wine industry

A Tier 2 approach is used to estimate emissions from the wine industry. Information on the wastewater treatment practices of the industry were obtained from a survey (Beca Ltd, unpublished). IPCC default values are used where New Zealand-specific information is not available.

Nitrous oxide emissions

Direct emissions of N_2O from domestic wastewater plants are typically minor and only occur in advanced centralised treatment plants. Good practice guidelines (IPCC, 2006a) advise that the estimation of direct N_2O emissions is only necessary where advanced centralised treatment plants account for a major proportion of wastewater treatment. This is not the case in New Zealand, so no direct emissions of N_2O are reported.

However, indirect emissions of N_2O may occur after disposal of effluent into waterways, lakes or the ocean. New Zealand reports indirect emissions of N_2O from domestic wastewater.

The IPCC Guidelines (IPCC, 2006a) indicate that, compared with domestic wastewater, the N_2O emissions from industrial wastewater are believed to be insignificant. However, these emissions are not insignificant in New Zealand, because the meat and dairy processing industries produce nitrogen-rich wastewaters.

The IPCC does not provide a method for calculating N_2O emissions from industrial wastewater and, consequently, a New Zealand-derived method has been applied. The total nitrogen load is calculated by adopting the COD load as determined in calculating CH_4 emissions from the same wastewater, and using an estimated ratio of COD to nitrogen in the wastewater for each of the different producers in the meat, dairy processing and leather and skins industries.

Choice of emission factors

Domestic wastewater (5.D.1)

Methane emissions from domestic wastewater treatment

Table 7.5.4 provides a summary of the parameter values applied for estimating CH_4 emissions from domestic wastewater treatment.

Table 7.5.4   **Parameter values applied by New Zealand for estimating methane emissions for domestic wastewater treatment**

Parameter	Value	Source	Reference
Methane correction factors			
Handling systems methane correction factor	Range of 0–0.65	New Zealand specific	SCS Wetherill Environmental (unpublished)
Aggregated methane correction factor	Range of 0.035–0.048	New Zealand specific	SCS Wetherill Environmental (unpublished)
Biochemical oxygen demand (BOD) (kg BOD/person/year)	26	New Zealand specific	Beca Infrastructure Ltd (unpublished)
Correction factor for BOD	Range of 1.0–14.9	New Zealand specific	Beca Infrastructure Ltd (unpublished)
Maximum methane producing capacity (kg CH_4/kg BOD)	0.625	IPCC default	IPCC (2006a)

Methane correction factors for handling systems

Methane correction factors for the different handling systems in New Zealand were estimated by SCS Wetherill Environmental (unpublished). These factors range from zero up to 0.65 for the different types of anaerobic treatment. The different treatment types are added together, weighted by the population for each type of treatment, to give an aggregated methane correction factor ranging between 0.035 and 0.048. Table 7.5.1 shows the aggregate methane correction factor applied across the time series.

Adjustments to biochemical oxygen demand

New Zealand uses a value of 26 kilograms biochemical oxygen demand (BOD) per person per year. This is equivalent to the IPCC high-range default value for the Oceania region of 70 grams per person per day (IPCC, 2006a). This value has been determined as a typical value for wastewater treatment methods adopted in New Zealand (Beca Infrastructure Ltd, unpublished).

This value has been increased by 25 per cent for most treatment plants, to allow for the additional wastewater that they take from commercial and industrial activity within the municipal area. Ten of the treatment plants have been identified as accepting much larger amounts of industrial and/or commercial wastewater. The correction factor for BOD for these plants ranges from 77 per cent to 1,390 per cent above the amount of domestic wastewater (Beca Infrastructure Ltd, unpublished). No adjustment to the BOD is made for septic tanks.

Recovery

Methane removal via flaring or for energy production is known to occur at eight plants in New Zealand. All CH_4 generated at these plants is flared or used for energy production and, consequently, there are no reported CH_4 emissions for those plants (Beca Infrastructure Ltd, unpublished).

Nitrous oxide emissions from domestic wastewater

Table 7.5.5 provides a summary of the parameter values applied for estimating N_2O emissions from domestic and commercial wastewater sludge treatment.

Table 7.5.5   Parameter values applied by New Zealand for estimating nitrous oxide emissions from domestic and commercial wastewater treatment

Parameter	Value	Source	Reference
Per capita protein consumption (kg/person/year)	36.135	New Zealand specific	Beca Infrastructure Ltd (unpublished)
Fraction of nitrogen in protein	0.16	IPCC default	IPCC (2006a)
Fraction of non-consumed protein	1.4	IPCC default	IPCC (2006a)
Fraction of industrial and commercial co-discharged protein	1.25	IPCC default	IPCC (2006a)
Nitrogen removed with sludge (kg)	0	IPCC default	IPCC (2006a)
Emission factor	0.005	IPCC default	IPCC (2006a)
Emissions from wastewater treatment plants	0	IPCC default	IPCC (2006a)

A value of 36.135 kilograms of protein per person per year is used. This figure was the maximum value reported by New Zealand to the Food and Agriculture Organization.

Recovery

There is no recovery of emissions reported for this source.

Industrial wastewater (5.D.2)

Methane emissions from industrial wastewater treatment – Meat industry

Table 7.5.6 provides a summary of the parameter values applied for estimating CH_4 emissions from wastewater treatment by the meat industry.

Table 7.5.6 **Parameter values applied by New Zealand for estimating methane emissions from wastewater treatment by the meat industry**

Parameter	Value	Source	Reference
Degradable organic component (kg COD/tonne of product)	50	New Zealand specific	SCS Wetherill Environmental (unpublished)
Methane correction factor	Range of 0–0.55	New Zealand specific	SCS Wetherill Environmental (unpublished)
Maximum CH_4-producing capacity (kg CH_4/kg COD)	0.25	IPCC default	IPCC (2006)
Overall emission factor	Range of 0.0344–0.0358	New Zealand specific	Cardno (unpublished)

Note: COD = chemical oxygen demand.

Recovery

There is no recovery of emissions reported for this source.

Methane emissions from industrial wastewater treatment – Pulp and paper

Table 7.5.7 provides a summary of the parameter values applied for estimating CH_4 emissions from wastewater treatment by the pulp and paper industry.

Table 7.5.7 **Parameter values applied by New Zealand for estimating methane emissions for wastewater treatment by the pulp and paper industry**

Parameter	Value	Source	Reference
Degradable organic component (kg COD/tonne of product)	36	New Zealand specific	Beca Infrastructure Ltd (unpublished)
Methane correction factor	Range of 0–0.8	New Zealand specific	Beca Infrastructure Ltd (unpublished)
Maximum CH_4-producing capacity (kg CH_4/kg COD)	0.25	IPCC default	IPCC (2006a)
Overall emission factor	0.0117	New Zealand specific	Cardno (unpublished)

Note: COD = chemical oxygen demand.

Recovery

There is no recovery of emissions reported for this source.

Methane emissions from industrial wastewater treatment – Wine

Table 7.5.8 provides a summary of the parameter values applied for estimating CH_4 emissions from wastewater treatment by the wine industry.

Table 7.5.8 **Parameter values applied by New Zealand for estimating methane emissions for wastewater treatment by the wine industry**

Parameter	Value	Source	Reference
Degradable organic component (kg COD/tonne of product)	12.42	New Zealand specific	Beca Infrastructure Ltd (unpublished)
Methane correction factor	Range of 0–0.5	New Zealand specific	Beca Infrastructure Ltd (unpublished)
Maximum CH_4-producing capacity (kg CH_4/kg COD)	0.25	IPCC default	IPCC (2006a)
Overall emission factor	0.0167	New Zealand specific	Cardno (unpublished)

Note: COD = chemical oxygen demand.

Recovery

There is no recovery of emissions reported for this source.

Methane emissions from industrial wastewater treatment – Wool scouring industry

Table 7.5.9 provides a summary of the parameter values applied for estimating CH_4 emissions from wastewater treatment by the wool scouring industry.

Table 7.5.9 **Parameter values applied by New Zealand for estimating methane emissions for wastewater treatment by the wool scouring industry**

Parameter	Value	Source	Reference
Degradable organic component (kg COD/tonne of product)	22	New Zealand specific	SCS Wetherill Environmental (unpublished)
Methane correction factor	0.29	New Zealand specific	SCS Wetherill Environmental (unpublished)
Maximum CH_4 producing capacity (kg CH_4/kg COD)	0.25	IPCC default	IPCC (2006a)
Overall emission factor	0.0065	New Zealand specific	SCS Wetherill Environmental (unpublished)

Note: COD = chemical oxygen demand.

Recovery

There is no recovery of emissions reported for this source.

Methane emissions from industrial wastewater treatment – Leather and skins industry

Table 7.5.10 provides a summary of the parameter values applied for estimating CH_4 emissions from wastewater treatment by the leather and skins industry.

Table 7.5.10 **Parameter values applied by New Zealand for estimating methane emissions for wastewater treatment by the leather and skins industry**

Parameter	Value	Source	Reference
Degradable organic component (kg COD/tonne of product)	180	New Zealand specific	SCS Wetherill Environmental (unpublished)
Methane correction factor	Range of 0–0.55	New Zealand specific	SCS Wetherill Environmental (unpublished)
Maximum CH_4-producing capacity (kg CH_4/kg COD)	0.25	IPCC default	IPCC (2006a)
Overall emission factor	0.0124	New Zealand specific	SCS Wetherill Environmental (unpublished)

Note: COD = chemical oxygen demand.

Recovery

There is no recovery of emissions reported for this source.

Nitrous oxide emissions from industrial wastewater treatment – Meat industry

Table 7.5.11 provides a summary of the parameter values applied for estimating N_2O emissions from wastewater sludge treatment by the meat industry.

Table 7.5.11 **Parameter values applied by New Zealand for estimating nitrous oxide emissions for wastewater treatment for the meat industry**

Parameter	Value	Source	Reference
Degradable organic component (kg COD/tonne of product)	50	New Zealand specific	SCS Wetherill Environmental (unpublished)
Ratio of total nitrogen to biodegradable COD (TN:COD_b)	0.090	New Zealand specific	Cardno (unpublished)
Overall emission factor	Range of 0.0013–0.0019	New Zealand specific	Cardno (unpublished)

Note: COD = chemical oxygen demand.

Recovery

There is no recovery of emissions reported for this source.

*Nitrous oxide emissions from industrial wastewater treatment
– Dairy processing industry*

Table 7.5.12 provides a summary of the parameter values applied for estimating N_2O emissions from wastewater treatment by the dairy processing industry.

Table 7.5.12   Parameter values applied by New Zealand for estimating nitrous oxide emissions for wastewater treatment for the dairy processing industry

Parameter	Value	Source	Reference
Degradable organic component (kg COD/tonne of product)	2	New Zealand specific	Cardno (unpublished)
Ratio of total nitrogen to biodegradable COD (TN:COD$_b$)	0.044	New Zealand specific	Cardno (unpublished)
Overall emission factor	0.0028	New Zealand specific	Cardno (unpublished)

Note: COD = chemical oxygen demand.

Recovery

There is no recovery of emissions reported for this source.

Nitrous oxide emissions from industrial wastewater treatment – Leather and skins industry

Table 7.5.13 provides a summary of the parameter values applied for estimating N_2O emissions from wastewater treatment by the leather and skins industry.

Table 7.5.13   Parameter values applied by New Zealand for estimating nitrous oxide emissions for wastewater treatment for the meat industry

Parameter	Value	Source	Reference
Degradable organic component (kg COD/tonne of product)	180	New Zealand specific	SCS Wetherill Environmental (unpublished)
Ratio of total nitrogen to biodegradable COD (TN:COD$_b$)	0.080	New Zealand specific	SCS Wetherill Environmental (unpublished)
Overall emission factor	0.02	New Zealand specific	SCS Wetherill Environmental (unpublished)

Note: COD = chemical oxygen demand.

Recovery

There is no recovery of emissions reported for this source.

7.5.3   Uncertainties and time-series consistency

Uncertainties

Table 7.5.14   Uncertainty in emissions from wastewater

Emissions category	Uncertainty in activity data (%)	Uncertainty in emission factors (%)
Domestic and industrial wastewater (CH$_4$)	±10%	±40%
Domestic and industrial wastewater (N$_2$O)	±10%	±90%

Methane emissions

The parameters used to estimate CH$_4$ emissions from domestic and industrial wastewater (table 7.5.14) have an estimated uncertainty of ±40 per cent (SCS Wetherill Environmental, unpublished). This uncertainty stems from:

- uncertainties in the factors used to calculate emissions from the different wastewater treatment processes
- uncertainties in the quantities of wastewater handled by the different wastewater treatment plants
- uncertainties in the accuracy and completeness of the data relating to each plant
- uncertainties in the factors used to calculate the degradable organic content in the wastewater
- uncertainties in the wastewater treatment methods.

Nitrous oxide emissions

Large uncertainties are associated with the IPCC default emission factors for N$_2$O emissions from wastewater treatment effluent (IPCC, 2006a). The uncertainty is estimated to be ±90 per cent based on the ranges experienced in collecting and applying similar data internationally, and expert judgement on the application of this experience to New Zealand (Law et al., 2012).

Time-series consistency

Time-series consistency is ensured by the use of consistent models and parameters across the period. Where changes to methodologies or emission factors have occurred, the entire time series has been recalculated.

7.5.4   Source-specific QA/QC and verification

In the preparation for this inventory submission, the data for the *Wastewater treatment and discharge* category underwent Tier 1 quality checks.

7.5.5   Source-specific recalculations

Emissions from domestic and industrial wastewater treatment

A recalculation has been made to domestic wastewater due to the inclusion of a previously unaccounted-for population group, and this affects the entire time series.

Activity data for the meat industry have also been updated to align better to the data used in the Agriculture sector, which has again resulted in a recalculation. Furthermore, a small error in the conversion milk from volume to weight in the estimation of emissions from dairy processing has been corrected. More details on recalculations are provided in chapter 10.

7.5.6   Source-specific planned improvements

No specific improvements are planned for this source category.

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Chapter 8: Other

New Zealand does not report any emissions under the United Nations Framework Convention on Climate Change category, 'Other'.

Chapter 9: Indirect carbon dioxide and nitrous oxide emissions

New Zealand elected not to report indirect carbon dioxide emissions in its 2016 Inventory submission. Indirect nitrous oxide emissions are reported in the Agriculture sector (chapter 5) and the LULUCF sector (chapter 7).

Chapter 10: Recalculations and improvements

This chapter summarises the recalculations and improvements made to the inventory following the 2017 submission. Further details on the recalculations and improvements for each sector are provided in chapters 3 to 7 and 11.

Recalculations of estimates reported in the previous submission of the inventory are due to improvements in:

- activity data

- parameters for estimating emissions including emission factors

- methodology, including correcting errors

- activity data and emission factors that became available for certain sources that were previously reported as NE (not estimated) because of insufficient data.

It is good practice to recalculate the whole time series from 1990 to the latest reporting year to ensure consistency across the time series. This means some estimates of emissions and/or removals reported in this submission are different from estimates reported in the previous submission. There may be exceptions to recalculating the entire time series and, where this has occurred, explanations are provided.

10.1 Implications and justifications

The effect of recalculations on New Zealand's gross emissions is shown in figure 10.1.1. There was a 1.9 per cent (1,241.0 kilotonnes carbon dioxide equivalent (kt CO_2-e)) increase in gross emissions in 1990 and a 0.7 per cent (547.9 kt CO_2-e) increase for the 2015 year.

Figure 10.1.1   Effect of recalculations on New Zealand's gross greenhouse gas emissions from 1990 to 2015
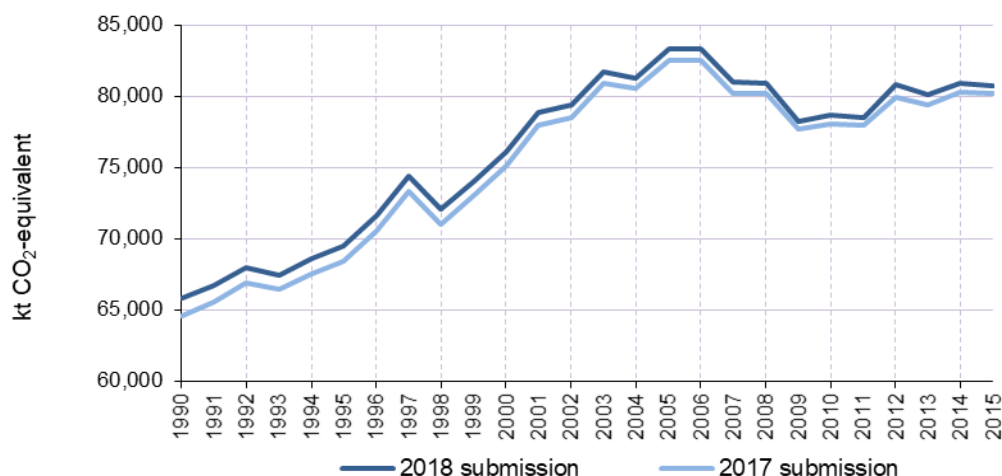
The greatest contribution to this change in estimates for gross emissions came from the Agriculture sector, primarily due to a correction in calculations for emissions from sheep. This has a greater effect in 1990 than 2015 because of the general decline in the population of sheep over the time series. In the previous submission, estimates for gross emissions for 2015 were 24.1 per cent above 1990 levels. As a result of the recalculations in this submission, estimates for gross emissions in 2015 are 22.6 per cent above 1990 levels.

The effect of recalculations on net emissions, including the Land Use, Land-Use Change and Forestry (LULUCF) sector, was an increase of 5.3 per cent (1,823.9 kt CO_2-e) in net emissions in 1990 and a decrease of 0.9 per cent (530.6 kt CO_2-e) in net emissions in 2015. This is the combined effect of a number of changes made to gross emissions and changes in LULUCF sector emissions due mainly to the revision of the age-based emission factors for post-1989 planted forests and the revision of the harvested wood products model.

The following sections detail the effect of recalculations for each sector and summarise the improvements that resulted in the recalculations.

10.1.1 Energy

The improvements made in the Energy sector have resulted in a 0.2 per cent (36.7 kt CO_2-e) increase in energy emissions in 1990 and a 0.2 per cent (68.6 kt CO_2-e) decrease in energy emissions in 2015 (figure 10.1.2). Explanations and justifications for recalculations of New Zealand's energy emission estimates in the 2018 submission are summarised in table 10.1.1.

Figure 10.1.2   Effect of recalculations on New Zealand's Energy sector from 1990 to 2015
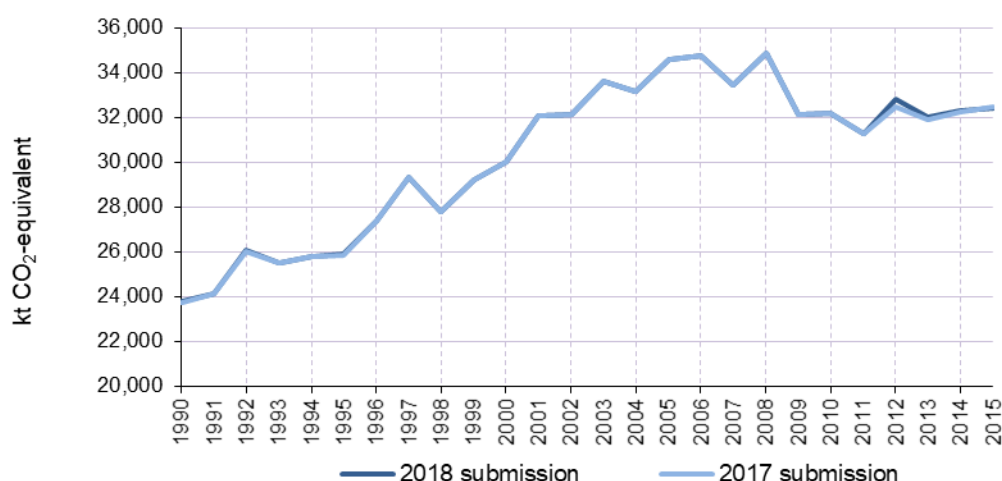
Table 10.1.1   Explanations and justification for recalculations in the Energy sector

Explanation of recalculation	Underpinning UNFCCC principle	Additional justification
The underlying workflow for the generation of activity and emissions data has been migrated from Microsoft Excel to the R programming language.	Time-series consistency	
The model used for determination of emissions for the category *Road transportation* was updated in the period 1990–2000 and has been updated to improve consistency between fuels and vehicle types.	Consistency	
Activity and emissions data for the category *Road transportation* are reported by type of vehicle.	Transparency	Raised during 2016 review.
Activity and emissions data for the category *Agriculture/forestry/fishing* are reported by source (stationary, mobile and off-road, fishing).	Transparency	Raised during 2016 review.
Fuel use calculations for international bunkers were recalculated to ensure consistency between reference approach data and memo items.	Consistency	Raised during 2016 review.
Calculations for natural gas emission factors were improved to generate a more accurate figure for national natural gas emissions.	Accuracy	

10.1.2 Industrial Processes and Product Use

Improvements and recalculations made in the Industrial Processes and Product Use (IPPU) sector have resulted in a 0.02 per cent (0.7 kt CO_2-e) increase in emissions in 1990 and a 0.7 per cent (35.6 kt CO_2-e) increase in emissions in 2015 (figure 10.1.3). The small decrease in 1990 is due to a recalculation of emissions from the *Lubricant use* category. The increase in reported emissions for 2015 is the result of reassessments of the amounts of refrigerant gases imported and used between during 2001 and 2015, including the use of previously stockpiled gas. This changed the timing of these emissions.

Other recalculations and improvements, as detailed in table 10.1.2, have had only a minor effect.

Figure 10.1.3   Effect of recalculations on the IPPU sector from 1990 to 2015
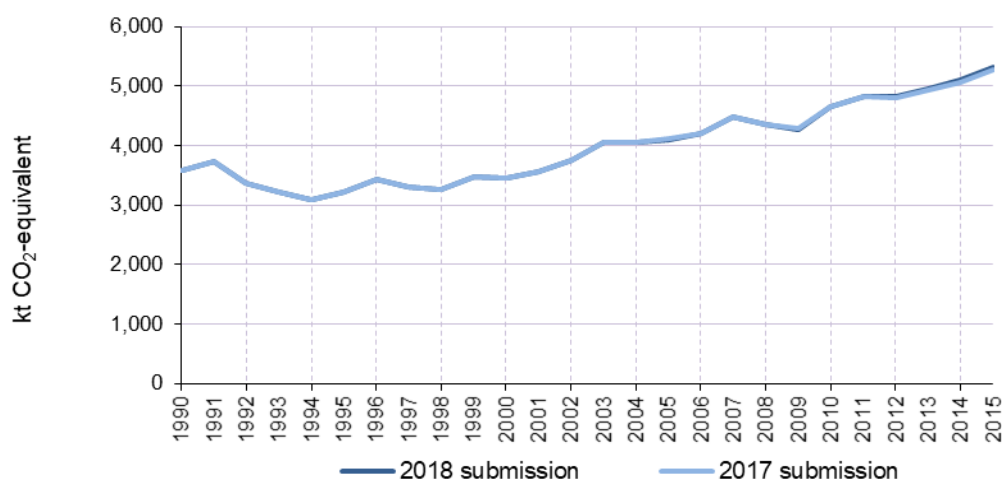
Table 10.1.2   Explanations and justifications for recalculations in the IPPU sector

Explanation of recalculation	Underpinning UNFCCC principle	Additional justification
Emissions in the *Refrigeration and air conditioning* category for the entire time series have been recalculated because of revised data indicating sale of previously stockpiled refrigerants.	Accuracy	Stockpiling of hydrofluorocarbons, on introduction of the New Zealand Emissions Trading Scheme (NZ ETS) and in response to price changes, can create an issue for accurate allocation of emissions over time.
Activity data for lime production has been revised so that data previously provided and recent data from the NZ ETS use comparable measures.	Time-series consistency	
Activity data for lubricants has been updated due to a revision in the imports and usage of lubricants.	Accuracy	Expert review team recommendation
Emissions of sulphur hexafluoride used in electrical equipment have been recalculated for all years, reflecting better information on loss rates.	Accuracy	There is limited data internationally on loss rates from switchgear, and ongoing improvement for the New Zealand National Inventory Report will require better management and reporting of sulphur hexafluoride stocks by industry.

10.1.3 Agriculture

Improvements and recalculations made to the Agriculture sector have resulted in a 4.4 per cent (1,459.0 kt CO_2-e) increase in estimated agricultural emissions in 1990 and a 1.9 per cent (717.0 kt CO_2-e) increase in agricultural emissions in 2015, as shown in figure 10.1.4. The individual effect of these improvements and recalculations on emissions estimates in 1990 and 2016 are outlined in the paragraphs below.

Figure 10.1.4   Effect of recalculations on New Zealand's Agriculture sector from 1990 to 2015
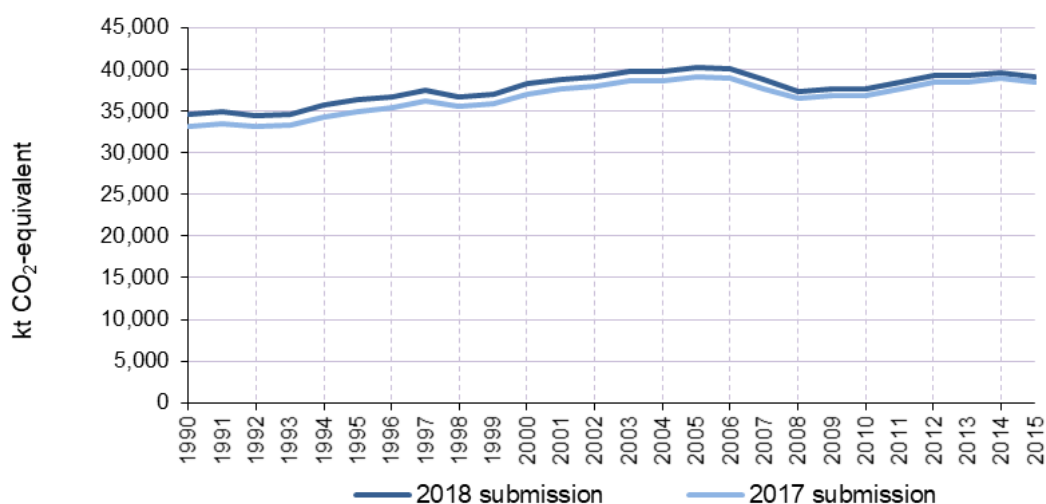
Corrections

Two inaccuracies were found and corrected in the 2018 (1990–2016) agriculture inventory, which related to:

- the calculation of the amount of nitrogen retained in the production of wool by sheep

- the set of equations used to estimate the population of deer in June of each year.

These corrections are explained in more detail in the following paragraphs, and the effects of these corrections on emissions estimates are summarised in the tables below.

Correction of calculation for nitrogen retained in wool

Late in 2017 it was found that the 2017 (1990–2015) version of the inventory model was overestimating the amount of nitrogen retained in the production of wool by sheep by a factor of ten. This error had a significant effect on emissions from *Agricultural soils*, causing estimates of nitrogen excretion for sheep to be lower than they should have been. This resulted in lower estimates of nitrous oxide (N_2O) emissions from sheep dung and urine.

The effect of this correction on emissions from *Agricultural soils* is outlined in chapter 5, section 5.5.5, and table 10.1.3 shows the effect of the correction on total agriculture emissions. After the correction, estimated emissions from the Agriculture sector increased by 4.5 per cent (1,496.6 kt CO_2-e) in 1990 and 1.8 per cent (681.8 kt CO_2-e) in 2016 (see table 5.5.11 and 10.1.3). The large fall in the sheep population between 1990 and 2016 (see chapter 5, figure 5.1.3.b) helps explain the difference between the 1990 change and the 2016 change.

Table 10.1.3 Comparison of current and previous emissions estimates before and after nitrogen wool correction, 1990 to 2016, for total agricultural emissions

Emissions (kt CO_2-e)		1990	2016	Change in emission outputs between 1990 and 2016 (kt CO_2-e)	Percentage change in emission outputs between 1990 and 2016
Total emissions from the Agriculture sector (kt CO_2-e)	2018 (1990–2016) emissions estimate *without* nitrogen wool correction	33,085.3	38,045.5	4,960.2	15.0
	2018 (1990–2016) emissions estimate *with* nitrogen wool correction	34,581.9	38,727.3	4,145.5	12.0
	Difference in emission estimates compared with current inventory	1,496.6	681.8	−814.8	
Percentage difference in the emission estimates		4.5	1.8		

Equation used to estimate the populations of deer in June

During 2017 a minor error was identified in one of the equations used to estimate the deer population in June of each year. This error has been corrected for the 2018 (1990–2016) national inventory report (NIR).

Because population estimates are used in the Tier 2 model to calculate energy requirements and intake, this correction affects *Enteric fermentation*, *Manure management* and *Agricultural soils* emissions estimates from deer.

The effect of this correction on agriculture emissions (shown in table 10.1.4) is small. After the correction, estimated emissions from the Agriculture sector decreased by 0.075 per cent (14.9 kt CO_2-e) in 1990 and 0.043 per cent (29.0 kt CO_2-e) in 2016.

Table 10.1.4 Comparison of current and previous emissions estimates before and after deer population correction, 1990 to 2016, for total agricultural emissions

Emissions (kt CO_2-e)		1990	2016	Change in emission outputs between 1990 and 2016 (kt CO_2-e)	Percentage change in emission outputs between 1990 and 2016
Total emissions from the Agriculture sector (kt CO_2-e)	2018 (1990–2016) emissions estimate *without* deer population correction	34,596.8	38,756.4	4,159.6	12.0
	2018 (1990–2016) emissions estimate *with* deer population correction	34,581.9	38,727.3	4,145.5	12.0
	Difference in emission estimates compared with current inventory	−14.9	−29.0	−14.2	
Percentage difference in the emission estimates		−0.043	−0.075		

Improvement to crop burning area methodology

For this submission, one improvement was made to the Agriculture sector inventory relating to the estimation of the areas of crops that are burned after harvest, between 2005 and 2016. The burning of crop residues following harvest results in emissions of methane (CH_4), carbon monoxide (CO), N_2O and oxides of nitrogen (NO_x), which are recorded in the *Field burning of agricultural residues* category.

Further details on the calculation of crop area burned are in chapter 5, section 5.7.2, while section 5.7.5 describes the effect of these changes on estimated emissions from *Field burning of agricultural residues*.

This improvement also affects *Agricultural soils* emissions slightly, because changes in crop burning areas also affect the amount of crop residues that are left to decay. However, the effect of this change on *Agricultural soils* is very small (less than 0.01 per cent), because crop residues make up only a small proportion of emissions from the *Agricultural soils* category.

The effect of this improvement on total estimated emissions from the Agriculture sector is very small. Table 10.1.5 shows that the improvement, once implemented, reduces estimated total agricultural emissions by 1.9 kt CO_2-e, or 0.0049 per cent. Emissions in 1990 are unaffected, because a different method is used to estimate crop burning areas between 1990 and 2004 (due to a lack of data collection on crop burning before 2005), which is still regarded as robust given the available data.

Table 10.1.5   Effect of crop burning area methodology improvement on agricultural emissions estimates

		1990	2016	Change in emission outputs between 1990 and 2016 (kt CO_2-e)	Percentage change in emission outputs between 1990 and 2016
Total emissions from the Agriculture sector (kt CO_2-e)	2018 (1990–2016) emissions estimate *before* crop burning area improvement	34,581.9	38,729.2	4,147.3	12.0
	2018 (1990–2016) emissions estimate *after* crop burning area improvement	34,581.9	38,727.3	4,145.5	12.0
	Difference in emission estimates compared with current inventory	0	–1.9	–1.9	
Percentage difference in the emission estimates		0	–0.0049		

Revision of agricultural statistics

Revision and finalisation of agricultural data from Statistics New Zealand can mean emissions estimates for the latest two years vary from the previous submission for certain source categories.

The calculation of emissions for the most recent year (2016 in this submission) requires data from Statistics New Zealand that is only provisional at the time the inventory is compiled. These figures can change after receiving final animal numbers and data.

10.1.4   Land use, land-use change and forestry

Improvements made to the LULUCF sector have resulted in a 1.9 per cent (582.9 kt CO_2-e) decrease in net LULUCF removals in 1990 and a 4.5 per cent (1,078.4 kt CO_2-e) increase in net LULUCF removals in 2015 (figure 10.1.5).
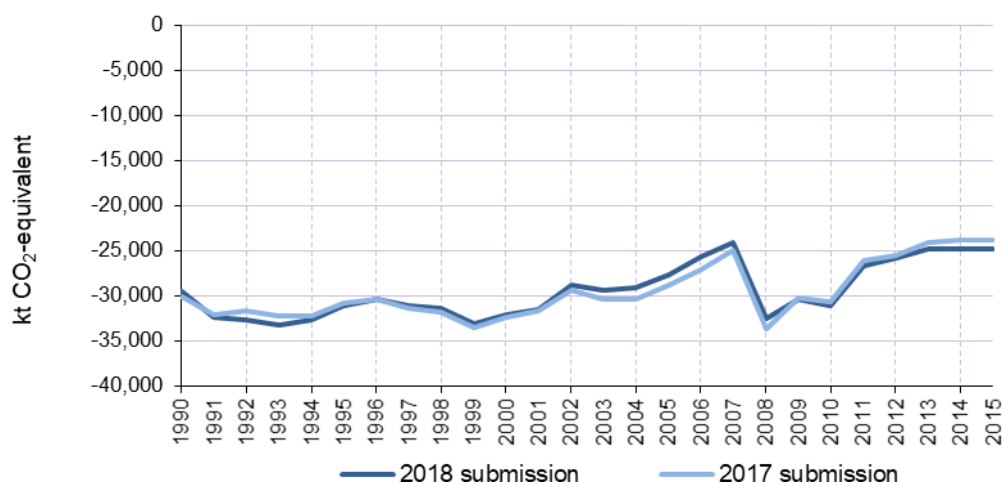
Note: Net emissions are expressed as a negative value to help clarify that the value is a removal and not an emission.

Significant improvements to the 2018 inventory submission include:

- the revision of the United Nations Framework Convention on Climate Change harvested wood products model to include information on export markets

- the post-1989 planted forest yield table being revised. The revised yield table is based on three measurements of post-1989 planted forest permanent sample plots carried out in 2007–08, 2011–12 and the transition to a continuous inventory in 2016. The analysis of the data collected has provided a plot-based estimate of carbon stock and mean carbon density within this forest type

- emissions from peat extraction are reported across the time series for the first time

- reporting the non-carbon dioxide emissions from controlled burning of other standing vegetation for the first time

- continued improvements to the 1990, 2008 and 2012 land use maps. These improvements have led to a reduction in the total area of *Pre-1990 natural forest* (5,540 hectares) and *Post-1989 natural forest* (1,108 hectares) following a review that showed these areas were not succeeding to forest and are more accurately classified as *Grassland with woody biomass*.

Further details on these changes are in chapter 6. The explanations and justifications for the major recalculations to New Zealand's LULUCF estimates in the 2018 inventory submission are summarised in table 10.1.6.

Table 10.1.6   Explanations and justifications for recalculations in the LULUCF sector

Explanation of recalculation	Underpinning UNFCCC principle	Additional justification
New Zealand's *Harvested wood products* estimates now include market specific activity data and emission factors for export raw materials.	Accuracy	Key category improvement (*Harvested wood products*)
The post-1989 planted forest yield table was revised. The revised yield table is based on three measurements of post-1989 planted forest permanent sample plots carried out in 2007–08, 2011–12 and in the transition to a continuous inventory in 2016. The analysis of the data collected has provided a plot-based estimate of carbon stock and mean carbon density within this forest type.	Accuracy	Key category improvement (*Land converted to forest land; Land converted to grassland*)
Emissions estimates from peat extraction are reported for the first time.	Completeness	

Explanation of recalculation	Underpinning UNFCCC principle	Additional justification
An estimate for controlled burning in *Grassland remaining grassland* is provided for the first time in this submission. This activity involves the clearance of vegetation for pasture regeneration.	Completeness	Key category improvement (*Grassland remaining grassland*)
Improvements to the accuracy of the 1990, 2008 and 2012 land use maps. These improvements have led to a reduction in the total area of *Pre-1990 natural forest* (5,540 hectares) and *Post-1989 natural forest* (1,108 hectares) following a review that showed these areas were not succeeding to forest and are more accurately classified as *Grassland with woody biomass.*	Accuracy	Key category improvement (*Forest land remaining forest land; Land converted to forest land; Grassland remaining grassland*)

10.1.5 Waste

Improvements and recalculations made in the Waste sector have resulted in a 6.2 per cent (255.4 kt CO_2-e) decrease in emissions in 1990 and a 3.4 per cent (136.1 kt CO_2-e) decrease in emissions in 2015 (figure 10.1.6). Numerous improvements and corrections have been made to the Waste sector in the 2018 submission, including responses to findings resulting from expert review team (ERT) reviews. The most significant changes are in the *Unmanaged waste disposal sites* source category. Together, these changes have resulted in a recalculation of all categories.

Significant changes to the Waste sector in the 2018 inventory submission are:

- incorporating additional survey data of farm waste, leading to a revision of quantities and composition of waste in farm fills, including the creation of an additional farm type 'other horticulture', to better characterise waste from the various farm types

- updating and correcting the waste composition of non-municipal solid waste, to better reflect the limited known data on composition

- updating the gross domestic product data used as a basis for estimating total placement for non-municipal solid waste

- correcting estimates for managed solid waste disposal sites, including removing placement for uncategorised sites (which was being double counted) and applying the correct waste composition and degradable organic carbon (DOC) values

- adding a correction to the estimates of CH_4 from domestic wastewater to ensure that the entire population is accounted for.

A full list of recalculations is made in table 10.1.7 below.

Figure 10.1.6   Effect of recalculations on New Zealand's Waste sector from 1990 to 2015
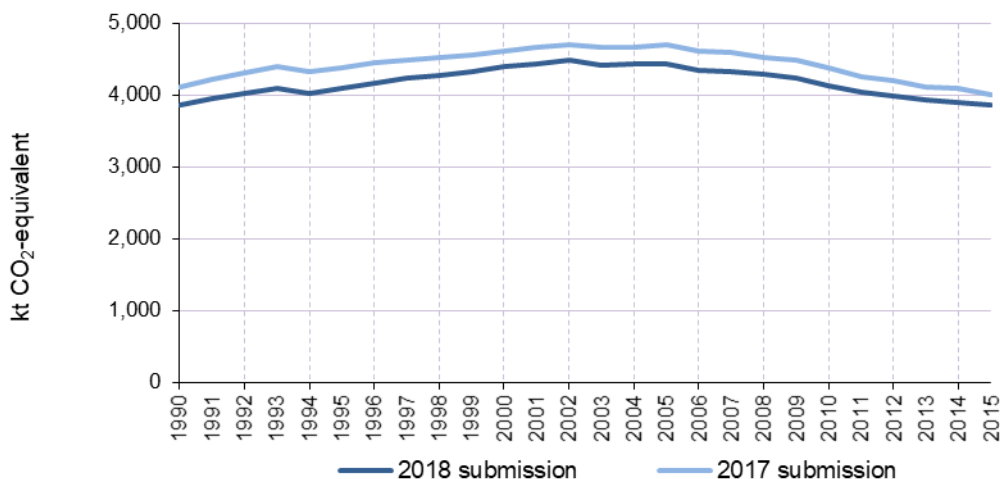
Table 10.1.7   Explanations and justifications for recalculations in the Waste sector

Explanation of recalculation	Underpinning UNFCCC principle	Additional justification
The composition and quantity of farm waste has been revised, following the incorporation of additional farm waste survey data from the Waikato and Bay of Plenty regions.	Completeness, accuracy	*Solid waste disposal* is a key category; expert review team (ERT) recommended to revise farm waste composition
The Chatham Islands area is now included in the estimates of emissions from farm waste.	Completeness	*Solid waste disposal* is a key category
An additional farm type 'other horticulture' has been used to characterise waste from these farms that were previously excluded.	Completeness	*Solid waste disposal* is a key category
Correction to calculation of farm waste emissions in the Wellington region.	Accuracy	*Solid waste disposal* is a key category
Revision to the characterisation of waste composition for non-municipal solid waste based on the information available, including the incorporation of survey data for waste deposited in 2016.	Accuracy	*Solid waste disposal* is a key category
Updating the gross domestic product data used as a basis for estimating total placement for non-municipal solid waste that has led to revising the overall placement.	Accuracy	*Solid waste disposal* is a key category
Correction of the waste composition in the calculations for managed landfills, to reflect the composition data available.	Accuracy, transparency	*Solid waste disposal* is a key category
Correcting an error where placement for uncategorised landfills was being double counted in the managed landfills category.	Completeness	*Solid waste disposal* is a key category
Revision of the year methane recovery was applied to one landfill.	Accuracy	*Solid waste disposal* is a key category
Adding a correction to the estimates of methane from domestic wastewater, to ensure that the entire population is accounted for.	Completeness	*Wastewater treatment and discharge* is a key category; ERT recommended to apply this correction
Correcting the factor for septic tanks so that they do not increase emissions by 25 per cent, to account for industrial wastewater, because septic tanks do not generally take industrial wastewater.	Accuracy	*Wastewater treatment and discharge* is a key category; ERT recommended to apply this correction
Inclusion of activity data for the meat industry, to better align data with that used in the Agriculture sector.	Accuracy	*Wastewater treatment and discharge* is a key category
Correction in the estimates for dairy processing in the conversion of volume to mass of milk processed.	Accuracy	*Wastewater treatment and discharge* is a key category
A minor correction has been made to emissions from incineration, where emissions were incorrectly reported one year later than when the actual emissions occurred.	Accuracy	

10.1.6   Article 3.3 activities under the Kyoto Protocol

New Zealand's greenhouse gas estimates for activities under Article 3.3 and Article 3.4 of the Kyoto Protocol have been recalculated since the 2017 inventory submission (tables 10.1.7, 10.1.8 and 10.1.9). The recalculations incorporate changes to meet new guidance as set out in the Kyoto Protocol Supplement (IPCC, 2014) and include improved activity data and emission factors (see chapter 11 and table 10.2.1). Table 10.1.8 lists the recalculations in order of decreasing magnitude.

Table 10.1.8   Explanations and justifications for recalculations of New Zealand's previous Kyoto Protocol estimates

Explanation of recalculation	Underpinning UNFCCC principle	Additional justification
New Zealand's harvested wood products model has been revised to include the contribution of export logs based on an export markets study.	Accuracy	Key category improvement (*Afforestation/reforestation; Forest management*)
The post-1989 planted forest yield table has been revised for the 2018 submission. The revised yield table is based on three inventories of post-1989 planted forest permanent sample plots; two complete sets, and a partial set measured in 2016. The analysis of the data collected has provided a plot-based estimate of carbon stock and mean carbon density within this forest type.	Accuracy	Key category improvement (*Forest management; Deforestation*)
Improvements to the accuracy of the 1990, 2008 and 2012 land use maps.	Accuracy	Key category improvement (*Afforestation/reforestation; Deforestation* and *Forest management*)

Since its last submission, New Zealand has revised its harvested wood products model to include the contribution of export logs based on an export markets study. This improvement has had the greatest impact on the emissions recalculations for Kyoto Protocol activities and on *Forest management* activities in particular (table 10.1.9).

The post-1989 planted forest yield table has been revised for the 2018 submission. This improvement has had the second greatest impact on the emissions recalculations for Kyoto Protocol activities and on *Afforestation/reforestation* activities in particular.

Improvements in activity data (table 10.1.10) have affected emissions recalculations for all three Kyoto Protocol activities.

Table 10.1.9   Impact of the recalculations of New Zealand's net emissions under Article 3.3 and Article 3.4 of the Kyoto Protocol in 2015

Activities under the Kyoto Protocol	2015 net emissions (kt CO_2-e)		Change from 2017 submission (%)
	2017 submission	2018 submission	
Afforestation/reforestation	−16,001.2	−17,172.8	−7.3
Deforestation	3,465.8	3,409.0	1.6
Forest management	−12,106.2	−18,119.7	−49.7
Total	**−24,641.5**	**−31,883.5**	**−29.4**

Note: Net emissions are expressed as a negative value to help clarify that the value is a removal and not an emission. Percentages presented are calculated from unrounded values.

Table 10.1.10   Recalculations to New Zealand's 2015 activity data under the Kyoto Protocol

Activities under the Kyoto Protocol	Area as at 2015 (ha)		Change from 2017 submission (%)
	2017 submission	2018 submission	
Afforestation/reforestation	647,558	651,567	0.6
Deforestation	188,409	187,969	−0.2
Forest management	9,257,310	9,252,023	−0.1
Activities occurring in 2015			
New planting	2,471	3,742	51.5
Deforestation			
Pre-1990 natural forest	887	874	−1.4
Pre-1990 planted forest	3,741	3,668	−2.0
Post-1989 forest	796	875	9.9

Note: Percentages presented are calculated from unrounded values.

10.2 Recalculations and planned improvements in response to the review process

New Zealand has made improvements to the inventory to take into account the findings from the reviews of previous submissions. The assessment review report from the review of the 2017 submission (2017 ARR) was not published in time to respond to the recommendations in this submission.

The 2016 ARR was published in August 2017 (UNFCCC, 2017) and includes findings from reviews of the 2016 and earlier submissions of New Zealand's inventory. New Zealand has endeavoured to address or resolve as many recommendations as practicable for the 2017 and 2018 submissions. Further improvements will be carried out for future submissions.

Table 3 and table 4 of the 2016 ARR contain recommendations relating to the reviews of the 2015 and earlier inventory submissions. The recommendations that are still relevant are detailed in table 10.2.1 along with New Zealand's responses to date to those recommendations.

Table 5 of the 2016 ARR contains recommendations relating to the review of the 2016 inventory submission. These recommendations, along with New Zealand's responses to date, are detailed in table 10.2.2.

Table 10.2.1   New Zealand's response to recommendations still relevant as reported in table 3 and table 4 of the 2016 assessment review report for issues raised in earlier reviews

Sector	ID number	Expert review team recommendation	New Zealand response
General	G.2 2016	Prioritise resources to resolve the issues related to improving the transparency of the National Inventory Report (NIR) in accordance with the detailed recommendations given under the different sectors.	**Resolved.** The issues identified prior to the 2016 submission have been resolved.
General	G.5 2016	Strengthen quality assurance/ quality control procedures related to consistency checks between information reported in the common reporting format tables and the NIR, in order to avoid similar mistakes in the next submission and thus improve the transparency of its reporting.	**Resolved.** The issues identified prior to the 2016 submission have been resolved.
Energy – Reference and sectoral approaches – carbon dioxide (CO_2)	E.1 2016	Endeavour to separate naphtha and crude oil with a view to improving the transparency of the reference approach as well as the accuracy of the reporting of non-energy use of fuels and feedstocks.	**Addressing.** Naphtha and crude oil are combined within the current data system but will be separated within the new energy database once it becomes operational.
Energy – Stationary combustion: solid fuels – CO_2	E.4 2016	Critically assess whether the New Zealand Emissions Trading Scheme (NZ ETS) factors reviewed in 2009 are indeed more appropriate for the estimation of emissions from solid fuels and report on this assessment.	**Not applicable.** NZ ETS factors are not used for the estimation of emissions from solid fuels, and the agency responsible for estimating these emissions does not have legal access to the relevant NZ ETS returns.
Energy – Reference approach – CO_2	E.8 2016	Disaggregate the naphtha and crude oil data in its 2016 submission. If this is not possible because of significant resource demands, as indicated in New Zealand's response to the expert review team's (ERT's) main provisional findings, the ERT recommends that New Zealand report in its NIR on progress made in addressing the recommendation.	**Addressing.** Naphtha and crude oil are combined within the current data system but will be separated within the new energy database once it becomes operational.

Sector	ID number	Expert review team recommendation	New Zealand response
Energy – Reference approach – CO_2	E.9 2016	Endeavour to incorporate disaggregated data for lubricants, petroleum coke and bitumen in the 2016 submission. If this is not possible because of significant resource demands, as indicated in New Zealand's response to the ERT's main provisional findings, the ERT recommends that New Zealand report in its NIR on progress made in addressing the recommendation.	**Addressing.** These are combined within the current data system but will be separated within the new energy database once it becomes operational.
Energy – Feedstocks, reductants and other non-energy uses of fuels – CO_2	E.10 2016	Improve the transparency of its reporting of non-energy uses of fuels by adding a table on energy and non-energy uses of fuels for natural gas together with associated emissions and the categories where these are reported.	**Resolved.** Further explanation, as well as a chart showing natural gas energy and non-energy use, has been included in the 2018 NIR.
Energy – Feedstocks, reductants and other non-energy uses of fuels – CO_2	E.11 2016	Review the notation keys reported for emissions from the different categories.	**Resolved.** Notation keys have been reviewed.
Energy – Manufacture of solid fuels and other energy industries: solid fuels – CO_2, methane (CH_4) and nitrous oxide (N_2O)	E.12 2016	Estimate and report these emissions or, if these emissions are considered insignificant by the Party, report them as 'NE' (not estimated) and provide a quantitative estimate of the likely level of the emissions in accordance with paragraph 37(b) of the UNFCCC Annex I inventory reporting guidelines in order for the ERT to assess whether the sum of all gases and categories considered insignificant remains below 0.1 per cent of the national total greenhouse gas emissions.	**Addressing.** This recommendation has been included in the improvements planning system.
Energy – Domestic aviation: liquid fuels – CO_2	E.13 2016	Estimate CO_2 emissions from domestic aviation using a Tier 2 or Tier 3 methodology, in accordance with the 2006 IPCC Guidelines.	**Addressing.** An aviation emissions model has been completed, although it was not released in time to be included in this submission. The new estimates will be included in the 2019 submission.
Energy – Road transportation: liquid and gaseous fuels – CO_2	E.14 2016	Continue to estimate the CO_2 emissions based on fuel sold but report the CO_2 emissions disaggregated by vehicle mode using the data collected for the estimation of CH_4 and N_2O emissions assuming that any discrepancies can be resolved between the top-down and bottom-up approaches; if this is not possible, continue to report CO_2 emissions aggregated, but investigate and describe in the NIR the possible reasons for the discrepancy in the results of the comparison.	**Resolved.** Data is now disaggregated, where possible, or estimated based on IPCC guidelines where disaggregated data is unavailable.
Energy – Coal mining and handling – CH_4	E.17 2016	Estimate these CH_4 emissions or, if these emissions are considered insignificant by the Party, report them as 'NE' (not estimated) and provide a quantitative estimate of the likely level of the emissions in accordance with paragraph 37(b) of the UNFCCC Annex I inventory reporting guidelines in order for the ERT to assess whether the sum of all gases and categories considered insignificant remains below 0.1 per cent of the national total greenhouse gas emissions.	**Not Resolved.** The data necessary for estimation of these emissions could not be obtained.
Energy – Natural gas processing – CH_4	E.18 2016	Encourages New Zealand to report fugitive (leakage) CH_4 emissions from natural gas processing under the category natural gas processing to enhance comparability with other Parties. If this is not possible, the ERT recommends that the Party report these emissions as 'IE' (included elsewhere) and clearly explain the allocation of the fugitive CH_4 emissions of the Kapuni gas treatment plant in the NIR.	**Resolved.** The CRF tables have been revised.

Sector	ID number	Expert review team recommendation	New Zealand response
IPPU – General	I.1 2016	Include in the NIR detailed information and methodological descriptions on how plant-specific data are estimated.	**Resolved.** Plant-specific descriptions and references to NZ ETS regulations have been included in the 2018 NIR.
IPPU – Cement production	I.2 2016	Continue with efforts to improve the transparency of the reporting regarding information on cement production by providing more detailed information in the NIR, while maintaining the confidentiality of the sensitive data.	**Addressing.** The activity data is confidential and will not be included in submissions, but can be provided to the ERT on request.
IPPU – Glass production – CO_2	I.3 2016	Continue with efforts to improve the transparency of the reporting regarding information on glass production by providing more detailed information in the NIR, while maintaining the confidentiality of the sensitive data.	**Resolved.** The use of confidential data was transparently described in the 2017 NIR.
IPPU – Other process uses of carbonates – CO_2	I.4 2016	Continue with efforts to improve the transparency of the reporting regarding information on limestone and dolomite use by providing more detailed information in the NIR, while maintaining the confidentiality of the sensitive data.	**Resolved.** The use of confidential data was transparently described in the 2017 NIR.
IPPU – Other process uses of carbonates – CO_2	I.5 2016	Continue with efforts to improve the transparency of the reporting regarding information on soda ash use, by providing more detailed information in the NIR, while maintaining the confidentiality of the sensitive data.	**Resolved.** The use of confidential data was transparently described in the 2017 NIR.
IPPU – Iron and steel production – CO_2	I.8 2016	Continue with efforts to improve the transparency of the reporting regarding information on steel slab production, by providing more detailed information in the NIR, while maintaining the confidentiality of the sensitive data.	**Resolved.** The process of steel production is now transparently described in the 2018 NIR in chapter 4, section 4.4.
IPPU – General	I.12 2016	Incorporate in the NIR the information available in the NZ ETS regulation, including regarding coverage and methodologies used for reporting, as well as the additional information not included in the NZ ETS regulation provided to the ERT during the review, for example, the frequency of measurement.	**Resolved.** A description of the NZ ETS data calculation and reporting is included in the 2018 NIR along with a reference to the relevant NZ ETS regulations.
IPPU – Electronics industry (2.D) Product uses as substitutes for ozone-depleting substances (2.F) Other product manufacture and use (2.G) – hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6) and nitrogen trifluoride (NF_3)	I.20 2016	Include all the information indicated in the section 'reporting and documentation' of the IPCC guidelines for these categories (e.g., volume 3, chapter 7.5.4.2) for the information to be included for the category *Product uses as substitutes for ozone-depleting substances*.	**Addressing.** This is not relevant for 2.E (*Electronics industry*). For 2.D and 2.G, all recommended information is reported in the NIR. For 2.F, the description of these information sources in the NIR has been improved and will be further reviewed and improved for future submissions.
IPPU – Other product manufacture and use (2.G) – SF_6	I.22 2016	Use a methodology in accordance with the 2006 IPCC Guidelines to estimate emissions of SF_6 from electrical equipment, where a Tier 1 method is used.	**Resolved.** The methods used for estimation of SF_6 emissions are now in accordance with the 2006 IPCC Guidelines.

Sector	ID number	Expert review team recommendation	New Zealand response
IPPU – Other product manufacture and use (2.G) – SF_6	I.23 2016	Include in the NIR the explanations provided to the ERT during the review on the analysis of SF_6 emissions from SF_6 use in shoes and double-glazed windows that were provided as direct responses and through the background report.	**Addressing.** The information will be included in the NIR for future submissions.
LULUCF – General – CO_2, CH_4 and N_2O	L.2 2016	Review and, where necessary, update the carbon fractions of biomass using the appropriate values in the 2006 IPCC Guidelines.	**Resolved.** New Zealand has updated the carbon fractions where appropriate.
Waste – General – CH_4	W.1 2016	Publish the reports provided to the ERT or make the information in the reports otherwise available to ERTs (e.g., by submitting a summary in the NIR).	**Resolved.** Additional information was added to the 2017 NIR. The reports cannot be published in full because of confidential information, however, they can be made available to ERTs on request.
Waste – General – CH_4	W.2 2016	Provide in the NIR tables with information on activity data (full time series) at the level at which the estimates are calculated. Or, where this is not possible owing to the large amount of data or for confidentiality reasons, provide summaries of activity data at an appropriate level, to increase transparency and to allow the ERT to review the accuracy of the estimates and time series.	**Resolved.** Aggregate activity data for key categories is provided in the NIR for the 2018 submission. This data is included in chapter 7, tables 7.2.2, 7.2.3, 7.5.1 and 7.5.2.
Waste – Solid waste disposal (5.A) – CH_4	W.3 2016	Provide a summary of activity data (amount) for the entire time series by waste type and solid waste disposal site (SWDS) type as well as additional information on the source of the data.	**Resolved.** Aggregate activity data for key categories is provided in the NIR for the 2018 submission. For managed solid waste disposal, activity data is provided in chapter 7, table 7.2.2.
Waste – Solid waste disposal (5.A) – CH_4	W.4 2016	Provide substantive justification for the country-specific default values on CH_4 recovery efficiency, including on the factors that can enhance the recovery (e.g., through measurement results or scientific literature confirming the used values) or that New Zealand revise its estimates for CH_4 recovery at SWDSs for which metered data are not available to 20 per cent, in order to be consistent with the guidance in the 2006 IPCC Guidelines.	**Resolved.** Significant justification has been provided in the NIR for the 2018 submission, under gas recovery in chapter 7, section 7.2.2.
Waste – Solid waste disposal (5.A) – CH_4	W.5 2016	Confirm the data used for each year, either by continuous monitoring of the CH_4 recovered from the sites or by using drivers such as electricity production using the recovered gas, in accordance with the 2006 IPCC Guidelines.	**Resolved.** New Zealand has provided an explanation of the drivers for CH_4 recovery in the NIR for the 2018 submission, under gas recovery in chapter 7, section 7.2.2.3, including a table 7.2.6, which reports data on CH_4 recovery at landfills.
Waste – Solid waste disposal (5.A) – CH_4	W.6 2016	Provide data on the SWDSs at which it is confirmed that CH_4 recovery takes place and data on the amount of CH_4 recovered for which metered data on the recovery is available in each future annual inventory submission. The ERT also recommends that the Party provides this information separately for energy recovery and flaring. The information can be provided as an aggregate value for the SWDSs in question.	**Resolved.** Details on CH_4 recovery are provided in the NIR for the 2018 submission, under gas recovery in chapter 7, section 7.2.2.3, including table 7.2.6, which reports data on CH_4 recovery at landfills.
Waste – Solid waste disposal (5.A) – CH_4	W.7 2016	Ensure consistency in the methodology and parameters used to estimate CH_4 generation across SWDSs and, if the methodology and parameters are not from the 2006 IPCC Guidelines, justify the applicability of the methodology used to the national circumstances.	**Resolved.** New Zealand has provided more detail on the methods applied to estimate emissions from SWDS in the NIR for the 2018 submission, under CH_4 generation rates in section 7.2.2.

Sector	ID number	Expert review team recommendation	New Zealand response
		The ERT also recommends that New Zealand improves the description in the NIR, when SWDS-specific parameters are used in the estimation of the CH_4 emissions from SWDSs, by clarifying the sources for the parameters and providing the reasons why different parameters are used.	
Waste – Biological treatment of solid waste (5.B) – CH_4 and N_2O	W.8 2016	Provide a quantified estimate of the potential emissions for composting in the NIR, so that the ERT can assess whether the sum of all gases and categories considered insignificant remains below 0.1 per cent of the national total greenhouse gas emissions.	**Resolved.** New Zealand justifies its use of 'NE' (not estimated) because it is not significant. This is evidenced by an order of magnitude calculation provided in the NIR for the 2018 submission in section 7.3. Further detail on categories reported as NE can be found in annex 6.

Table 10.2.2   **New Zealand's response to recommendations as reported in table 5 of the 2016 assessment review report from the review of New Zealand's 2016 inventory submission**

Sector	ID number	Expert review team recommendation	New Zealand response
Energy – 1.A.3.b Road transportation – liquid fuels – methane (CH_4) and nitrous oxide (N_2O)	E.19 2016	Apply the procedure for validating vehicle-kilometres travelled with fuel statistics data before estimating CH_4 and N_2O emissions with the COPERT IV model and describe this procedure in the NIR.	**Resolved.** This recommendation has been implemented.
Energy – 1.A.4.c Agriculture/forestry/fishing – liquid fuels – CH_4 and N_2O	E.22 2016	Collect separate activity data for off-road vehicles and other machinery, fishing and stationary combustion activities in this category, and that it estimate CH_4 and N_2O emissions by applying appropriate emission factors (EFs) for mobile combustion and stationary combustion.	**Resolved.** The emissions estimates have been disaggregated and reported in the common reporting format (CRF) tables.
Energy – Feedstocks, reductants and other NEU of fuels – solid fuels – carbon dioxide (CO_2)	E.23 2016	Correct the emissions reported in CRF table 1.A(d) from kilotonnes carbon to kilotonnes carbon dioxide equivalent.	**Resolved.** This issue has been corrected.
Energy – 1.A.3.e.i Pipeline transport – CO_2, CH_4 and N_2O	E.24 2016	Improve comparability by reporting combustion emissions for pipeline transport under category 1.A.3.e.i (pipeline transport), as required by the 2006 IPCC Guidelines.	**Resolved.** Pipeline transport has been recategorised from 1.A.1.c to 1.A.3.e.i
Energy – 1.B.1.a Coal mining and handling – CH_4	E.25 2016	Either document in the National Inventory Report (NIR) that the CH_4 EF applied for surface mining is representative of national circumstances in New Zealand or use the CH_4 EF for surface mining provided in the 2006 IPCC Guidelines and report the results of this change in its NIR.	**Resolved.** We now use the 2006 IPCC default EF.
Energy – 1.B.1.a Coal mining and handling – CH_4	E.26 2016	Improve transparency by describing in the NIR its rationale for the choice of CH_4 EFs for underground mining of bituminous and sub-bituminous coal, as well as by providing a description of the number and types of coal mines active in New Zealand.	**Resolved.** Further explanation has been included in the 2018 NIR
Energy – 1.B.2.b Natural gas – CO_2	E.27 2016	Improve comparability by reporting CO_2 venting from natural gas processing in category 1.B.2.c.2 (gas venting).	**Resolved.** This change has already been implemented.

Sector	ID number	Expert review team recommendation	New Zealand response
Energy – 1.B.2.b Natural gas – CO_2	E.28 2016	The expert review team (ERT), noting its recommendation in ID#E.14 in table 3 [of the 2016 assessment review report, or table 10.2.1 above], recommends that, if it chooses not to report CH_4 emissions from the Kapuni gas treatment plant, New Zealand changes the notation key used for fugitive CH_4 emissions from natural gas processing (category 1.B.2.b.3) from 'NO' (not occurring) to 'NE' (not estimated) and describes these emissions in the NIR, as well as provides a justification for their insignificance in accordance with decision 24/CP.19, annex, paragraph 37(b).	**Resolved.** The CRF tables and the 2018 NIR have been updated.
Energy – 1.B.2.c Venting and flaring – CO_2	E.29 2016	The ERT, taking note of the national circumstances, encourages New Zealand to continue to report emissions from hydrogen production at the Marsden Point Refinery under the Industrial Processes and Product Use sector in order to maintain confidentiality, but recommends that, in order to improve transparency, the Party describes this allocation and the underlying reason for it in the NIR.	**Resolved.** Further explanation has been included in the 2018 NIR.
Energy – 1.B.2.d Other (oil, natural gas and other emissions from energy production) – CO_2	E.30 2016	Improve transparency by describing in the NIR the rationale for excluding the geothermal sites from the inventory and, further, encourages the Party to attempt to assess the significance of emissions from the excluded sites.	**Resolved.** Further explanation was included in the 2017 NIR.
IPPU – 2.A.2 Lime production – CO_2	I.26 2016	Correct the year for the emission estimates in this category and reassess the related quality assurance/quality control (QA/QC) check in order to avoid similar errors.	**Resolved.** The error was corrected for the 2017 submission.
IPPU – 2.A.4 Other process uses of carbonates – CO_2	I.27 2016	Improve comparability by reallocating emissions from iron and steel to iron and steel production and recalculating CO_2 emissions from the iron and steel and the other process uses of carbonates categories in the annual submission.	**Resolved.** As explained in the 2017 NIR (4.2.2), New Zealand considers that the allocation of these emissions to 2.A.4 is necessary to preserve confidentiality of data provided by the glass industry. The amount is small and has no material effect on comparability for iron and steel production.
IPPU – 2.A.4 Other process uses of carbonates – CO_2	I.28 2016	Correct the period for activity data in this category.	**Resolved.** The error has been corrected for the 2017 submission.
IPPU – 2.B Chemical industry – CO_2	I.29 2016	Correct the NIR description of the category chemical industry by removing coke as a chemical product in the annual submission.	**Resolved.** The error has been corrected for the 2017 submission.
IPPU – 2.B.5 Carbide production – CO_2	I.30 2016	Include the category carbide production in the NIR under chemical industry, including information on the methodology used, choice of EF and source of activity data for this category and review QA/QC checks related to this category.	**Resolved.** This information is now included in the 2018 NIR, and QA procedures are expected to identify any similar omissions in future submissions.
IPPU – 2.C.1 Iron and steel production – CO_2	I.31 2016	The ERT welcomes the carbon balances provided by New Zealand during the review and recommends that the Party includes this information in its submission.	**Resolved.** The carbon balance for iron and steel making was transparently described in the 2017 NIR (4.4.2).
IPPU – 2.C.5 Lead production – CO_2	I.32 2016	Include in its NIR information on the method and EF chosen for CO_2 emission estimates from secondary lead production, and reassess the QA/QC checks for this category in order to ensure consistency of the information between the NIR and CRF table 2(I).A-Hs2.	**Resolved.** This information was included in the 2017 NIR.

Sector	ID number	Expert review team recommendation	New Zealand response
IPPU – 2.D Non-energy products from fuels and solvents use – CO_2	I.33 2016	Describe the activity data for paraffin wax use and lubricant use in CRF table 2(I).A-Hs2 consistently with the description in the NIR, and reassess the QA/QC checks for these sources in order to ensure consistency of the information between the NIR and CRF table 2(I).A-Hs2.	**Resolved.** This information is now correctly described in the CRF tables for the 2018 NIR submission.
IPPU – 2.F.4 Aerosols – hydrofluorocarbons (HFCs)	I.35 2016	Correct the error identified in the activity data description by correctly referring to HFC-134a as an HFC and not a perfluorocarbon (PFC).	**Resolved.** The error was corrected for the 2017 submission.
IPPU – 2.G Other product manufacture and use – PFCs and SF_6	I.36 2016	Remove the reference to HFCs in the use of PFCs in eye surgery.	**Resolved.** The error was corrected for the 2017 submission.
IPPU – 2.E Electronics industry 2.F Product uses as substitutes for ozone depleting substances 2.G Other product manufacture and use – HFCs, PFCs, SF_6 and NF_3	I.37 2016	Describe in its NIR the methodology it used to derive the 2 per cent decline in refrigerant charge in vehicle air-conditioning systems, and demonstrate that this methodology is in line with the splicing techniques in the 2006 IPCC Guidelines.	**Resolved.** This description is included in the 2017 NIR.
Agriculture – 3.B.1 Cattle – CH_4	A.5 2016	Include more detailed information in the NIR on possible reasons for the significant inter-annual changes in the CH_4 implied emission factor (e.g., the variability of typical climate events in New Zealand, the distribution of agricultural industries across New Zealand, commodity prices and improvements in breeding and genetics).	**Addressing.** New Zealand will provide more comprehensive information on the causes of inter-annual changes in the CH_4 implied emission factor in future submissions.
Agriculture – 3.D.a.1 Inorganic N fertilisers – N_2O	A.6 2016	Correct the observed inconsistency between the NIR and CRF tables regarding N_2O emissions from synthetic nitrogen fertiliser use, and improve the QA/QC procedures related to this category.	**Addressing.** Updated information on synthetic nitrogen fertiliser use is provided in the 2017 NIR.
Agriculture – 3.F Field burning of agricultural residues – CH_4, and N_2O	A.7 2016	Correct the inconsistencies between the NIR and CRF table 3.F relating to the field burning of agricultural residues, specifically reporting information in the NIR for the years for which greenhouse gas emissions are reported in the CRF tables, and improve the QA/QC procedures related to this category.	**Addressing.** Updated information on the burning of agricultural residues is provided in the 2017 NIR.
Waste – 5. General (waste) – CH_4, N_2O and CO_2	W.10 2016	Noting the general recommendation in ID#W.2 in table 3 [of the 2016 assessment review report, or table 10.2.1 above], provide, in the NIR, tables with information on waste generation and various treatment options (with the full time series).	**Resolved.** Aggregate activity data for key categories is provided in the NIR for the 2018 submission. This data is included in chapter 7, tables 7.2.2, 7.2.3, 7.5.1 and 7.5.2.
Waste – 5.A.1 Managed waste disposal sites – CH_4	W.11 2016	Either provide a better justification for the country-specific rate constant for biodegradation in landfills for municipal solid waste, or calculate CH_4 generation for municipal landfills with the default rate constant for biodegradation from the 2006 IPCC Guidelines.	**Resolved.** New Zealand has provided more detail on the methods applied to estimate emissions from solid waste disposal sites in the NIR for the 2018 submission, under CH_4 generation rates in chapter 7, section 7.2.2.
Waste – 5.A.2 Unmanaged waste disposal sites – CH_4	W.12 2016	Improve the degradable organic carbon content of farm waste based on the average waste composition of the various farm wastes determined from local studies.	**Resolved.** New Zealand has incorporated additional survey data on farm waste for the 2018 submission and has also derived degradable organic carbon values based on the composition of waste for each specific farm type.

Sector	ID number	Expert review team recommendation	New Zealand response
Waste – 5.D.1 Domestic wastewater – CH$_4$	W.14 2016	Ascertain whether the increased values of 'I' (the correction factor for industrial BOD) at specific wastewater treatment plants are related to wastewater discharged by industries that are included in the industries contributing to emissions from industrial wastewater. If this is the case, apply the default 'I' of 1.25 for these plants to avoid double counting.	**Resolved.** New Zealand confirmed to the ERT that industrial wastewater reported under 5.D.2 is separate and additional to emissions from industries discharging wastewater into domestic wastewater treatment plants.
Waste – 5.D.1 Domestic wastewater – CH$_4$	W.15 2016	Calculate emissions from septic tanks assuming an 'I' of 1.	**Resolved.** New Zealand has revised and corrected this parameter for septic tanks in domestic wastewater calculations for the 2018 submission.
KP-LULUCF – Forest management – CO$_2$, CH4 and N$_2$O	KL.2 2016	Improve the transparency of the reporting of the FMRL$_{corr}$ by clearly separating the original forest management reference level, the various technical corrections and their totals, and the FMRL$_{corr}$.	**Resolved.** Refer to annex 5.1.
KP-LULUCF – Forest management – CO$_2$	KL.3 2016	Report consistently across the NIR and the CRF tables, and correct the values in the NIR tables in its annual submission.	**Resolved:** Reporting of 'total technical corrections' has been revised in the NIR and CRF tables of the 2018 submission.

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Chapter 11: KP-LULUCF

11.1 General information

Emissions summary

2016

In 2016, net emissions from land subject to Article 3.3 and Article 3.4 activities under the Kyoto Protocol were –29,569.0 kilotonnes carbon dioxide equivalent (kt CO_2-e) (table 11.1.1). This is comparable to net emissions in the previous two years.

In 2016, net emissions from *Afforestation and reforestation* and *Deforestation* activities were –14,710.9 kt CO_2-e. This value is the total of all emissions and removals from activities under Article 3.3 of the Kyoto Protocol. It includes: removals from the growth of post-1989 forest and emissions from the conversion of land to post-1989 forest; emissions from harvesting of forests planted on non-forest land after 31 December 1989; emissions and removals from *Harvested wood products* from afforestation activities; emissions from deforestation of all *Forest land* subcategories; and emissions from *Biomass burning* and *Mineralisation of soil nitrogen* associated with afforestation, reforestation or deforestation activities since 1990.

In 2016, net emissions from *Forest management* were –14,858.1 kt CO_2-e (table 11.1.1). This includes removals from growth of pre-1990 natural forest and pre-1990 planted forest, emissions from harvesting of these forests, emissions and removals from *Harvested wood products* from these forests, and emissions from *Biomass burning*.

Table 11.1.1 New Zealand's emissions under Article 3.3 and Article 3.4 of the Kyoto Protocol during the second reporting period

	2013	2014	2015	2016
Afforestation and reforestation				
Net cumulative area since 1990 (ha)	644,706	648,700	651,567	655,323
Area in calendar year (ha)	4,838	4,847	3,742[P]	4,302[P]
Net emissions in calendar year (kt CO_2-e)	–17,044.7	–17,239.6	–17,172.8	–16,897.1
Deforestation				
Net cumulative area since 1990 (ha)	173,684	182,552	187,969	191,682
Area in calendar year (ha)	9,589	8,868	5,417[P]	3,713[P]
Net emissions in calendar year (kt CO_2-e)	6,200.8	6,276.1	3,409.1	2,186.2
Forest management				
Area included (ha)	9,264,580	9,256,565	9,252,023	9,249,653
Net emissions in calendar year (kt CO_2-e)	–21,697.1	–20,585.1	–18,119.7	–14,858.1
Total area included (ha)	**10,082,970**	**10,087,817**	**10,091,559**	**10,096,658**
Net emissions in calendar year (kt CO_2-e)	**–32,541.0**	**–31,548.6**	**–31,883.4**	**–29,569.0**
Accounting quantity (kt CO_2-e)	**–10,843.9**	**–10,963.5**	**–13,763.7**	**–14,710.9**

Note: Where net emissions result in removals, they are expressed as a negative value as per section 2.2.3 of the IPCC Guidelines (IPCC, 2006a). The accounting quantity excludes net emissions from forest management as these will be accounted for at the end of the commitment period against a forest management reference level and a cap will apply to limit credits; further information on these is included later in the chapter. Columns may not total due to rounding. ha = hectares; P = provisional figure. Afforestation and deforestation differs from that in chapter 6 due to carbon equivalent forests being reported separately.

Between 1 January 1990 and 31 December 2016, 655,323 hectares of new forest (post-1989 forest) were established as a result of afforestation and reforestation activities – an average of 25,261 hectares per year. During 2016, an estimated 4,302 hectares of new forest were planted, slightly more than the area planted in 2015 (3,742 hectares) (table 11.1.1).

Deforestation of all subcategories of *Forest land* (post-1989, pre-1990 planted and pre-1990 natural forest) during 2016 was estimated at 3,713 hectares. Since 1990, the area of deforestation of all subcategories of *Forest land* is estimated as 191,682 hectares.

The carbon equivalent forest provision creates a misalignment for the afforestation and deforestation area reported under the Kyoto Protocol and the United Nations Framework Convention on Climate Change (UNFCCC) sections of the inventory. The carbon equivalent forest provision is not recognised under the UNFCCC and is reported as *Land converted to forest land* (afforestation) and *Forest land converted to other land uses* (deforestation).

Between 1 January 1990 and 31 December 2016, the net area under *Forest management* decreased by 164,155 hectares, or 1.7 per cent, due to deforestation activities less the addition of 797 hectares due to the application of the carbon equivalent forest provision. During this time, 164,952 hectares of land transferred from Article 3.4 – *Forest management* reporting to Article 3.3 – *Deforestation* reporting and 797 hectares of non-forest land were added to Article 3.4 – *Forest management* under the Kyoto Protocol (Kyoto Protocol Supplement, IPCC, 2014a, section 2.7.2).

New Zealand's Article 3.3 and Article 3.4 emissions by source for the second commitment period

Table 11.1.2 provides a breakdown of New Zealand's emissions under the Kyoto Protocol by greenhouse gas source category for the first four years of the second commitment period.

Table 11.1.2   New Zealand's emissions for the second commitment period of the Kyoto Protocol by greenhouse gas source category

Greenhouse gas source category	Source form	Net emissions for 2013–2016 (kt)	
		Source emission	CO_2-equivalent
Emissions from afforestation and reforestation	CO_2	−68,704.0	−68,704.0
Emissions from deforestation	CO_2	17,938.4	17,938.4
Emissions from forest management activities	CO_2	−75,335.0	−75,335.0
Mineralisation of soil nitrogen associated with land-use change	N_2O	1.1	324.9
Biomass burning	CH_4	8.6	216.0
Biomass burning	N_2O	0.06	17.1
Net emissions			**−125,541.9**

Note: CO_2 = carbon dioxide; N_2O = nitrous oxide; CH_4 = methane. Columns may not total due to rounding.

Key categories

Conversion to *Forest land* (*Afforestation and reforestation*), conversion to *Grassland* (*Deforestation*) and *Forest land remaining forest land* (*Forest management*) are all key categories for New Zealand (table 1.5.4).

11.1.1 Definitions of forest and any other criteria

New Zealand is using the same *Forest land* definition for the period to 2020 as that used for the first commitment period and as defined in *New Zealand's Initial Report under the Kyoto Protocol* (Ministry for the Environment, 2006). This definition is consistent with that used for the Land Use, Land-Use Change and Forestry (LULUCF) sector under the UNFCCC reporting (chapter 6). Table 11.1.3 provides the defining parameters for *Forest land*.

Table 11.1.3   **Parameters defining Forest land in New Zealand**

Forest parameter	Kyoto Protocol range	New Zealand selected value
Minimum land area (ha)	0.05–1	1
Minimum crown cover (%)	10–30	30
Minimum height (m)	2–5	5

Note: The range values represent the minimum forest definition values as defined under the Kyoto Protocol, Decision 16/CMP.1 (UNFCCC, 2006).

New Zealand also uses a minimum forest width of 30 metres, which removes linear shelterbelts from the *Forest land* category. Linear shelterbelts can vary in width and height, because they are trimmed and topped from time to time. Further, they form part of non-forest land uses, namely *Cropland* and *Grassland* as shelter to crops and/or animals.

For reporting under the Kyoto Protocol, New Zealand has categorised its forests into three types: pre-1990 natural forest, pre-1990 planted forest and post-1989 forest. These subcategories are also used for inventory reporting on the LULUCF sector under the UNFCCC (see chapter 6).

For post-1989 forest, emissions and removals from carbon losses and gains due to *Afforestation and reforestation*[52] and *Deforestation* activities are reported under Article 3.3, along with emissions from *Deforestation* activities in pre-1990 natural and pre-1990 planted forest. For all *Forest land* that existed on 31 December 1989, which has been categorised as either pre-1990 natural forest or pre-1990 planted forest, all emissions and removals not associated with *Afforestation and reforestation* or *Deforestation* activities are reported under Article 3.4 – *Forest management*. Emissions and removals from the harvest and conversion of forest plantations and establishment of new forests that satisfy the requirements of Decision 2/CMP.7 (Annex, para 37, UNFCCC, 2012) are reported under Article 3.4 – *Forest management* as carbon equivalent forests.

The definition of forest used for reporting to the Food and Agriculture Organization (FAO) is currently different from that used for reporting under the Convention and the Kyoto Protocol. For reporting to the FAO, New Zealand subdivided forests into two estates based on their biological characteristics, the management regimes applied to the forests and their respective roles and national objectives (Ministry of Agriculture and Forestry, 2002). The two estates are indigenous and planted production forest. The former estate is included within the pre-1990 natural forest as reported in this submission. The planted production forest area largely equates to the productive area in pre-1990 planted forest and post-1989 planted forest.

11.1.2 Elected activities under Article 3.4

New Zealand has not elected to report on any of the voluntary activities under Article 3.4 of the Kyoto Protocol for the second commitment period. This is consistent with New Zealand's reporting for the first commitment period.

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[52]   Including emissions from harvesting of post-1989 forest.

11.1.3 Election of the Natural disturbance provision

In the event of a significant natural disturbance, New Zealand intends to apply the provision to exclude emissions due to natural disturbances from accounting for *Afforestation and reforestation* under Article 3.3, and *Forest management* under Article 3.4, of the Kyoto Protocol in accordance with Decision 2/CMP.7 (Annex, paras 33 and 34, UNFCCC, 2012).

Information on how New Zealand has calculated the background level for natural disturbance is included in annex 5.2.

11.1.4 Implementation of Article 3.3 and Article 3.4 reporting

New Zealand reports *Afforestation and reforestation*, *Deforestation* and *Forest management* under Article 3.3 and Article 3.4 respectively. In 2016, this covered 10,096,658 hectares, or 37.5 per cent, of New Zealand's total land area.

The hierarchy used by New Zealand in the reporting of these activities is as set out in section 1.2 of the Kyoto Protocol Supplement (IPCC, 2014a). This hierarchy means that once a forest area has been identified as deforested, it remains in this category. Therefore, all subsequent stock changes, emissions and removals on this land are reported under *Deforestation*.

Tracking of these deforested areas during the calculation and land use mapping processes (explained in chapter 6, section 6.2.2) ensures that land areas, once deforested, cannot be reported under *Afforestation and reforestation* or *Forest management*, and that the emissions and removals associated with the new land use or any subsequent land uses are reported under *Deforestation*. The process for identification of deforested land is outlined in section 11.5.

Areas subject to the carbon equivalent forest provision are tracked separately and reported under *Forest management* (refer to sections 11.2.2 and 11.3.4 below for more detail).

11.2 Land-related information

11.2.1 Spatial assessment unit

New Zealand is using a minimum mapping unit of 1 hectare.

11.2.2 Methodology for land transition matrix

The land transition matrix is based on data derived from the following sources:

- the 1990, 2008 and 2012 land use maps

- an estimate of total afforestation for the period 2008 to 2016 from the National Exotic Forest Description (Ministry for Primary Industries, 2016a)

- deforestation mapping for 2013 and 2014 (Indufor Asia Pacific, 2016)

- estimates for 2015 and 2016 deforestation based on the Deforestation Survey 2015 (Manley, 2016) and the Deforestation Intentions Survey 2016 (Manley, 2017).

Due to the land use category definitions used by New Zealand, which splits forests established before 1990 from those established after 1989, the land transition matrix can be derived from the sequence of land-use changes occurring through the reporting period. Using the 1990 land use map as the baseline, areas of deforestation can be tracked through time to ensure that, regardless of subsequent land-use change, the net emissions that occur on the deforested land are reported under *Deforestation*. Where a pre-1990 planted forest is harvested and converted to

another land use under the carbon equivalent forest provision, the land is tracked spatially and its net emissions are reported under *Forest management*, as are the areas and net emissions due to the new forest that was established to compensate for the harvested and converted forest.

The relationship between mapped land-use changes and activities reported under Article 3.3 and Article 3.4 is shown in table 11.2.1.

Table 11.2.1   Relationship between mapped land-use changes and activities reported under Article 3.3 and Article 3.4

Initial \ Final	Pre-1990 natural forest	Pre-1990 planted forest	Post-1989 forest	Grassland	Cropland	Wetland	Settlements	Other land
Pre-1990 natural forest	FM	FM	–	D	D	D	D	D
Pre-1990 planted forest	FM	FM	–	D/FM	D/FM	D/FM	D/FM	D/FM
Post-1989 forest	–	–	A	D	D	D	D	D
Grassland	*D	*D	A/FM					
Cropland	*D	*D	A/FM					
Wetland	*D	*D	A/FM					
Settlements	*D	*D	A/FM					
Other land	*D	*D	A/FM					

Note: A = *Afforestation and reforestation*; D = *Deforestation*; FM = *Forest management*; A/FM indicates that a forest establishment activity could be accounted for under *Forest management* if the land is subject to the carbon equivalent forest provision; D/FM indicates that a forest harvest and conversion activity could be accounted for under *Forest management* if the land is subject to the carbon equivalent forest provision; '–' denotes land-use changes that are not possible given the land use definitions; '*D' denotes land-use changes that are valid only if the land was forested at 1990, in which case the land use transition is accounted for under deforestation (e.g., pre-1990 planted forest converted to grassland since 1990 that is later converted back to pre-1990 planted forest would be reported under *Deforestation*).

Mapping of land-use change is described in chapter 6, sections 6.2.2 and 6.2.3. Further information on the estimation of the total area of afforested and reforested land occurring between 2008 and 2016 can be found in section 6.4.1.

Accurate classification of pre-1990 forest is essential to correctly determine the area reported as afforested and reforested in the land transition matrix. Satellite imagery at various dates near to 1990 and mapping from the New Zealand Emissions Trading Scheme (NZ ETS) have been used to ensure that these forests are classified correctly. An illustration of this process is shown in chapter 6, figure 6.2.4.

Transitions to deforestation are based on deforestation mapping, as described in chapter 6, section 6.2.2. All areas of deforestation are confirmed using oblique aerial photography. For deforestation occurring between 2008 and 2014, annual Landsat and/or Sentinel-2 satellite imagery is used to estimate the year of the conversion.

11.2.3 Identifying geographical locations

New Zealand has used Reporting Method's 1 and 2 for preparing estimates of emissions and removals for *Afforestation and reforestation* and *Deforestation*, and Approaches 2 and 3 to map land-use change. Wall-to-wall mapping is completed every four to five years, with national statistics and ancillary mapping data used in the intervening years to estimate afforested, reforested or deforested areas.

Included in New Zealand's geographical extent are the following uninhabited offshore islands: Kermadec Islands, Three Kings Islands and sub-Antarctic Islands (Auckland Islands, Campbell Island, Antipodes Islands, Bounty Islands and Snares Islands). These islands are protected conservation sites with a total area of 74,052 hectares. They are not subject to land-use change and are therefore reported in a steady state of land use.

11.2.4 Planned improvements

The NZ ETS provides an ongoing source of mapping information on forest extent and age along with information on deforestation activity and carbon equivalent forest activities. This will be used as part of a continuous improvement programme to update the 1990, 2008 and 2012 land use maps.

During 2017–18, field checking of areas where forest loss occurred during 2015 and 2016 will be completed. This will allow areas of deforestation to be identified, as well as areas of harvest activity and areas of non-anthropogenic change.

Work on a 2016 national land use map is also under way and scheduled to be completed in time for the next submission. This map will update most land-use change estimates between 2013 and 2016 with actual observations. The only exception to this is afforestation occurring from 2012 onwards. This will continue to be based on the National Exotic Forest Description (Ministry for Primary Industries, 2016a) because the first version of the 2016 land use map will not include all afforestation occurring up to 31 December 2016. This is because new forest planting is often not visible in satellite imagery until three or four years after planting.

11.3 Activity-specific information

11.3.1 Estimating carbon stock change

Emissions and removals from *Afforestation and reforestation*, *Deforestation* and *Forest management* are determined using plot-network-based estimates for each type of forest (pre-1990 natural forest, pre-1990 planted forest and post-1989 forest). Carbon analyses are performed to estimate the carbon per hectare per pool and are described in chapter 6, section 6.4.2.

11.3.2 Afforestation and reforestation (CRF 4(KP.A.1))

Between 1990 and 2016, it is estimated that 682,054 hectares of new forest (post-1989 forest) were established as a result of *Afforestation and reforestation* activities (table 11.3.1). The net area of post-1989 forest (calculated from the total area of new forest planted since 31 December 1989 minus the deforestation of post-1989 forest since 1 January 1990) as at the end of 2016 was 655,323 hectares. Emissions from this land in 2016 were –16,897.1 kt CO_2-e, compared with –17,172.8 kt CO_2-e in 2015. Of the total area afforested or reforested between 1990 and 2016, an estimated 26,731 hectares were deforested between 1990 and 2016 (table 11.3.1). The emissions for this area are reported under *Deforestation*.

The afforestation rate between 1990 and 2016 was, on average, 25,261 hectares per year. New planting rates were high from 1992 to 1998, averaging 60,209 hectares per year. This followed a change in the taxation regime, an unprecedented price spike for forest products with subsequent favourable publicity, a government focus on forestry as an instrument for regional development and the conclusion of the state forest assets sale. The removal of agricultural subsidies and the generally poor performance of the New Zealand and international share markets also encouraged investors to seek alternatives (Rhodes and Novis, 2002). The rate of new planting declined from 1996, reaching an estimated low of 2,788 hectares in 2008. Afforestation recovered slightly from

this low to 14,016 hectares and 13,397 hectares of new planting in 2011 and 2012 respectively. The increase in planting between 2008 and 2012 is largely attributable to the NZ ETS (Ministry for Primary Industries, 2015d), Afforestation Grant Scheme (Ministry for Primary Industries, 2015a) and Permanent Forest Sink Initiative (Ministry for Primary Industries, 2015b), which have been introduced by the New Zealand Government to encourage new planting and regeneration of natural ecosystems. The afforestation rate reduced after 2012 to average 4,432 hectares between 2013 and 2016. A total of 4,302 hectares were subject to *Afforestation and reforestation* activities in 2016. The reduction in *Afforestation and reforestation* activities that has occurred since the 1990s is likely caused by the relative profitability of other forms of land use, high rural land prices and a lack of confidence in the carbon market. The exclusion of international units from the NZ ETS scheme on 31 May 2015, the conclusion of the NZ ETS review and the implementation of some of its findings have contributed to higher carbon prices, and this is expected to encourage larger areas of afforestation in future.

The activity data used to estimate new planting in planted forests between 2008 and 2016 are obtained from a national survey of forest owners (Ministry for Primary Industries, 2016a) and the NZ ETS scheme for areas subject to the carbon equivalent forest provision. The survey respondents report areas as net stocked area. However, gross stocked area is reported in the inventory. To account for the difference between the two sources of data (mapping and survey), an unstocked area component is added to the new planting statistic between 2008 and 2016. For estimating emissions associated with new planting, the net planted forest area is modelled separately from the unstocked area component. This ensures the net new planting and NZ ETS data used in the inventory are consistent with the gross mapped forest area.

New Zealand's post-1989 forest is described in further detail in chapter 6, section 6.4.

Table 11.3.1   New Zealand's estimated annual area under Afforestation and reforestation from 1990 to 2016

Year	Annual area of Afforestation and reforestation (ha)			
	Afforestation/reforestation+	Harvesting	Deforestation	Net cumulative area
1990	14,342	0	0	14,342
1991	14,000	0	0	28,342
1992	43,943	0	0	72,284
1993	53,682	0	0	125,967
1994	84,965	0	0	210,932
1995	64,299	0	0	275,230
1996	72,844	0	0	348,074
1997	55,959	0	0	404,033
1998	45,771	0	0	449,804
1999	36,124	0	0	485,928
2000	31,252	0	0	517,180
2001	28,325	0	0	545,505
2002	21,469	0	704	566,270
2003	20,227	0	2,220	584,277
2004	12,704	0	2,039	594,942
2005	9,043	200	2,320	601,665
2006	6,187	600	1,988	605,864
2007	6,187	600	4,773	607,277
2008	2,788	779	1,102	608,964
2009	5,453	935	2,503	611,914
2010	7,349	1,454	1,696	617,566
2011	14,016	1,668	1,839	629,743

	Annual area of Afforestation and reforestation (ha)			
Year	Afforestation/reforestation+	Harvesting	Deforestation	Net cumulative area
2012	13,397	2,155	1,166	641,973
2013	4,838	3,986	2,105	644,706
2014	4,847	4,437	853	648,700
2015 P	3,742	5,225	875	651,567
2016 P	4,302	6,313	547	655,323
Total	**682,054**	**28,352**	**26,731**	**655,323**

Note: P = provisional figure; + = gross area. Columns may not total due to rounding. Afforestation differs from that in chapter 6 due to carbon equivalent forests being reported separately.

Since 1993, the New Zealand Government has introduced legislation and government initiatives to encourage forest establishment and discourage deforestation of planted forests. These measures include the:

- Climate Change Response Act 2002 (amended 8 December 2009)

- Erosion Control Funding Programme (Ministry for Primary Industries, 2014)

- Permanent Forest Sink Initiative (Ministry for Primary Industries, 2015b)

- Hill Country Erosion Programme (Ministry for Primary Industries, 2015c)

- Afforestation Grant Scheme (Ministry for Primary Industries, 2015a).

The NZ ETS was introduced under the Climate Change Response Act 2002. *Forest land* was introduced into the scheme on 1 January 2008. Under the scheme, owners of post-1989 forest land may voluntarily participate in the NZ ETS and receive emission units (New Zealand Units (NZUs)) for any increase in carbon stocks in their forests from 1 January 2008.

The Erosion Control Funding Programme, formerly the East Coast Forestry Project, is a grant scheme that was established in 1993. Its aim is to address soil erosion on the worst eroding land in the Gisborne District through planting trees or encouraging natural reversion to native bush. Funding has been approved to 2020 (Ministry for Primary Industries, 2014). To date, 40,500 hectares of forest have been established under the scheme (Ministry for Primary Industries, pers. comm., 2017).

The Permanent Forest Sink Initiative enables landowners to earn carbon credits through the establishment of permanent forests on land that was not forested prior to 1990 (Ministry for Primary Industries, 2015b). As at January 2016, 15,464 hectares were registered under this scheme (Ministry for Primary Industries, pers. comm., 2017).

The Hill Country Erosion Programme, like the Erosion Control Funding Programme, is focused on the retiring and afforestation of erosion-prone, hill-country farmland in the North Island. It underwent a review in 2011 and continues with an expanded target area throughout erosion-prone land in the North Island (Ministry for Primary Industries, 2015c).

The Afforestation Grant Scheme was first established in 2008 to promote carbon sequestration and sustainable land use. The first round of the scheme established 11,533 hectares of new forest between 2008 and 2013 (Ministry for Primary Industries, pers. comm., 2017). A second afforestation grant scheme was established in 2015. This scheme aims to establish around 15,000 hectares of new forest between 2015 and 2020 (Ministry for Primary Industries, 2015a).

New Zealand reports on *Harvested wood products* originating from *Afforestation and reforestation* activities. This is described further in section 11.3.6.

New Zealand may choose to apply the provision for the treatment of natural disturbance emissions to its afforestation and reforestation accounting (Ministry for the Environment, 2015). The method used to set New Zealand's natural disturbance background level is outlined in annex 5.2.

While some wildfire has occurred within *Afforestation and reforestation* activities since 2013, this was not at a high enough level for New Zealand to trigger the natural disturbance provision.

11.3.3 Deforestation (CRF 4(KP.A.2))

In 2016, *Deforestation* emissions were 2,186.2 kt CO_2-e, compared with 3,409.1 kt CO_2-e in 2015. These emissions result from the loss of carbon, which was stored in the biomass prior to deforestation, occurring in the year that deforestation occurs; soil carbon stock changes including lagged emissions from previous deforestation events; mineralisation of soil nitrogen associated with the land-use change; emissions from burning biomass on deforested land; and removals from biomass growth of the new land use, which accumulates at the rates given in chapter 6, table 6.1.5.

The estimated area reported under *Deforestation* for 2016 was 3,713 hectares. This is 31.4 per cent lower than the 5,417 hectares reported for 2015, resulting in lower emissions reported under *Deforestation* in 2016.

Table 11.3.2 shows the areas of *Forest land* subject to *Deforestation* activities since 2008 by forest category.

Table 11.3.2   Area of New Zealand subject to deforestation

	Annual area of deforestation (ha)			
Year	Pre-1990 natural forest	Pre-1990 planted forest	Post-1989 forest	Total
2008	907	3,894	1,102	5,903
2009	2,586	6,143	2,503	11,231
2010	1,894	7,194	1,696	10,785
2011	863	5,847	1,839	8,549
2012	689	7,642	1,166	9,498
2013	594	6,891	2,105	9,589
2014	332	7,684	853	8,868
2015 [P]	874	3,668	875	5,417
2016 [P]	874	2,292	547	3,713

Note: P = provisional figure. Areas as at 31 December. Deforestation differs from that in chapter 6 due to carbon equivalent forests being reported separately.

Figure 11.3.1 shows the annual areas deforested since 1990, by forest category. This illustrates the increase in pre-1990 planted forest deforestation that occurred in the four years leading up to 2008.

While the conversion of land from one land use to another is not uncommon in New Zealand, plantation forest deforestation on the scale seen between 2004 and 2008 was a new phenomenon. Most of the area of planted forest that was deforested from the mid-2000s onwards has subsequently been converted to grassland. This conversion is due in part to the relative profitability of some forms of pastoral farming (particularly dairy farming) compared with forestry, as well as to the anticipated introduction of the NZ ETS.

Figure 11.3.1   New Zealand's annual areas of deforestation from 1990 to 2016
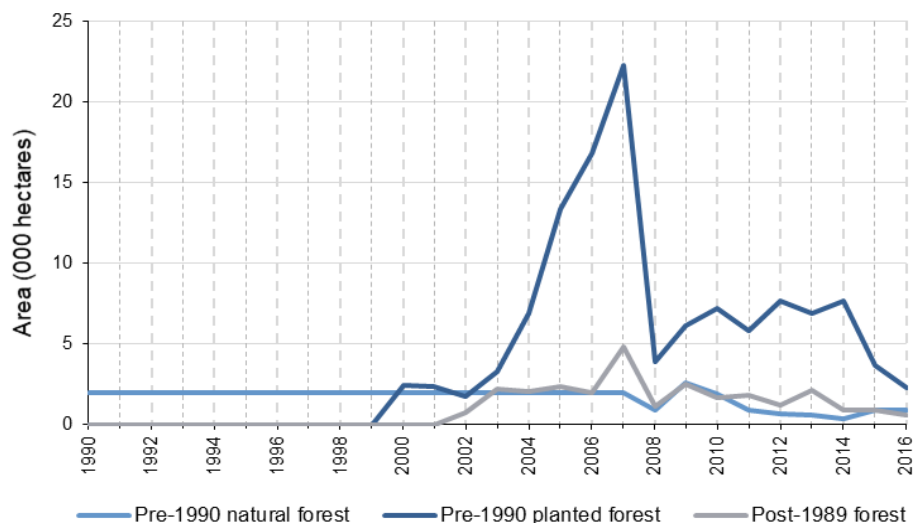
There are no emissions from deforestation of pre-1990 planted forest or post-1989 forest estimated before 2000. This activity was not significant, and insufficient data exist to reliably report the small areas of deforestation that may have occurred.

Since the introduction of the NZ ETS in 2008, owners of pre-1990 planted forest have been able to deforest a maximum of 2 hectares in any five-year period without having to surrender emission units. Above this level of deforestation, they are required to surrender units equal to the reported emissions, with some exemptions for smaller forest owners and tree weeds within protected areas (Ministry for Primary Industries, 2015d). Since 2007, there has been a significant reduction in the rate of deforestation of pre-1990 planted forest. Post-1989 forest owners, who are registered in the scheme, also have legal obligations to surrender units if the carbon stocks in their registered forest area fall below a previously reported level (for example, due to deforestation, harvesting or fire).

It was expected that the level of deforestation during the first Kyoto Protocol commitment period (2008–12) would be less than that seen prior to the introduction of the NZ ETS in 2008 (Manley, 2009). However, following the introduction of the NZ ETS, the carbon price went into a steady decline. The low carbon price reduced the liability on pre-1990 planted forest owners for deforestation. Consequently, more deforestation has occurred since 2008 than previously expected. The exclusion of international units from the scheme on 31 May 2015, the conclusion of the NZ ETS review and the implementation of some of its findings have contributed to higher carbon prices. These higher carbon prices are coincident with reduced deforestation activities and the first participants of the domestic version of the carbon equivalent forests provision, which is now available within the NZ ETS.

The area of deforestation of pre-1990 natural forest prior to 2008 has been estimated by linear interpolation from the average land-use change mapped between 1 January 1990 and 1 January 2008. However, a number of factors suggest that the rate of pre-1990 natural forest deforestation is unlikely to have been constant over the 18-year period between 1990 and 2007, but instead mostly occurred prior to 2002. The area available for harvesting (and potentially deforestation) was higher before 1993 when amendments were made to the Forests Act 1949 that restricted natural forest harvesting. Further restrictions on the harvesting of natural forests were also introduced in 2002, resulting in the cessation of harvesting of publicly owned forests on the West Coast of New Zealand from that time on. Both of these developments are likely to have reduced pre-1990 natural forest deforestation since 2002.

Further detail on the methods employed for estimating deforestation is provided in chapter 6, section 6.2.3.

11.3.4 Forest management CRF 4(KP.B.1))

New Zealand reports emissions and removals from *Forest management* from 2013 onwards. New Zealand has applied the broad approach to interpreting the definition of forest management so that it includes the whole area classified as pre-1990 natural forest and pre-1990 planted forest. The area in this category excludes any area deforested since 1990, as this is reported under Article 3.3 – *Deforestation*, and includes areas to which the carbon equivalent forest provision is applied.

In 2016, emissions on this land were –14,858.1 kt CO_2-e. This included emissions of –9,500.1 kt CO_2-e from *Harvested wood products* originating from *Forest management*. The total area remaining in *Forest management* at the end of 2016 was 9,249,653 hectares; this is a decrease of 164,155 hectares (or 1.7 per cent) since 1990.

The source of the activity data and emission factors applied to *Forest management* activities is described in more detail in chapter 6, sections 6.2 and 6.4.

As agreed in Decision 2/CMP.7 (UNFCCC, 2012), accounting for *Forest management* is now mandatory and measured against the Forest Management Reference Level (FMRL) inscribed in the appendix to the annex to Decision 2/CMP.7 (UNFCCC, 2012). This means New Zealand is only required to take responsibility for emissions from land under *Forest management* where these emissions are greater than the reference level, and can claim reductions where emissions are less than the reference level (up to a cap set at 3.5 per cent of New Zealand's gross emissions in the base year). New Zealand's FMRL is 11.150 megatonnes (Mt) CO_2-e per year. It was set using a business-as-usual projection of emissions for *Forest management* over the period to 2020 and represents the estimated annual average emissions between 2013 and 2020. Technical corrections to the FMRL as required by Decision 2/CMP.7, Annex I, para 14 (UNFCCC, 2012) were made in the 2016 submission. Details of these corrections are provided in annex 5.1. New Zealand has decided not to make any additional technical corrections for the 2018 submission, as discussed below.

The emissions for *Forest management* in 2013, 2014, 2015 and 2016 were lower than the $FMRL_{corr}$ (technically corrected FMRL) of –6.10 Mt CO_2-e (as New Zealand's removals were higher). This is expected because the FMRL is the estimated annual average over the eight years from 2013 to 2020 inclusive, and over this period New Zealand expects harvesting of pre-1990 planted forest to increase, which will mean emissions from *Forest management* will also increase.

Technical corrections to the Forest Management Reference Level

New Zealand's FMRL, as inscribed in the appendix to the annex to Decision 2/CMP.7 (UNFCCC, 2012), is 11.150 Mt CO_2-e. For the 2016 submission, New Zealand submitted a technical correction of –17.25 Mt CO_2-e to achieve consistency with the methods used for reporting of *Forest management*, including incorporating changes to *Harvested wood products*.

New Zealand has not made any further technical corrections for this submission. This is because the changes to data that would make a technical correction for each reporting year necessary, such as changes to the area under forest management, are still provisional for the latest reporting years. New Zealand will also be making ongoing changes to the reporting of *Harvested wood products* as improved activity data are collected and estimates further refined. For this reason, New Zealand will wait until the 2019 submission to make further technical corrections.

Carbon equivalent forests

New Zealand is reporting emissions under the carbon equivalent forest provision for the first time in this submission. The carbon equivalent forest provision allows pre-1990 planted forests that meet the conditions specified in Decision 2/CMP.7 paragraph 37 (UNFCCC, 2012) to be

harvested and converted to another land use without being classified as deforested, provided a new forest that will reach carbon equivalence is established elsewhere.

Table 11.3.3   **Carbon equivalent forests (2013–16)**

	2013	2014	2015	2016	Total
CEF_{HC} area (kha)	Nil	0.04	0.5	1.2	**1.7**
Net emissions (kt CO_2)	NA	33.3	391.9	919.8	**1,345.0**
CEF_{NE} area (kha)	NIL	NIL	NIL	0.8	**0.8**
Net emissions (kt CO_2)	NA	NA	NA	−0.004	**−0.004**
Total (kt CO_2)	**NA**	**33.3**	**391.9**	**919.8**	**1,345.0**

Note: CEF_{HC} refers to the existing forest land that is harvested and converted to non-forest land; CEF_{NE} refers to the non-forest land on which a forest is newly established. Columns may not total due to rounding. Disaggregated data on the application of the provision are provided in annex 5.3.

The carbon equivalent forest provision is administered domestically by the New Zealand Ministry for Primary Industries as part of the NZ ETS. The domestic carbon equivalent forest rules are broadly aligned with those in the Kyoto Protocol Supplement (IPCC, 2014a). Misalignments between the domestic and international rulesets include:

- domestically, the carbon equivalent forest can be established before the forest land is converted to another land use, and

- the newly established carbon equivalent forest can be established on land that was forested on 31 December 1989.

Where these misalignments are detected these activities are instead reported as separate afforestation and deforestation events.

Emissions from the conversion of forest land under the carbon equivalent forest provision are calculated as a deforestation event. In calculating these emissions, all biomass is instantly emitted at the time of conversion and soil organic carbon changes due to land-use change are accounted for. The emissions from the establishment of the new forest under the provision are calculated as an afforestation event and include biomass loss and soil organic carbon changes resulting from this land-use change. Net emissions from the activities are reported under *Forest management* and monitored over time to ensure carbon equivalence.

The carbon equivalent forest provision creates a misalignment for the afforestation and deforestation area reported under the Kyoto Protocol and the UNFCCC sections of the inventory. The carbon equivalent forest provision is not recognised under the UNFCCC and is reported as *Land converted to forest land* (afforestation) and *Forest land converted to other land uses* (deforestation).

11.3.5 Voluntary activities under Article 3.4

New Zealand has not elected to report on any voluntary activities under Article 3.4 of the Kyoto Protocol.

11.3.6 Harvested wood products (CRF 4(KP-I)C)

The *Harvested wood products* category comprises all wood material that leaves a harvest site and is subsequently processed. This wood constitutes a carbon reservoir (section 12.1, IPCC, 2006a).

New Zealand is required to report changes in the harvested wood products pool under the Kyoto Protocol from 2013. For *Afforestation and reforestation* and *Forest management*, estimates are

derived from a modified Intergovernmental Panel on Climate Change (IPCC) Convention reporting model. The emissions from *Harvested wood products* originating from *Deforestation* activities are instantly oxidised.

Harvested wood product emissions for 2016 for *Afforestation and reforestation* were –1,343.5 kt CO_2-e; and for *Forest management* they were –9,500.1 kt CO_2-e.

New Zealand has a large planted forest estate that provides most wood products consumed domestically and exported in either product or raw material form. A more detailed description of the forest estate and New Zealand wood use is provided in chapter 6, section 6.10.

New Zealand has developed a Tier 2 method to report *Harvested wood products* under the Kyoto Protocol. New Zealand uses the default Tier 2 methodology, as described in the IPCC guidance (IPCC, 2014a), and some country-specific activity data and parameters where available. IPCC default half-lives and some conversion factors are used. Country-specific conversion factors are used for domestically produced sawnwood and veneer sheets (see chapter 6, table 6.10.1).

Data on the production, import and export of harvested wood products from 1990 to 2016 were sourced from the FAO Statistics database (FAOSTAT). These data are provided to the FAO by the Ministry for Primary Industries. The basic data are the same as those used for IPCC Convention reporting, except the time series begins in 1990 for *Afforestation and reforestation* and 2013 for *Forest management*. Also, the *Solid wood* category used for IPCC Convention reporting is disaggregated into *Sawnwood* and *Panels* for Kyoto Protocol reporting. Errors within the data sourced from FAOSTAT were corrected and missing data were added, using data directly from the Ministry for Primary Industries.

In 2016, a large proportion (over 50 per cent) of New Zealand's harvest was exported as raw materials in the form of logs or wood chips (Ministry for Primary Industries, 2017). The FAOSTAT database provides data on the export quantity of raw materials but provides no information on the conversion of these materials to products and their expected half-lives. A project was completed in 2016 to provide information on harvested wood products from exported logs in New Zealand's three main export markets (China, South Korea and India). The study found that most New Zealand wood is converted into construction and packaging materials. Therefore, weighted half-lives were found to be 6.6 years, 18 years and 2.5 years for China, South Korea and India respectively (Ministry for Primary Industries, 2016b). The weighted half-lives for China and India are significantly lower than the IPCC default half-lives for sawnwood and panels (35 years and 25 years respectively). These findings have now been included in New Zealand's *Harvested wood products* estimates and provide an improvement on the previous assumption of instant emission for exported raw materials.

Emissions from the harvest of *Afforestation and reforestation* land are reported from 1990 onwards. These lands provide a small contribution to *Harvested wood products* because most post-1989 planted forest is yet to reach harvest age. Harvested wood products originating from these lands are estimated by prorating the proportion of *Afforestation and reforestation* harvest emissions to total harvest emissions (excluding *Deforestation*).

Emissions from the harvest occurring on *Forest management* land, specifically pre-1990 planted forest, are estimated from 2013 onwards, and these lands currently provide around 85 per cent of New Zealand's annual harvest in terms of their contribution to emissions. Harvested wood products originating from these lands are estimated by prorating the proportion of *Forest management* harvest emissions to total harvest emissions (excluding *Deforestation*). Accounting of harvested wood products on these lands is against New Zealand's projected FMRL and, therefore, emissions from harvest occurring prior to 2013 are excluded.

Harvested wood products originating from *Deforestation* are instantly emitted, as required under the Kyoto Protocol; however, the production statistics do not identify whether the products were derived originally from the wood that was harvested as part of the deforestation activity. The share of harvest volume originating from *Deforestation* is estimated by comparing emissions from *Deforestation* with emissions from harvesting. This provides a proportion to apply to the production statistics to separate harvested wood products originating from *Deforestation*.

Non-forest harvest is treated as an instant emission. Harvest from these lands is assumed to be used for fuel wood. Therefore, the harvested wood products contribution from non-forest lands is assumed to be zero.

11.3.7 Other greenhouse gas sources

Direct nitrous oxide emissions from nitrogen fertilisation (CRF 4(KP-II)1)

New Zealand's activity data on nitrogen fertilisation are not currently disaggregated by land use; therefore, all nitrous oxide (N_2O) emissions from nitrogen fertilisation are reported in the Agriculture sector under the category *Direct N2O emissions from managed soils* (CRF 3.D). The notation key IE (included elsewhere) is reported in the common reporting format (CRF) tables for the KP-LULUCF sector (section 2.4.4.2, IPCC, 2014a).

Methane and nitrous oxide emissions from drained and rewetted organic soils (CRF 4(KP-II)2)

The methodology for estimating these emissions is contained within the *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands* (IPCC, 2014b). This supplement was not adopted by the Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol and, as such, its use is voluntary unless a country has elected 'Wetland drainage and rewetting'. Given this, New Zealand reports NE (not estimated) in the CRF table for methane and N_2O emissions from drained and rewetted organic soils.

Nitrous oxide emissions from nitrogen mineralisation and immobilisation associated with land-use conversions and management in mineral soils (CRF 4(KP-II)3)

Nitrous oxide emissions, resulting from nitrogen mineralisation and immobilisation associated with land conversion, are reported for *Afforestation and reforestation*, *Deforestation* and *Forest management*. These are calculated following the IPCC Guidelines (IPCC, 2006a). Total emissions for these three activities are 0.2 kt N_2O.

Emissions associated with *Indirect N₂O emissions from managed soils* are also reported under the Agriculture sector. New Zealand reports IE (included elsewhere) in the relevant CRF tables.

Biomass burning (CRF 4(KP-II)4)

Afforestation and reforestation

Non-carbon dioxide emissions from wildfires in *Land converted to forest land* are reported under *Afforestation and reforestation*. The activity data do not distinguish between *Forest land* categories (*Afforestation and reforestation* or *Forest management*); therefore, non-CO_2 emissions resulting from wildfire are attributed to *Afforestation and reforestation* by the proportion of the total planted forest area that these forests make up. An age-based carbon yield table is then used to estimate non-CO_2 emissions for *Afforestation and reforestation* land. This approach assumes that the carbon stock affected by wildfire is equivalent to the carbon stock at the average stand age

each year throughout the time series (Wakelin, unpublished(a)). Carbon dioxide emissions resulting from wildfire events are reported as IE (included elsewhere) in the CRF table because these are assumed to be captured in the harvest emissions of salvage logged stands.

A survey of controlled burning activities in planted forests was carried out in 2011. The survey indicated that, on average, 5 per cent of conversions to planted forest between 1990 and 2011 involved burning to clear vegetation. This area is allocated to *Forest management* (*Land converted from natural forest*) and *Afforestation* (*Land converted from grassland with woody biomass*) on a pro rata basis (Wakelin, unpublished(b)).

It is understood that controlled burning of post-harvest residues prior to replanting on *Afforestation* land does not occur due to the nature of harvest in short-rotation forest grown for pulp (where most biomass is removed from the site). However, this assumption will be revisited for the 2019 submission as the harvest rate in these forests increases.

Deforestation

An estimate is provided for controlled burning of post-harvest slash associated with *Deforestation*. No information is available on the extent of burning associated with *Deforestation* in New Zealand. Therefore, it is assumed that 30 per cent of conversions involve burning. This percentage is chosen as a conservative proportion of one of the four main methods for disposing of residues in New Zealand. The other methods for residue disposal are chipping and removal, mulching into the soil and leaving to decay (Goulding, unpublished). To estimate emissions from the burning of harvest residue, the IPCC default combustion proportion for non-eucalypt temperate forest (0.62) is applied to an emission factor derived from the national plot network (table 2.6, IPCC, 2006a). The emission factor excludes the proportion of logs taken offsite (70 per cent of above-ground biomass) and is taken from the relevant yield tables at the average age of harvest in New Zealand.

Estimates are provided for wildfire on deforested land (forest land converted to grassland) in the inventory. The activity data do not identify deforested land; therefore, non-CO_2 emissions resulting from wildfire are attributed to deforested land by the proportion of area that deforested land makes up of the total *Grassland* area. The methodology follows that described in chapter 6, section 6.11.5. Around 1 per cent of wildfire emissions in *Grassland* are estimated to have occurred on deforested land between 2008 and 2016.

Forest management

Non-CO_2 emissions from wildfires in pre-1990 forest land are reported under *Forest management*. A plot-network-derived biomass density is used to estimate non-CO_2 emissions from wildfire on *Forest management* land. Aggregated wildfire activity data are attributed to each forest management category by proportion of forest type estimated to be burned over the time series. The split attributes 87.5 per cent to planted forest and the remaining to natural forest (Wakelin, unpublished(a)). The planted forest activity data are further split into pre-1990 and post-1989 forest (see 'Afforestation and reforestation' above). In planted forest, it is assumed that the carbon stock affected by wildfire is equivalent to the carbon stock at the average stand age in each category (Wakelin, unpublished(a)).

A survey of controlled burning in planted forest was carried out in 2011 (Wakelin, unpublished(b)). Estimates were provided for burning associated with the clearing of vegetation (i.e., natural forest and grassland with woody biomass) prior to the establishment of exotic planted forest (see 'Afforestation and reforestation' above).

The survey also provided data on the burning of post-harvest slash prior to restocking. This activity was found to occur mainly as a training exercise for wildfire control or for the clearing of slash heaps on skid sites. The data indicated that 0.8 per cent of restocked area was burned annually in recent years (Wakelin, unpublished(b)). This estimate was combined with two

earlier estimates of controlled burning in planted forest (Forest Industry Training and Education Council, 2005; Robertson, 1998) to provide activity data throughout the time series. It is assumed that 1.6 per cent of restocked area was burned from 1990 to 1997 (Wakelin, unpublished(b)). From 1997, the area burned declines linearly to 0.8 per cent, which is used from 2005 onwards (Wakelin, unpublished(b)).

A more detailed description of *Biomass burning* on *Forest land* is provided in chapter 6, section 6.11.5.

11.4 Other methodological issues

11.4.1 Uncertainty and time-series consistency

The uncertainty in net emissions from *Afforestation and reforestation* is ±23.7 per cent. This is based on the uncertainty in emissions from post-1989 forest and a small contribution from *Harvested wood products* (tables 11.4.1 and 11.4.2).

The uncertainty in emissions from *Deforestation* is determined by the type of *Forest land* (table 11.4.1). The combined uncertainty introduced into emissions from *Deforestation* is ±1.7 per cent (table 11.4.2).

The combined uncertainty in *Forest management* is ±58.3 per cent at a 95 per cent confidence interval. This is the combined uncertainty of pre-1990 natural forest and pre-1990 planted forest, and includes uncertainty associated with *Harvested wood products*.

Further detail on the uncertainty in emissions for pre-1990 natural forest, pre-1990 planted forest, post-1989 forest and *Harvested wood products* is provided in chapter 6, sections 6.1.3 and 6.4.3.

Table 11.4.1   **Uncertainty in New Zealand's estimates for afforestation and reforestation, deforestation and forest management in 2016**

| | Uncertainty (%) at a 95% confidence interval | | | | | |
| | Afforestation and reforestation | Deforestation | | | Forest management | |
	Post-1989 forest	Pre-1990 natural forest	Pre-1990 planted forest	Post-1989 forest	Pre-1990 natural forest	Pre-1990 planted forest
Activity data						
Uncertainty in land area	±8.0	±5.0	±5.0	±5.0	±5.0	±5.0
Emission factors						
Uncertainty in biomass carbon stocks	±29.2	±6.7	±11.4	±29.2	±6.7	±11.4
Uncertainty in soil carbon stocks	±10.4	±7.9	±12.3	±10.4	±7.9	±12.3
Uncertainty in harvested wood products	±51.3	–	–	–	–	±51.3
Uncertainty introduced into emissions for Kyoto Protocol	**±23.7**	**±0.2**	**±1.5**	**±0.2**	**±41.3**	**±41.1**

Note: All land that has been afforested or reforested since 1 January 1990 is defined as post-1989 forest. Land deforested since 1 January 1990 may be pre-1990 natural forest, pre-1990 planted forest or post-1989 forest.

Total uncertainty in New Zealand's estimates of emissions for Article 3.3 and Article 3.4 of the Kyoto Protocol is ±62.9 per cent at a 95 per cent confidence interval.

Table 11.4.2   Total uncertainty in New Zealand's estimates for afforestation and reforestation, deforestation and forest management in 2016

Variable	Uncertainty (%) at a 95% confidence interval
Afforestation and reforestation uncertainty introduced into emissions for Kyoto Protocol	±23.7
Deforestation uncertainty introduced into emissions for Kyoto Protocol	±1.7
Forest management uncertainty introduced into emissions for Kyoto Protocol	±58.3
Total uncertainty for Kyoto Protocol	**±62.9**

11.4.2 Quality control and quality assurance

Quality-control and quality-assurance procedures have been adopted for all data collection and data analyses, to be consistent with the *IPCC General Guidance and Reporting* (IPCC, 2006b) and New Zealand's inventory quality-control and quality-assurance plan. Quality-control and quality-assurance plans were established for each type of data used to determine carbon stock and stock changes, as well as the areal extent and spatial location of land-use changes. All data were subject to an independent and documented quality-assurance process. Data validation rules and reports were established to ensure that all data are fit for purpose and are of consistent and known quality, and that data quality continues to be improved over time. The data used to derive the country-specific yield tables and average carbon values have also undergone quality assurance, as described in chapter 6, section 6.4.4.

11.4.3 Recalculations

New Zealand's greenhouse gas estimates for activities under Article 3.3 of the Kyoto Protocol have been recalculated since the previous submission to incorporate improved activity data and emission factors.

Activity data

Table 11.4.3 shows that there has been an increase in the estimated total area of new planting for 2015 since the last submission. This is due to updated new planting data being provided by the National Exotic Forest Description survey (Ministry for Primary Industries, 2016a).

The total area of deforestation has decreased, compared with the estimate made for the 2017 submission. This is due to mapping improvements completed during the year. The small changes in the estimated deforestation areas for 2015 are also a result of these mapping improvements because the mapped areas of deforestation occurring between 2008 and 2014 contribute to the estimate for 2015. For example, the pre-1990 natural forest deforestation estimate for 2015 is based on the average pre-1990 forest deforestation for the years 2010 to 2014.

Further information on the deforestation mapping process can be found in chapter 6, section 6.2.3.

Activity data associated with the application of the carbon equivalent provision have had a minor impact on the area recalculations.

Table 11.4.3   Recalculations of New Zealand's 2015 activity data under Article 3.3 and
                      Article 3.4 of the Kyoto Protocol

Activities under Article 3.3 of the Kyoto Protocol	Area as at 2015 (ha)		Change from 2017 submission (%)
	2017 submission	2018 submission	
Afforestation and reforestation	647,558	651,567	0.6
Deforestation	188,409	187,969	–0.2
Forest management	9,257,310	9,252,023	–0.1

Activities occurring in 2015	Area change in 2015 (ha)		Change from 2017 submission (%)
New planting	2,471	3,742	51.5
Deforestation			
Pre-1990 natural forest	887	874	–1.4
Pre-1990 planted forest	3,741	3,668	–2.0
Post-1989 forest	796	875	9.9

Emission factors

The post-1989 planted forest yield table has been revised for the 2018 submission. The revised yield table is based on two complete inventories of post-1989 planted forest permanent sample plots and a partial re-measure in 2016. The analysis of the data collected has provided a plot-based estimate of carbon stock and mean carbon density within this forest type, and is further described in section 6.4.2.

Harvested wood products

Since its last submission, New Zealand has revised its harvested wood products model to include the contribution of export logs based on an export markets study. This improvement has had a major impact on the emissions recalculations and has had the greatest impact on *Forest management* activities (table 11.4.4).

Table 11.4.4   Recalculations of New Zealand's total net emissions estimates from 2013
                      under Article 3.3 and Article 3.4 of the Kyoto Protocol

Activities	Total net emissions 2013–15 (Gg CO_2-e)		Change from 2017 submission (%)
	2017 submission	2018 submission	
Afforestation and reforestation	–47,508.6	–51,457.1	–8.3
Deforestation	16,069.9	15,885.6	–1.1
Forest management	–38,604.8	–60,401.9	–56.5
Total	**–70,043.5**	**–95,973.3**	**–37.0**

11.4.4 Planned improvements

The assumption that controlled burning of post-harvest residues on afforested or reforested land does not occur will be revisited for the 2019 submission, due to the increasing harvest rate in these forests as they reach maturity.

The complete planted forest plot network (pre-1990 and post-1989) is currently being re-measured on a continuous basis (at five-year intervals), from 2016 onwards. These data will be incorporated into the inventory annually, as they become available.

Field checking of areas of suspected deforestation on land that was cleared during 2015 and 2016 will occur during the 2017–18 summer season. This will allow actual rather than estimated areas of deforestation to be reported for 2015 and 2016 in the 2019 submission.

11.5 Demonstration that activities apply

11.5.1 Year of the onset of an activity

Paragraph 18 of the annex to Decision 16/CMP.1 (UNFCCC, 2006) requires Parties to account for land use, land-use change and forestry emissions and removals from Article 3.3 activities beginning with the onset of the activity or the beginning of the commitment period, whichever is later. In practical terms, paragraph 18 means there is a need to differentiate activities that occurred between 1 January 1990 and 31 December 2007 from those after this period.

The *Afforestation* area is estimated from the National Exotic Forest Description survey, which includes information from the Afforestation Grant Scheme and the East Coast Forestry Project (Ministry for Primary Industries, 2016a). This information ensures that the activity is attributed to the correct year of onset.

The annual area of *Deforestation* reported from 2008 to 2012 is based on deforestation mapping completed in 2013 and supported by earlier deforestation mapping activities. Deforestation was confirmed using oblique aerial photography, and the year of onset (destocking year) was determined using annual Landsat imagery. Therefore, the year of onset of the activity was clearly defined. Deforestation mapping was also carried out in early 2016 covering activity occurring in the calendar years of 2013 and 2014. The year of onset of activity was determined by identifying the first observation of forest loss visible in Landsat 8 imagery. As no further deforestation mapping was carried out for 2015 and 2016 activity, the total deforestation area for these years has been estimated as described in chapter 6, section 6.2.3.

It can take up to four years following the loss of forest cover to determine that replanting or revegetation has occurred. This is because sometimes the landowner does not replant trees immediately but leaves the land fallow for a period of time. The process for monitoring this unclassified deforestation is described in section 11.5.3. When deforestation is finally confirmed, the deforestation is attributed to the year when forest cover was removed, regardless of whether that forest loss occurred in a previous commitment period.

11.5.2 Distinction between harvesting and deforestation

The reporting guidelines under the Convention require that countries provide information on how harvesting or forest disturbance that is followed by the re-establishment of forest is distinguished from *Deforestation*.

New Zealand has used the definition of *Deforestation* from Decision 16/CMP.1: "the direct human-induced conversion of forested land to non-forested land" (Annex A, UNFCCC, 2006). Deforestation is different from harvesting, in that harvesting is part of usual forest management practice and involves the removal of biomass from a site followed by reforestation (replanting or natural regeneration, i.e., no change in land use).

In New Zealand, temporarily unstocked or cleared areas of forest (e.g., harvested areas and areas subject to disturbances) remain designated as *Forest land* unless there is a confirmed change in land use or if, after four years, no reforestation (replanting or regeneration) has occurred. This follows the process for determining whether land is subject to direct human-induced deforestation set out in section 2.6.2.1 of the Kyoto Protocol Supplement (IPCC, 2014a). New Zealand has defined the expected time period between the removal of tree cover and successful natural regeneration or planting as four years. In New Zealand, the tree grower and landowner are often different people. Forest land can be temporarily unstocked for a number of years while landowners decide what to do with land after harvesting.

A number of activities are carried out to determine if land-use change has occurred, including the analysis of satellite imagery and oblique aerial photography. The use of oblique aerial photography is described in chapter 6, section 6.2.

Evidence from the NZ ETS is also used to confirm *Deforestation*. Under the NZ ETS, owners of pre-1990 planted forest or post-1989 forest who are participants in the scheme are required to notify the Government of any deforestation activity (Ministry for Primary Industries, 2015d). There is a data-sharing agreement that allows for the Ministry for Primary Industries, the agency that administers forestry aspects of the NZ ETS, to provide the Ministry for the Environment with regular updates of the area of confirmed *Deforestation*.

A summary of the decision-making process for determining whether *Deforestation* has occurred, including all sources of information, is shown in figure 11.5.1. Once a land-use change is mapped and confirmed, the *Deforestation* emissions will be reported in the year of forest clearance.

Figure 11.5.1   Verification of deforestation in New Zealand
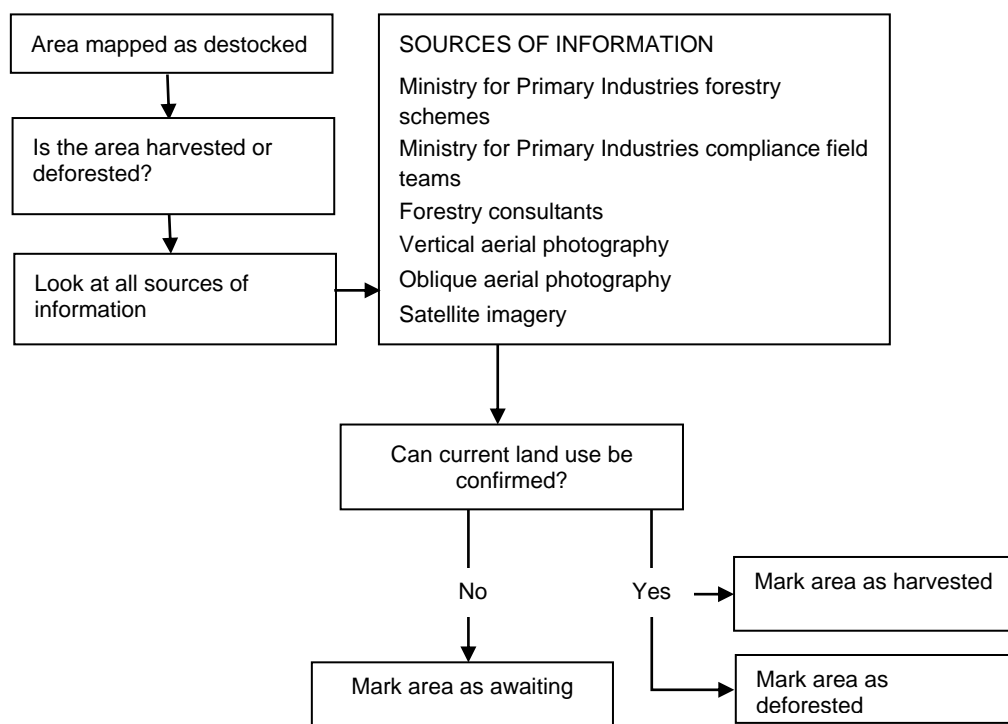
11.5.3 Unclassified deforestation

The reporting guidelines under the Convention require that countries provide information on the size and geographical location of forest areas that have lost forest cover but that are not yet classified as deforested.

To identify these areas, destocked land is mapped into three main classes: harvested, deforested and awaiting. The awaiting areas are those where there is no clear evidence to support harvesting (replanting activity, forestry context) or *Deforestation* (confirmed land-use change, such as pasture establishment, fences and stock). The areas are therefore awaiting a land use determination.

Wall-to-wall mapping of harvested, deforested and awaiting areas was completed for 2008 to 2012. Each year, areas of awaiting land that have been destocked for more than four years are reviewed to determine whether deforestation or replanting has occurred. Where a recent imagery evidence source is available, these awaiting areas are reclassified as either harvested (where there is evidence of replanting) or deforested (where there is evidence of land-use change).

Areas classed as awaiting land are still considered to be forested land until either evidence of land-use change is identified or four years have passed since destocking and the land is

confirmed to be in a new land use (whichever comes first). This is consistent with section 2.6.2.1 of the Kyoto Protocol Supplement (IPCC, 2014a), which states that (p 82):

> In the absence of land-use change (such as conversion to Cropland or construction of settlements) areas without tree cover are considered "forest" provided that the time since forest cover loss is shorter than the number of years within which tree establishment is expected.

Estimates of the total areas of awaiting land for 2012 to 2014 are shown in table 11.5.1.

Table 11.5.1   Estimate of land destocked in New Zealand between 2012 and 2014 awaiting a land use determination

Year of destocking	Pre-1990 natural forest (ha)	Pre-1990 planted forest (ha)	Post-1989 forest (ha)	Total (ha)
2012	1,059	4,207	1,023	6,289
2013	1,493	6,032	1,460	8,984
2014	539	6,803	2,480	9,821

Note: Rows may not total due to rounding.

No estimates of awaiting land for 2015 or 2016 have been made because land use mapping has not been undertaken for these years. The *Deforestation* areas reported for 2015 and 2016 are provisional and based on survey estimates as described in chapter 6, section 6.2.3.

11.6   Other information

11.6.1 Justification when omitting any carbon pool or greenhouse gas emissions from activities under Article 3.3 and Article 3.4

New Zealand has accounted for all carbon pools for mandatory reporting activities under Article 3.3 and Article 3.4 of the Kyoto Protocol. New Zealand has not elected any of the voluntary activities under Article 3.4.

Direct N_2O emissions from nitrogen fertilisation to land subject to *Afforestation and reforestation*, and *Indirect N_2O emissions from managed soils* are reported as IE (included elsewhere), because these emissions are reported in the Agriculture sector.

11.6.2 Factoring out information

New Zealand does not factor out from reporting either emissions or removals from:

- elevated CO_2 concentrations above pre-industrial levels
- indirect nitrogen deposition
- the dynamic effects of age structure resulting from activities prior to 1 January 1990. These are factored out of accounting by the FMRL.

11.6.3 Key category analysis for Article 3.3 and Article 3.4 activities (CRF NIR-3)

Land converted to forest land (*Afforestation and reforestation*), *Land converted to grassland* (*Deforestation*) and *Forest land remaining forest land* (*Forest management*) are all key categories.

11.7   Information relating to Article 6

New Zealand is not involved in any LULUCF activities under Article 6 of the Kyoto Protocol.

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Chapter 12: Information on accounting of the Kyoto Protocol units

12.1 Background information

Assigned amount and commitment period reserve

In January 2008, New Zealand's national registry was issued with New Zealand's assigned amount of 309,564,733 metric tonnes of carbon dioxide equivalent (CO_2-e).

The commitment period reserve for the first commitment period (CP1) of 278,608,260 metric tonnes of CO_2-e is 90 per cent of the assigned amount, fixed after the initial review in 2007.

Holdings and transactions of Kyoto Protocol units

Tables detailing holdings and transactions of commitment period units have been submitted to the United Nations Framework Convention on Climate Change (UNFCCC) Secretariat electronically, and are also provided in the MS Excel worksheets available for download with this report from the Ministry for the Environment's website (www.mfe.govt.nz/publications/climate).

General note

Abbreviations used in this chapter include:
AAUs   Assigned amount units
ERUs   Emission reduction units
RMUs   Removal units
CERs   Certified emission reduction units
tCERS   Temporary certified emission reduction units
lCERs   Long-term certified emission reduction units
CDM   Clean Development Mechanism

12.2 Summary of the standard electronic format tables for reporting Kyoto Protocol units

At the beginning of the calendar year 2017, New Zealand's national registry held 308,343,858 CP1 AAUs, 110,744,560 CP1 ERUs, 21,685,909 CP1 CERs and 100,845,399 CP1 RMUs. No second commitment period (CP2) units were held by New Zealand in 2017.

At the end of 2017, the units held in New Zealand's national registry remained at 308,343,858 AAUs, 110,744,560 ERUs, 21,685,909 CERs and 100,845,399 RMUs.

New Zealand's national registry did not hold any tCERS or lCERs during 2017.

The transactions made to New Zealand's national registry during 2017 are summarised below.

- No external transfers of Kyoto units occurred. A total of 11,333 AAUs and 5,283 ERUs were subtracted internally through voluntary cancellation. There were no conversions to ERUs. No CP2 Kyoto units were held by New Zealand during the 2017 year.

Table 12.2.1   New Zealand's submission of the standard electronic format

Annual submission item	New Zealand's national registry response
15/CMP.1 annex I.E paragraph 11: Standard electronic format (SEF)	The standard electronic format reports for 2017 first and second commitment period units have been submitted to the UNFCCC Secretariat electronically.

12.3 Discrepancies and notifications

New Zealand has not received any notification of discrepancies, failures or invalid units,

Table 12.3.1   Discrepancies and notifications from New Zealand's national registry

Annual submission item	New Zealand's national registry response
15/CMP.1 annex I.E, paragraph 12: List of discrepant transactions	No discrepant transactions occurred in 2017.
15/CMP.1 annex I.E, paragraph 13 & 14: List of CDM notifications	No CDM notifications occurred in 2017.
15/CMP.1 annex I.E, paragraph 1 15: List of non-replacements	No non-replacements occurred in 2017.
15/CMP.1 annex I.E, paragraph 1 15: List of invalid units	No invalid units exist as at 31 December 2017.
15/CMP.1 annex I.E, paragraph 1 17: Actions and changes to address discrepancies	No actions were taken or changes made to address discrepancies for the period under review.

12.4 Publicly accessible information

New Zealand's national registry list of publicly accessible information is available at www.emissionsregister.govt.nz, 'Public information and reports' link. A list of publicly accessible information is provided in table 12.4.1.

Table 12.4.1   List of the publicly accessible information in New Zealand's national registry

Type of information to be made public pursuant to part E of the annex to 13/CMP.1, paragraphs 44 to 48	Publicly available on New Zealand's national registry website (refer www.emissionsregister. govt.nz Public information and reports) (yes/no/partial)	Timing of information to be made available under New Zealand's Climate Change Response Act 2002	Relevant reference to New Zealand's Climate Change Response Act 2002 where information is not publicly available in accordance with paragraphs 44 to 48
44. Each national registry shall make non-confidential information publicly available and provide a publicly accessible user interface through the Internet that allows interested persons to query and view it.	Details of information availability are provided below.		
45. The information referred to in paragraph 44 above shall include up-to-date information for each account number in that registry on the following:			
(a) Account name: the holder of the account.	Yes (refer Public information and reports: Accounts).	Up to date (note, refreshed daily)	n/a
(b) Account type: the type of account (holding, cancellation or retirement).	Yes (refer Public information and reports: Accounts).	Up to date (note, refreshed daily)	n/a

Type of information to be made public pursuant to part E of the annex to 13/CMP.1, paragraphs 44 to 48	Publicly available on New Zealand's national registry website (refer www.emissionsregister. govt.nz Public information and reports) (yes/no/partial)	Timing of information to be made available under New Zealand's Climate Change Response Act 2002	Relevant reference to New Zealand's Climate Change Response Act 2002 where information is not publicly available in accordance with paragraphs 44 to 48
(c) Commitment period: the commitment period with which a cancellation or retirement account is associated.	Yes (refer Public information and reports: Accounts).	Up to date (note, refreshed daily)	n/a
(d) Representative identifier: the representative of the account holder, using the Party identifier (the two-letter country code defined by ISO 3166) and a number unique to that representative within the Party's registry.	No – the representative identifiers for representatives are not publicly available and have been withheld for security reasons.	n/a	Section 27(1)(a) of the Climate Change Response Act 2002 does not require this information to be made publicly available. Only the holding account number for each account in the registry is publicly available under this section.
(e) Representative name and contact information: the full name, mailing address, telephone number, facsimile number and email address of the representative of the account holder.	Partial – publication of the mailing address, email addresses, telephone numbers and facsimile number of the representatives has been withheld for security reasons. (Refer Public information and reports: Accounts.)	Up to date (note, refreshed daily)	Section 13 of the Climate Change Response Act 2002 permits the Registrar to withhold access to the email address and phone and fax numbers of account holder's representatives on the grounds of security or integrity of the registry.
46. The information referred to in paragraph 44 shall include the following Article 6 project information, for each project identifier against which the Party has issued ERUs:			
(a) Project name: a unique name for the project.	Yes (refer Public information and reports: Joint implementation (JI) projects).	Up to date	n/a
(b) Project location: the Party and town or region in which the project is located.	Yes (refer Public information and reports: Joint implementation (JI) projects).	Up to date	n/a
(c) Years of ERU issuance: the years when ERUs have been issued as a result of the Article 6 project.	Yes (refer Public information and reports: Ministers' directions, which lists directions relating to the transfer of emission reduction units to individual JI Projects. The New Zealand Emission Trading Register Unit Holding and Transaction Summary Report shows in aggregate the total ERUs converted from AAUs by year).	Joint implementation projects annually by 31 January for the previous calendar year Ministers' directions – up to date (note, refreshed daily)	n/a

Type of information to be made public pursuant to part E of the annex to 13/CMP.1, paragraphs 44 to 48	Publicly available on New Zealand's national registry website (refer www.emissionsregister.govt.nz **Public information and reports) (yes/no/partial)**	Timing of information to be made available under New Zealand's Climate Change Response Act 2002	Relevant reference to New Zealand's Climate Change Response Act 2002 where information is not publicly available in accordance with paragraphs 44 to 48
(d) Reports: downloadable electronic versions of all publicly available documentation relating to the project, including proposals, monitoring, verification and issuance of ERUs, where relevant, subject to the confidentiality provisions in decision 9/CMP.1.	Partial – some of this information is published on the Ministry for the Environment's website for JI projects at www.mfe.govt.nz/climate-change/reducing-greenhouse-gas-emissions/former-government-initiatives. This provides a link to the project documentation on the UNFCCC site and is not replicated on the New Zealand's national registry website. The following information for each JI project is published on the Ministry for the Environment website: • project description • non-host party project approval • annual reports • verification reports. Project proposals are not included as they contain financial information that is considered to be commercially sensitive and confidential.	This information becomes publicly available once New Zealand gives its approval to the JI project. The information is then updated when necessary and annual reports are added annually.	n/a
47. The information referred to in paragraph 44 shall include the following holding and transaction information relevant to the national registry, by serial number, for each calendar year (defined according to Greenwich Mean Time):			
(a) The total quantity of ERUs, CERs, AAUs and RMUs in each account at the beginning of the year.	Partial – aggregate unit holdings of ERUs, CERs, AAUs and RMUs for the previous calendar year are disclosed by 31 January of each year (refer Public information and reports: Holding & transaction summary). Total quantity of unit holdings in each account within the most recent calendar year is considered to be confidential information. Therefore the total quantity of unit holdings in each account provided consists of only those completed more than one year in the past.	Annually by 31 January for the previous calendar year 1 January for the beginning of the previous calendar year	Section 27(2) of the Climate Change Response Act 2002 requires total holdings of AAUs, ERUs, CERs, ICERs, tCERs and RMUs to be publicly available by 31 January of each year for the previous calendar year. Section 27(3) of the Climate Change Response Act 2002 only requires holdings of Kyoto units by each holding account for the beginning of the previous calendar year to be made publicly available.

Type of information to be made public pursuant to part E of the annex to 13/CMP.1, paragraphs 44 to 48	Publicly available on New Zealand's national registry website (refer www.emissionsregister. govt.nz Public information and reports) (yes/no/partial)	Timing of information to be made available under New Zealand's Climate Change Response Act 2002	Relevant reference to New Zealand's Climate Change Response Act 2002 where information is not publicly available in accordance with paragraphs 44 to 48
	(Refer Public information and reports: Kyoto unit holdings by account. Use Search Criteria to find information about more than one year in the past.)		
(b) The total quantity of AAUs issued on the basis of the assigned amount pursuant to Article 3, paragraphs 7 and 8.	Yes (refer Public information and reports: Holding & transaction summary).	Annually by 31 January for the previous calendar year	n/a
(c) The total quantity of ERUs issued on the basis of Article 6 projects.	Yes (refer Public information and reports: Holding & transaction summary – Units converted to).	Annually by 31 January for the previous calendar year	n/a
(d) The total quantity of ERUs, CERs, AAUs and RMUs acquired from other registries and the identity of the transferring accounts and registries.	Partial – the total quantity of ERUs, CERs, AAUs and RMUs acquired from other registries, and the identity of the registries is publicly available by 31 January for the previous calendar year (refer Public information and reports: Incoming transactions by year). The identity of the individual transferring accounts is not available as it is considered to be confidential information.	Annually by 31 January for the previous calendar year	n/a Section 27(j) of the Climate Change Response Act 2002 requires that only the following be made publicly available: • total quantity of units transferred • total quantity and type of unit transferred • the identity of the transferring overseas registries, including the total quantity of units transferred from each overseas registry and each type of unit transferred from each overseas registry.
(e) The total quantity of RMUs issued on the basis of each activity under Article 3, paragraphs 3 and 4.	Yes (refer Public information and reports: Holding & transaction summary).	Annually by 31 January for the previous calendar year	n/a
(f) The total quantity of ERUs, CERs, AAUs and RMUs transferred to other registries and the identity of the acquiring accounts and registries.	Partial – the total quantity of ERUs, CERs, AAUs and RMUs transferred to other registries, and the identity of the registries are publicly available by 31 January for the previous calendar year (refer Public information and reports: Outgoing transactions by year). The identity of the individual acquiring accounts is not available as it is considered to be confidential information.	Annually by 31 January for the previous calendar year	n/a Section 27(k) of the Climate Change Response Act 2002 requires that only the following be publicly available: • total quantity of units transferred • total quantity and type of unit transferred • the identity of the acquiring overseas registries, including the total quantity of units transferred to each overseas registry and each

Type of information to be made public pursuant to part E of the annex to 13/CMP.1, paragraphs 44 to 48	Publicly available on New Zealand's national registry website (refer www.emissionsregister.govt.nz Public information and reports) (yes/no/partial)	Timing of information to be made available under New Zealand's Climate Change Response Act 2002	Relevant reference to New Zealand's Climate Change Response Act 2002 where information is not publicly available in accordance with paragraphs 44 to 48
			type of unit transferred to each overseas registry.
(g) The total quantity of ERUs, CERs, AAUs and RMUs cancelled on the basis of activities under Article 3, paragraphs 3 and 4.	Yes (refer Public information and reports: Holding & transaction summary).	Annually by 31 January for the previous calendar year	n/a
(h) The total quantity of ERUs, CERs, AAUs and RMUs cancelled following determination by the Compliance Committee that the Party is not in compliance with its commitment under Article 3, paragraph 1.	Yes (refer Public information and reports: Holding & transaction summary). NOTE: Reported as '0' because this event did not occur in the specified period.	Annually by 31 January for the previous calendar year	n/a
(i) The total quantity of other ERUs, CERs, AAUs and RMUs cancelled.	Yes (refer Public information and reports: Holding & transaction summary).	Annually by 31 January for the previous calendar year	n/a
(j) The total quantity of ERUs, CERs, AAUs and RMUs retired.	Yes (refer Public information and reports: Holding & transaction summary).	Annually by 31 January for the previous calendar year	n/a
(k) The total quantity of ERUs, CERs, and AAUs carried over from the previous commitment period.	Yes (refer Public information and reports: Holding & transaction summary). NOTE: Reported as '0' because this event did not occur in the specified period.	Annually by 31 January for the previous calendar year	n/a
(l) Current holdings of ERUs, CERs, AAUs and RMUs in each account.	Partial – aggregate unit holdings of ERUs, CERs, AAUs and RMUs from the previous calendar year are disclosed by 31 January (refer Public information and reports: Kyoto unit holdings by account). Total quantity of unit holdings in each account within the most recent calendar year is considered to be confidential information. Therefore the total quantity of unit holdings in each account provided consists of only those completed more than one year in the past. (Refer Public information and reports: Kyoto unit holdings by account.)	Annually by 31 January for the previous calendar year 1 January for the beginning of the previous calendar year	Section 27(2) of the Climate Change Response Act 2002 only requires total holdings of AAUs, ERUs, CERs, ICERs, tCERs and RMUs to be publicly available by 31 January of each year for the previous calendar year. Section 27(3) of the Climate Change Response Act 2002 only requires holdings of Kyoto units by each holding account for the beginning of the previous calendar year to be made publicly available.
48. The information referred to in paragraph 44 shall include a list of legal entities authorised by the Party to hold ERUs, CERs, AAUs and/or RMUs under its responsibility.	Yes (refer Public information and reports: Account holders for list of authorised entities).	Up to date (note, refreshed daily)	n/a

12.5 Calculation of the commitment period reserve

New Zealand's commitment period reserve calculation is based on the assigned amount for the first commitment period and is therefore fixed. The commitment period reserve is 278,608,260 metric tonnes of CO_2-e, 90 per cent of the assigned amount of 309,564,733, fixed after the review of *New Zealand's Initial Report under the Kyoto Protocol* (Ministry for the Environment, 2006).

The commitment period reserve level as at 31 December 2017 is:

Commitment period reserve (CPR) limit:	278,608,260
Units held:	515,587,481
Commitment period reserve level:	515,587,481
Commitment period reserve level = (% of assigned amount):	185.06%
CPR level comprises the following units:	
AAUs	308,273,566
ERUs (converted from AAUs)	110,450,922
CERs	16,262,930
RMUs	80,600,063
Total units	515,587,481

Chapter 12: Reference

Ministry for the Environment. 2006. *New Zealand's Initial Report under the Kyoto Protocol.* Wellington: Ministry for the Environment. Retrieved from www.mfe.govt.nz/publications/climate/new-zealands-initial-report-under-the-kyoto-protocol/index.html (17 February 2016).

Chapter 13: Information on changes to the National Inventory System

No changes have been made in the legal or institutional arrangements in the National Inventory System since the last (2017) inventory submission. However, changes are planned for between 2018 and 2020, as a result of New Zealand extending its ratification of the Paris Agreement to include Tokelau.

New Zealand ratified the Paris Agreement on 4 October 2016. On 14 November 2017, New Zealand extended its ratification of the United Nations Framework Convention on Climate Change and of the Paris Agreement to include Tokelau, with implications for including Tokelau in the obligatory climate change reporting managed by the New Zealand Ministry for the Environment. Delivering on this obligation, among others, means that New Zealand's greenhouse gas (GHG) inventory would include the GHG estimates from Tokelau.

In January 2018, New Zealand's Ministry for the Environment and Ministry of Foreign Affairs and Trade and the Tokelau Climate Change Programme initiated the project to include Tokelau into New Zealand's National GHG Inventory System (project GHG-Tokelau). The relevant memorandum of understanding between New Zealand and Tokelau has been signed (18 January 2018) and the detailed project plan has been developed. It is expected the entire project will be completed within the next two years.

The purpose of project GHG-Tokelau is to investigate how the New Zealand Government could incorporate reporting for Tokelau into New Zealand's GHG reporting. The ultimate objective of the project is to produce a New Zealand GHG inventory that would include the GHG estimates from Tokelau. The achievement of this objective would signify a new development in New Zealand's National Inventory System.

New Zealand will report on progress of the project in the next annual inventory submission.

Chapter 14: Information on changes to the national registry

This chapter contains information required for the reporting of changes to New Zealand's national registry. The changes made to New Zealand's national registry since the 2017 submission are included in table 14.1.

Recommendations were made in the review of New Zealand's 2017 submission by the expert review team. Refer to table 14.2 for recommendations and how these were addressed.

Table 14.1 Changes made to New Zealand's national registry

Section subheading	New Zealand's response
15/CMP.1 Annex II.E, paragraph 32.(a): Change in the name or contact for the national registry	The contact details for the national registry have not been changed during the reporting period.
15/CMP.1 Annex II.E, paragraph 32.(b): Change in cooperation arrangement	No change of cooperation arrangement occurred during the reported period.
1/CMP.1 Annex II.E, paragraph 32.(c): Change to the database or the capacity of the national registry	No change to the database or the capacity of the national registry occurred during the reporting period.
15/CMP.1 Annex II.E, paragraph 32.(d): Change in the conformance to technical standards	No change in the conformance to technical standards occurred during the reporting period.
15/CMP.1 Annex II.E, paragraph 32.(e): Change in the discrepancy procedures	No change of discrepancies procedures occurred during the reporting period.
15/CMP.1 Annex II.E, paragraph 32.(f): Change in security	No change in security occurred during the reporting period.
15/CMP.1 Annex II.E, paragraph 32.(g): Change in the list of publicly available information	No significant changes to the list of publicly available information occurred during the reporting period.
15/CMP.1 Annex II.E, paragraph 32.(h): Change to the internet address	No change to the internet address occurred during the reporting period.
15/CMP.1 Annex II.E, paragraph 32.(i): Change to the data integrity measures	No change to the data integrity measures occurred during the reporting period.
15/CMP.1 Annex II.E, paragraph 32.(j): Change of the test results	No change to the test results occurred during the reporting period.

Table 14.2 Previous recommendations for New Zealand from the expert review team

	Review descriptions	New Zealand addressed the recommendation as follows
2.4.2.1	The SIAR assessor recommended that Party in its next submission clearly stated whether change of data integrity occurred or not.	Party states there was no change to data integrity measures.
2.4.2.2	The SIAR assessor recommended that Party provided clear distinction between CP1 and CP2 units in this publically available information on holdings and transaction.	A release into the Register ensures that it is clear to users of the publically available information that all units relate to commitment period one (CP1) unless otherwise stated.

Table 14.3   Contact details

Organisation designated as the administrator of New Zealand's national registry	Environmental Protection Authority Private Bag 63002, Wellington 6140, New Zealand Phone: +64 4 462 4289 Fax: +64 4 978 3661 Web: www.epa.govt.nz
Main Contact	Guy Windley Team Leader, Registry Operations, ETS Environmental Protection Authority Private Bag 63002, Wellington 6140, New Zealand Phone: +64 4 474 5514 Fax: +64 4 978 3661 Email: guy.windley@epa.govt.nz
Alternative Contact	Justin Bloomfield Systems Analyst, Information Technology Team Environmental Protection Authority Private Bag 63002, Wellington 6140, New Zealand Phone: +64 4 474 5435 Fax: +64 4 978 3661 Email: justin.bloomfield@epa.govt.nz

Chapter 15: Information on minimisation of adverse impacts

This chapter provides information on New Zealand's implementation of policies and measures that minimise adverse social, environmental and economic impacts on non-Annex I Parties, as required under Article 3.14 of the Kyoto Protocol.

15.1 Overview

New Zealand is undertaking a number of mitigation actions and policies to reduce emissions to meet its Kyoto and Paris commitments. This includes through:

- an emissions trading scheme

- energy efficiency initiatives

- investment in public transport

- supporting afforestation

- research, technology development and sharing of technical expertise, most notably in the agricultural sector

- an increased proportion of electricity produced from renewable energy sources

- playing a leading role in the Friends of Fossil Fuel Subsidy Reform, a group aimed at encouraging the global phase out of harmful and inefficient subsidies to fossil fuel consumption

- sharing New Zealand's long-standing expertise in renewable energy development internationally

- climate-related support delivered by the New Zealand Aid Programme (https://mfat.govt.nz/en/aid-and-development).

In the development of major policy initiatives related to these mitigation measures, an analysis of impacts of the proposed policy is completed, as appropriate, considering the benefits and risks of proposed options including those with possible international implications.

In addition, through the New Zealand Government's regular engagement with other governments, including many non-Annex I Parties, there are opportunities for those concerned about the possible or actual adverse impacts of New Zealand policies to raise concerns and have them resolved within the bilateral relationship. There is also an opportunity for people or organisations to raise concerns and highlight issues about new policies at the public consultation phase. To date, no specific concerns have been raised about any negative impacts of New Zealand's climate change response policies.

New Zealand's development assistance in each country is required to be aligned to the priorities and needs of the partner country while also reflecting New Zealand's priorities and policies. Regular development assistance talks provide an opportunity for partner country governments to raise concerns about any impacts and to ask for or prioritise assistance to deal with those impacts. From these discussions, New Zealand works closely with the partner country to agree priorities for the particular country aid programme.

New Zealand's development assistance focuses on countries within the Pacific region that face serious climate-related challenges. All activities funded under the aid programme are required to assess and respond to environmental and climate-related impacts and risks, and one of the New Zealand Aid Programme's main investment priorities is to strengthen resilience.

In September 2015, the international community adopted the Sustainable Development Goals (SDGs), including Goal 7, which calls for a substantial increase in the share of renewables and will ensure access to affordable, reliable, sustainable and modern energy for all. Along with the Paris Climate Change Conference (COP21), held in Paris, France, and the work undertaken under the umbrella of the Decade of Sustainable Energy for All (SEforALL), renewable energy is of increasing significance to transform lives and economies.

Small Island Developing States continue to increase their uptake of renewable energy, which is a critical element of their long-term sustainable development efforts. The New Zealand Aid Programme has been supporting a major push to increase the uptake of renewable energy in the Pacific and reduce the region's reliance on imported diesel. Further afield, the Aid Programme supports a number of programmes to develop geothermal energy resources in Africa, the Caribbean and Indonesia.

15.2 Market imperfections, fiscal incentives, tax and duty exemptions and subsidies

Annex I Parties are required to report any progressive reduction or phasing out of market imperfections, fiscal incentives, tax and duty exemptions and subsidies in all greenhouse-gas-emitting sectors, taking into account the need for energy price reforms to reflect market prices and externalities.

New Zealand does not have any inefficient market imperfections, fiscal incentives, tax and duty exemptions or subsidies in greenhouse-gas-emitting sectors of this nature. New Zealand maintains a liberalised and open trading environment, consistent with the principles of free trade and investment, ensuring that both developed and developing countries can maximise opportunities in New Zealand's market regardless of the response measures undertaken.

New Zealand is a founding member of the Friends of Fossil Fuel Subsidy Reform. This is an informal group of the non-Group of Twenty (G20) countries that aims to build international political consensus on the importance of fossil fuel subsidy reform, and to encourage and support the G20 and Asia-Pacific Economic Cooperation (APEC) economies to meet their commitments to reform inefficient fossil fuel subsidies. The group's support for reform is based on the essential notion that it is incoherent to continue to underwrite the costs of emissions from fossil fuels at the same time as making concerted efforts to mitigate those emissions through actions elsewhere.

New Zealand has been working in several international fora to promote the global reform of inefficient fossil fuel subsidies. In April 2015 and 2016, New Zealand jointly hosted side events on fossil fuel subsidy reform with the United States and World Bank in the margins of the World Bank–International Monetary Fund Spring Meetings. The events provided an opportunity to hear first-hand accounts from countries about their experiences with reform, and to understand the tools and initiatives available to support reform. At the 2016 Spring Meetings, New Zealand and other members of the Friends of Fossil Fuel Subsidy Reform, encouraged additional endorsements of the Fossil Fuel Subsidy Reform Communiqué launched the previous year, rallying for accelerated action to eliminate inefficient fossil fuel subsidies as a major contribution to climate change mitigation.

New Zealand supports the APEC Inefficient Fossil Fuel Subsidy Reform Peer Review Mechanism. New Zealand was one of the first APEC economies to volunteer to undertake an APEC peer review of New Zealand's fossil fuel policies. New Zealand put forward for peer review a comprehensive set of policy measures that directly or indirectly support fossil fuels. The review expert panel in-country visit took place in March 2015. This provided a useful 'health check' for New Zealand policies, and the international review panel did not identify any inefficient subsidies that encourage wasteful consumption. New Zealand has also participated in the peer review panels for Peru and the Philippines, and, in 2016, co-sponsored a project on capacity building for APEC economies, enabling the successful implementation of fossil fuel subsidy reform by developing practical solutions to common challenges.

At the twenty-second session of the Conference of the Parties (COP22) in November 2016, New Zealand hosted a side event to promote fossil fuel subsidy reform as an important climate change mitigation policy.

15.3 Removal of subsidies

Annex I Parties are required to report information concerning the removal of subsidies associated with the use of environmentally unsound and unsafe technologies.

New Zealand does not have any subsidies of this nature.

15.4 Technological development of non-energy uses of fossil fuels

Annex I Parties are required to report on cooperation in the technological development of non-energy use of fossil fuels and support provided to non-Annex I Parties.

The New Zealand Government has not participated actively in activities of this nature, as yet.

15.5 Carbon capture and storage technology development

Annex I Parties are required to report on cooperation in the development, diffusion and transfer of less-greenhouse-gas-emitting advanced fossil fuel technologies, and/or technologies relating to fossil fuels that capture and store greenhouse gases, and encouragement of their wider use; and on facilitating the participation of non-Annex I Parties.

New Zealand is a member of the United States-led Carbon Sequestration Leadership Forum (www.cslforum.org) and the International Energy Agency Greenhouse Gas Research and Development Programme (www.ieaghg.org).

15.6 Improvements in fossil fuel efficiencies

Annex I Parties are required to report on how they have strengthened the capacity of non-Annex I Parties identified in Article 4.8 and Article 4.9 of the United Nations Framework Convention on Climate Change, by improving the efficiency in upstream and downstream activities related to fossil fuels and by taking into consideration the need to improve the environmental efficiency of these activities.

The New Zealand Aid Programme maintains a focus on energy efficiency and the transition away from fossil fuel dependency to clean, efficient, affordable and reliable energy generation. Introducing clean and affordable energy technologies is a high priority for the Pacific region. On average, 10 per cent of the region's gross domestic product is expended on imported fossil fuel, and 80 per cent of electricity generation depends on the combustion of diesel.

Following the New Zealand Government and the European Union Pacific Energy Conference in 2016, New Zealand has committed a further $100 million over 2017–21 to renewable energy investments in Micronesia, in addition to the $200 million investment in renewable energy across eight countries since 2013 (Cook Islands, Kiribati, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu, Vanuatu). Projects to implement renewable energy resources, particularly solar energy for remote island communities, have been completed in Cook Islands, Samoa, Solomon Islands and Tuvalu. In Samoa, three solar photovoltaic systems have been installed, including the largest solar array in the southern Pacific, at the Faleata Racecourse in Apia. This will meet approximately 4.5 per cent of Samoa's total electricity needs, reducing demand for imported diesel by more than a million litres per year, with annual savings of about WST$3.4 million (NZ$1.7 million).

New Zealand is also a member of the International Renewable Energy Agency (IRENA), an intergovernmental organisation that aims to promote the widespread use of all forms of renewable energy. New Zealand is involved with several of IRENA's work programmes in the Pacific and further afield. New Zealand is also a member of other multilateral institutions that play a role in the energy sector, for example, the International Energy Agency and APEC.

15.7 Assistance to non-Annex I Parties dependent on the export and consumption of fossil fuels for diversifying their economies

Annex I Parties are required to report on assistance provided to non-Annex I Parties that are highly dependent on the export and consumption of fossil fuels in diversifying their economies.

The New Zealand Aid Programme provides support to a number of non-Annex I Parties for purposes of economic diversification (refer to section 15.6).

For example, New Zealand has a long-standing partnership with the government of Indonesia to accelerate the development of Indonesia's geothermal energy sector. In 2016, New Zealand supported Indonesia to develop a geothermal energy human resource development strategy. New Zealand is also providing technical assistance and capacity building support through training and scholarships in geothermal project management, production skills and geothermal well control, in partnership with the University of Auckland's Geothermal Institute, GNS Science, the Gadjah Mada University and Indonesian Ministry of Energy and Mineral Resources.

New Zealand is committed to providing long-term assistance to non-Annex I Parties in achieving economic diversification that is independent of fossil fuels.

Annex 1: Key categories

A1.1 Methodology used for identifying key categories

The key categories in the inventory have been assessed using the Approach 1 level and trend methodologies from the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006). The methodology applied was determined using the decision tree shown in figure A1.1.1. Because some categories in the inventory apply default uncertainties values for emission estimates, and developing country-specific uncertainty values is resource prohibitive, Approach 1 level and trend methodologies are used.

Figure A1.1.1   Decision tree to identify key source categories (figure 4.2, IPCC, 2006)
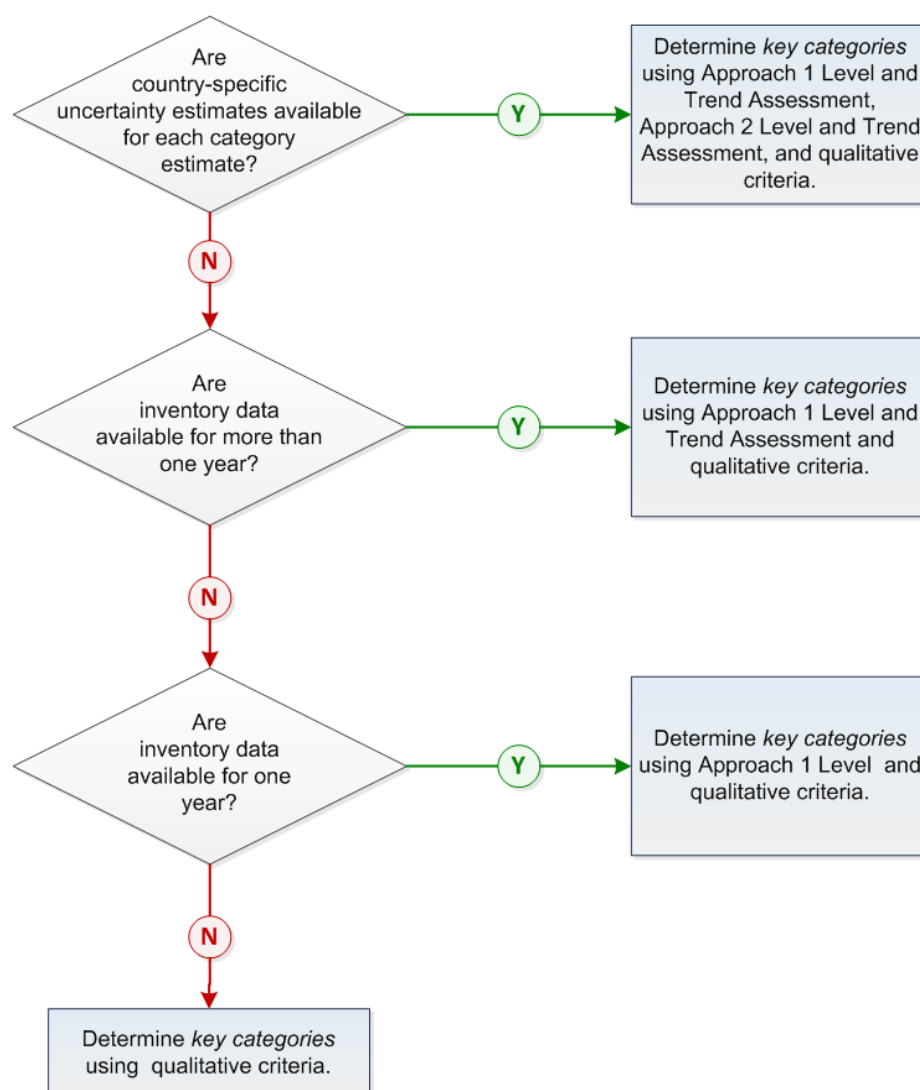
For this inventory submission, the Approach 1 level and trend assessments were applied, including the Land Use, Land-Use Change and Forestry (LULUCF) sector and excluding the LULUCF sector (IPCC, 2003).

The 'including LULUCF' level and trend assessments are calculated as per equations 5.4.1 and 5.4.2 of *Good Practice Guidance for Land Use, Land-Use Change and Forestry* (IPCC, 2003). The 'excluding LULUCF' level and trend assessments are calculated as per equations 4.1 and 4.2 of the IPCC 2006 Guidelines (IPCC, 2006). Key categories are defined as those categories whose cumulative percentages, when summed in decreasing order of magnitude, contributed 95 per cent of the total level or trend.

A1.2 Disaggregation

The classification of categories follows the classification of the common reporting format (CRF) tables by:

- identifying categories using carbon dioxide (CO_2) equivalent emissions and considering each greenhouse gas from each category separately

- either including or excluding LULUCF categories at the level shown in *Good Practice Guidance for Land Use, Land-Use Change and Forestry* table 5.4.1 (IPCC, 2003).

The level of aggregation used for the key category analysis is similar to the default aggregation used for the key category analysis within the CRF tables, with adjustments to better reflect New Zealand's emissions profile. Specifically, a large proportion of emissions from the Energy and Agriculture sectors are disaggregated further than the key category analysis generated in the CRF tables, to allow for a more evenly proportioned analysis of categories.

A1.3 Tables 4.2–4.3 of the IPCC 2006 Guidelines (General Guidance and Reporting)

The following tables specify the level analyses for 2016 and 1990, and trend analyses, each including and excluding LULUCF. The tables show the categories that comprise 99 per cent of emissions for each analysis. Only the categories that comprise the top 95 per cent of emissions for the 2016 level analysis and the trend analysis are key categories. The 1990 level analysis tables are included for information only.

Table A1.3.1(a) Results of the key category level analysis for 99 per cent of the net emissions and removals for New Zealand in 2016

IPCC Tier 1 category level assessment – including LULUCF (net emissions): 2016					
CRF category code	IPCC category	Gas	2016 estimate (kt CO$_2$-e)	Level assessment (%)	Cumulative total (%)
3.A.1	Option A – Dairy Cattle	CH$_4$	13,623.6	12.2	12.2
1.A.3.b	Transport – Road Transportation Liquid Fuels	CO$_2$	13,470.5	12.1	24.3
4.A.2	Forest Land – Land Converted to Forest Land	CO$_2$	–13,149.7	11.8	36.0
4.A.1	Forest Land – Forest Land Remaining Forest Land	CO$_2$	–8,787.5	7.9	43.9
3.A.2	Other (please specify) – Sheep	CH$_4$	8,412.6	7.5	51.4
4.G	Land Use, Land-Use Change and Forestry – Harvested Wood Products	CO$_2$	–5,946.4	5.3	56.7
3.D.1.3	Direct N$_2$O Emissions From Managed Soils – Urine and Dung Deposited by Grazing Animals	N$_2$O	5,503.3	4.9	61.7
3.A.1	Option A – Non-Dairy Cattle	CH$_4$	5,228.7	4.7	66.3
5.A	Waste – Solid Waste Disposal	CH$_4$	3,439.0	3.1	69.4
4.C.2	Grassland – Land Converted to Grassland	CO$_2$	3,070.8	2.7	72.2

IPCC Tier 1 category level assessment – including LULUCF (net emissions): 2016					
CRF category code	IPCC category	Gas	2016 estimate (kt CO$_2$-e)	Level assessment (%)	Cumulative total (%)
1.A.1.a	Energy Industries – Public Electricity and Heat Production Gaseous Fuels	CO$_2$	2,586.9	2.3	74.5
1.A.2.c	Manufacturing Industries and Construction – Chemicals Gaseous Fuels	CO$_2$	1,939.5	1.7	76.2
2.C.1	Metal Industry – Iron and Steel Production	CO$_2$	1,712.1	1.5	77.8
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Solid Fuels	CO$_2$	1,496.5	1.3	79.1
3.D.1.1	Direct N$_2$O Emissions From Managed Soils – Inorganic N Fertilisers	N$_2$O	1,332.2	1.2	80.3
1.A.4.c	Other Sectors – Agriculture/Forestry/Fishing Liquid Fuels	CO$_2$	1,321.7	1.2	81.5
4.C.1	Grassland – Grassland Remaining Grassland	CO$_2$	1,306.4	1.2	82.6
2.F.1	Product Uses as Substitutes for ODS – Refrigeration and Air conditioning	HFCs	1,282.5	1.1	83.8
3.B.1.1	Option A – Dairy Cattle	CH$_4$	930.4	0.8	84.6
3.D.2.1	Indirect N$_2$O Emissions From Managed Soils – Atmospheric Deposition	N$_2$O	910.1	0.8	85.4
1.A.3.a	Domestic Aviation – Jet Kerosene	CO$_2$	893.7	0.8	86.2
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Gaseous Fuels	CO$_2$	864.3	0.8	87.0
1.A.1.b	Energy Industries – Petroleum Refining Liquid Fuels	CO$_2$	690.2	0.6	87.6
1.B.2.d	Other (please specify) – Geothermal	CO$_2$	659.1	0.6	88.2
3.H	Agriculture – Urea Application	CO$_2$	574.4	0.5	88.7
2.C.3	Metal Industry – Aluminium Production	CO$_2$	539.4	0.5	89.2
3.G	Agriculture – Liming	CO$_2$	514.4	0.5	89.7
1.A.2.g.iii	Other (please specify) – Mining (excluding fuels) and quarrying Liquid Fuels	CO$_2$	510.5	0.5	90.1
3.D.2.2	Indirect N$_2$O Emissions From Managed Soils – Nitrogen Leaching and Run-off	N$_2$O	501.6	0.4	90.6
2.A.1	Mineral Industry – Cement Production	CO$_2$	486.4	0.4	91.0
3.A.4	Other livestock – Deer	CH$_4$	465.0	0.4	91.4
1.A.4.a	Other Sectors – Commercial/Institutional Liquid Fuels	CO$_2$	458.5	0.4	91.8
1.A.1.a	Energy Industries – Public Electricity and Heat Production Solid Fuels	CO$_2$	445.7	0.4	92.2
1.A.4.a	Other Sectors – Commercial/Institutional Gaseous Fuels	CO$_2$	439.6	0.4	92.6
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Liquid Fuels	CO$_2$	411.2	0.4	93.0
1.A.2.d	Manufacturing Industries and Construction – Pulp, Paper and Print Gaseous Fuels	CO$_2$	359.2	0.3	93.3
1.A.4.b	Other Sectors – Residential Gaseous Fuels	CO$_2$	343.2	0.3	93.6
4.B.1	Cropland – Cropland Remaining Cropland	CO$_2$	340.5	0.3	93.9
1.A.3.d	Domestic Navigation – Residual Fuel Oil	CO$_2$	300.7	0.3	94.2
1.B.2.c.2.iii	Flaring – Combined	CO$_2$	294.5	0.3	94.5

CRF category code	IPCC category	Gas	2016 estimate (kt CO$_2$-e)	Level assessment (%)	Cumulative total (%)
	IPCC Tier 1 category level assessment – including LULUCF (net emissions): 2016				
1.A.2.f	Manufacturing Industries and Construction – Non-metallic Minerals Solid Fuels	CO$_2$	275.3	0.2	94.7
1.A.1.c	Energy Industries – Manufacture of Solid Fuels and Other Energy Industries Gaseous Fuels	CO$_2$	273.3	0.2	95.0
1.B.2.c.1.ii	Venting – Gas	CO$_2$	268.2	0.2	95.2
5.D	Waste – Wastewater Treatment and Discharge	CH$_4$	266.0	0.2	95.4
3.D.1.4	Direct N$_2$O Emissions From Managed Soils – Crop Residues	N$_2$O	252.6	0.2	95.7
1.A.4.b	Other Sectors – Residential Liquid Fuels	CO$_2$	206.4	0.2	95.9
1.A.2.g.viii	Other (please specify) – Other (please specify) Liquid Fuels	CO$_2$	200.4	0.2	96.0
1.B.2.b.5	Natural Gas – Distribution	CH$_4$	200.1	0.2	96.2
2.A.2	Mineral Industry – Lime Production	CO$_2$	176.0	0.2	96.4
1.B.2.d	Other (please specify) – Geothermal	CH$_4$	172.8	0.2	96.5
2.B.10	Chemical Industry – Other (please specify)	CO$_2$	172.2	0.2	96.7
1.A.1.b	Energy Industries – Petroleum Refining Gaseous Fuels	CO$_2$	157.1	0.1	96.8
1.B.2.b.2	Natural Gas – Production	CH$_4$	138.5	0.1	96.9
1.A.3.c	Transport – Railways Liquid Fuels	CO$_2$	130.8	0.1	97.1
5.D	Waste – Wastewater Treatment and Discharge	N$_2$O	130.8	0.1	97.2
1.A.2.f	Manufacturing Industries and Construction – Non-metallic Minerals Liquid Fuels	CO$_2$	127.0	0.1	97.3
2.B.8	Chemical Industry – Petrochemical and Carbon Black Production	CH$_4$	125.3	0.1	97.4
1.A.3.b	Transport – Road Transportation Liquid Fuels	N$_2$O	115.3	0.1	97.5
1.A.4.c	Other Sectors – Agriculture/Forestry/Fishing Solid Fuels	CO$_2$	114.7	0.1	97.6
1.B.1.a.1	Coal Mining and Handling – Underground Mines	CH$_4$	113.5	0.1	97.7
1.A.4.a	Other Sectors – Commercial/Institutional Solid Fuels	CO$_2$	99.9	0.1	97.8
2.F.4	Product Uses as Substitutes for ODS – Aerosols	HFCs	96.2	0.1	97.9
1.A.2.a	Manufacturing Industries and Construction – Iron and Steel Gaseous Fuels	CO$_2$	95.5	0.1	98.0
1.A.2.g.viii	Other (please specify) – Other (please specify) Solid Fuels	CO$_2$	92.0	0.1	98.1
3.B.1.2	CH$_4$ Emissions – Sheep	CH$_4$	86.9	0.1	98.1
1.A.4.c	Other Sectors – Agriculture/Forestry/Fishing Gaseous Fuels	CO$_2$	86.7	0.1	98.2
1.A.2.d	Manufacturing Industries and Construction – Pulp, Paper and Print Liquid Fuels	CO$_2$	86.0	0.1	98.3
1.A.2.f	Manufacturing Industries and Construction – Non-metallic Minerals Gaseous Fuels	CO$_2$	82.0	0.1	98.4
3.B.2.5	N$_2$O and NMVOC Emissions – Indirect N$_2$O Emissions	N$_2$O	76.0	0.1	98.4
3.B.1.1	Option A – Non-Dairy Cattle	CH$_4$	70.1	0.1	98.5
4.B.2	Cropland – Land Converted to Cropland	CO$_2$	68.4	0.1	98.5
4.E.1	Settlements – Settlements Remaining Settlements	CO$_2$	64.5	0.1	98.6

IPCC Tier 1 category level assessment – including LULUCF (net emissions): 2016					
CRF category code	IPCC category	Gas	2016 estimate (kt CO$_2$-e)	Level assessment (%)	Cumulative total (%)
2.A.4	Mineral Industry – Other Process Uses of Carbonates	CO$_2$	64.4	0.1	98.7
3.D.1.2	Direct N$_2$O Emissions From Managed Soils – Organic N Fertilisers	N$_2$O	63.2	0.1	98.7
4.A.2	Forest Land – Land Converted to Forest Land	N$_2$O	62.4	0.1	98.8
1.B.2.c.2.iii	Flaring – Combined	CH$_4$	60.3	0.1	98.8
2.G.3	Other Product Manufacture and Use – N$_2$O from Product Uses	N$_2$O	59.0	0.1	98.9
1.B.1.a.2	Coal Mining and Handling – Surface Mines	CH$_4$	58.3	0.1	98.9
1.A.2.d	Manufacturing Industries and Construction – Pulp, Paper and Print Solid fuels	CO$_2$	54.6	0.0	99.0
4.C.1	Grassland – Grassland Remaining Grassland	CH$_4$	51.9	0.0	99.0

Note: Key categories are those that comprise 95 per cent of the total. Removals from the LULUCF sector are shown as negatives in this table. The absolute values for those removals were used for the calculations.

Table A1.3.1(b) Results of the key category level analysis for 99 per cent of the gross emissions and removals for New Zealand in 2016

IPCC Tier 1 category level assessment – gross emissions (excluding LULUCF): 2016					
CRF category code	IPCC Category	Gas	2016 estimate (kt CO$_2$-e)	Level assessment (%)	Cumulative total (%)
3.A.1	Option A – Dairy Cattle	CH$_4$	13,623.6	17.3	17.3
1.A.3.b	Transport – Road Transportation Liquid Fuels	CO$_2$	13,470.5	17.1	34.4
3.A.2	Other (please specify) – Sheep	CH$_4$	8,412.6	10.7	45.1
3.D.1.3	Direct N$_2$O Emissions From Managed Soils – Urine and Dung Deposited by Grazing Animals	N$_2$O	5,503.3	7.0	52.1
3.A.1	Option A – Non-Dairy Cattle	CH$_4$	5,228.7	6.6	58.7
5.A	Waste – Solid Waste Disposal	CH$_4$	3,439.0	4.4	63.1
1.A.1.a	Energy Industries – Public Electricity and Heat Production Gaseous Fuels	CO$_2$	2,586.9	3.3	66.4
1.A.2.c	Manufacturing Industries and Construction – Chemicals Gaseous Fuels	CO$_2$	1,939.5	2.5	68.9
2.C.1	Metal Industry – Iron and Steel Production	CO$_2$	1,712.1	2.2	71.0
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Solid Fuels	CO$_2$	1,496.5	1.9	72.9
3.D.1.1	Direct N$_2$O Emissions From Managed Soils – Inorganic N Fertilisers	N$_2$O	1,332.2	1.7	74.6
1.A.4.c	Other Sectors – Agriculture/Forestry/Fishing Liquid Fuels	CO$_2$	1,321.7	1.7	76.3
2.F.1	Product Uses as Substitutes for ODS – Refrigeration and Air Conditioning	HFCs	1,282.5	1.6	77.9
3.B.1.1	Option A – Dairy Cattle	CH$_4$	930.4	1.2	79.1
3.D.2.1	Indirect N$_2$O Emissions From Managed Soils – Atmospheric Deposition	N$_2$O	910.1	1.2	80.3
1.A.3.a	Domestic Aviation – Jet Kerosene	CO$_2$	893.7	1.1	81.4

CRF category code	IPCC Category	Gas	2016 estimate (kt CO_2-e)	Level assessment (%)	Cumulative total (%)
IPCC Tier 1 category level assessment – gross emissions (excluding LULUCF): 2016					
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Gaseous Fuels	CO_2	864.3	1.1	82.5
1.A.1.b	Energy Industries – Petroleum Refining Liquid Fuels	CO_2	690.2	0.9	83.4
1.B.2.d	Other (please specify) – Geothermal	CO_2	659.1	0.8	84.2
3.H	Agriculture – Urea Application	CO_2	574.4	0.7	84.9
2.C.3	Metal Industry – Aluminium Production	CO_2	539.4	0.7	85.6
3.G	Agriculture – Liming	CO_2	514.4	0.7	86.3
1.A.2.g.iii	Other (please specify) – Mining (excluding fuels) and Quarrying Liquid Fuels	CO_2	510.5	0.6	86.9
3.D.2.2	Indirect N_2O Emissions From Managed Soils – Nitrogen Leaching and Run-off	N_2O	501.6	0.6	87.6
2.A.1	Mineral Industry – Cement Production	CO_2	486.4	0.6	88.2
3.A.4	Other livestock – Deer	CH_4	465.0	0.6	88.8
1.A.4.a	Other Sectors – Commercial/Institutional Liquid Fuels	CO_2	458.5	0.6	89.4
1.A.1.a	Energy Industries – Public Electricity and Heat Production Solid Fuels	CO_2	445.7	0.6	89.9
1.A.4.a	Other Sectors – Commercial/Institutional Gaseous Fuels	CO_2	439.6	0.6	90.5
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Liquid Fuels	CO_2	411.2	0.5	91.0
1.A.2.d	Manufacturing Industries and Construction – Pulp, Paper and Print Gaseous Fuels	CO_2	359.2	0.5	91.5
1.A.4.b	Other Sectors – Residential Gaseous Fuels	CO_2	343.2	0.4	91.9
1.A.3.d	Domestic Navigation – Residual Fuel Oil	CO_2	300.7	0.4	92.3
1.B.2.c.2.iii	Flaring – Combined	CO_2	294.5	0.4	92.7
1.A.2.f	Manufacturing Industries and Construction – Non-metallic Minerals Solid Fuels	CO_2	275.3	0.3	93.0
1.A.1.c	Energy Industries – Manufacture of Solid Fuels and Other Energy Industries Gaseous fuels	CO_2	273.3	0.3	93.3
1.B.2.c.1.ii	Venting – Gas	CO_2	268.2	0.3	93.7
5.D	Waste – Wastewater Treatment and Discharge	CH_4	266.0	0.3	94.0
3.D.1.4	Direct N_2O Emissions From Managed Soils – Crop Residues	N_2O	252.6	0.3	94.3
1.A.4.b	Other Sectors – Residential Liquid Fuels	CO_2	206.4	0.3	94.6
1.A.2.g.viii	Other (please specify) – Other (please specify) Liquid Fuels	CO_2	200.4	0.3	94.9
1.B.2.b.5	Natural Gas – Distribution	CH_4	200.1	0.3	95.1
2.A.2	Mineral Industry – Lime Production	CO_2	176.0	0.2	95.3
1.B.2.d	Other (please specify) – Geothermal	CH_4	172.8	0.2	95.6
2.B.10	Chemical Industry – Other (please specify)	CO_2	172.2	0.2	95.8
1.A.1.b	Energy Industries – Petroleum Refining Gaseous Fuels	CO_2	157.1	0.2	96.0
1.B.2.b.2	Natural Gas – Production	CH_4	138.5	0.2	96.2
1.A.3.c	Transport – Railways Liquid Fuels	CO_2	130.8	0.2	96.3

CRF category code	IPCC Category	Gas	2016 estimate (kt CO$_2$-e)	Level assessment (%)	Cumulative total (%)
IPCC Tier 1 category level assessment – gross emissions (excluding LULUCF): 2016					
5.D	Waste – Wastewater Treatment and Discharge	N$_2$O	130.8	0.2	96.5
1.A.2.f	Manufacturing Industries and Construction – Non-metallic Minerals Liquid Fuels	CO$_2$	127.0	0.2	96.6
2.B.8	Chemical Industry – Petrochemical and Carbon Black Production	CH$_4$	125.3	0.2	96.8
1.A.3.b	Transport – Road Transportation Liquid Fuels	N$_2$O	115.3	0.1	97.0
1.A.4.c	Other Sectors – Agriculture/Forestry/Fishing Solid Fuels	CO$_2$	114.7	0.1	97.1
1.B.1.a.1	Coal Mining and Handling – Underground Mines	CH$_4$	113.5	0.1	97.2
1.A.4.a	Other Sectors – Commercial/Institutional Solid Fuels	CO$_2$	99.9	0.1	97.4
2.F.4	Product Uses as Substitutes for ODS – Aerosols	HFCs	96.2	0.1	97.5
1.A.2.a	Manufacturing Industries and Construction – Iron and Steel Gaseous Fuels	CO$_2$	95.5	0.1	97.6
1.A.2.g.viii	Other (please specify) – Other (please specify) Solid Fuels	CO$_2$	92.0	0.1	97.7
3.B.1.2	CH$_4$ Emissions – Sheep	CH$_4$	86.9	0.1	97.8
1.A.4.c	Other Sectors – Agriculture/Forestry/Fishing Gaseous Fuels	CO$_2$	86.7	0.1	98.0
1.A.2.d	Manufacturing Industries and Construction – Pulp, Paper and Print Liquid Fuels	CO$_2$	86.0	0.1	98.1
1.A.2.f	Manufacturing Industries and Construction – Non-metallic Minerals Gaseous Fuels	CO$_2$	82.0	0.1	98.2
3.B.2.5	N$_2$O and NMVOC Emissions – Indirect N$_2$O Emissions	N$_2$O	76.0	0.1	98.3
3.B.1.1	Option A – Non-Dairy Cattle	CH$_4$	70.1	0.1	98.4
2.A.4	Mineral Industry – Other Process Uses of Carbonates	CO$_2$	64.4	0.1	98.4
3.D.1.2	Direct N$_2$O Emissions From Managed Soils – Organic N Fertilisers	N$_2$O	63.2	0.1	98.5
1.B.2.c.2.iii	Flaring – Combined	CH$_4$	60.3	0.1	98.6
2.G.3	Other Product Manufacture and Use – N$_2$O from Product Uses	N$_2$O	59.0	0.1	98.7
1.B.1.a.2	Coal Mining and Handling – Surface Mines	CH$_4$	58.3	0.1	98.7
1.A.2.d	Manufacturing Industries and Construction – Pulp, Paper and Print Solid Fuels	CO$_2$	54.6	0.1	98.8
1.A.4.b	Other Sectors – Residential Biomass	CH$_4$	48.7	0.1	98.9
2.C.3	Metal Industry – Aluminium Production	PFCs	48.7	0.1	98.9
1.A.2.d	Manufacturing Industries and Construction – Pulp, Paper and Print Biomass	N$_2$O	47.8	0.1	99.0
2.D	Industrial Processes and Product Use – Non-energy Products from Fuels and Solvent Use	CO$_2$	46.5	0.1	99.1

Note: Key categories are those that comprise 95 per cent of the total.

Table A1.3.2(a)   Results of the level analysis for 99 per cent of the net emissions and removals for New Zealand in 1990 included for reference only

CRF category code	IPCC category	Gas	1990 estimate (kt CO₂-e)	Level assessment (%)	Cumulative total (%)
IPCC Tier 1 category level assessment – including LULUCF (net emissions): 1990

CRF category code	IPCC category	Gas	1990 estimate (kt CO$_2$-e)	Level assessment (%)	Cumulative total (%)
4.A.2	Forest Land – Land Converted to Forest Land	CO$_2$	– 19,911.5	20.2	20.2
3.A.2	Other (please specify) – Sheep	CH$_4$	14,361.3	14.6	34.8
4.A.1	Forest Land – Forest Land Remaining Forest Land	CO$_2$	−9,143.7	9.3	44.0
1.A.3.b	Transport – Road Transportation Liquid Fuels	CO$_2$	7,164.6	7.3	51.3
3.A.1	Option A – Dairy Cattle	CH$_4$	5,951.6	6.0	57.4
3.A.1	Option A – Non-Dairy Cattle	CH$_4$	5,737.5	5.8	63.2
3.D.1.3	Direct N$_2$O Emissions From Managed Soils – Urine and Dung Deposited by Grazing Animals	N$_2$O	5,131.8	5.2	68.4
5.A	Waste – Solid Waste Disposal	CH$_4$	3,510.9	3.6	71.9
1.A.1.a	Energy Industries – Public Electricity and Heat Production Gaseous Fuels	CO$_2$	3,011.8	3.1	75.0
4.G	Land Use, Land-Use Change and Forestry – Harvested Wood Products	CO$_2$	−2,072.9	2.1	77.1
1.A.1.c	Energy Industries – Manufacture of Solid Fuels and Other Energy Industries Gaseous Fuels	CO$_2$	1,720.1	1.7	78.8
2.C.1	Metal Industry – Iron and Steel Production	CO$_2$	1,306.7	1.3	80.2
1.A.4.c	Other Sectors – Agriculture/Forestry/Fishing Liquid Fuels	CO$_2$	1,072.3	1.1	81.3
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Solid Fuels	CO$_2$	938.6	1.0	82.2
2.C.3	Metal Industry – Aluminium Production	PFCs	909.9	0.9	83.1
1.A.3.a	Domestic Aviation – Jet Kerosene	CO$_2$	892.6	0.9	84.0
1.A.1.b	Energy Industries – Petroleum Refining Liquid Fuels	CO$_2$	778.9	0.8	84.8
1.A.2.g.viii	Other (please specify) – Other (please specify) Solid Fuels	CO$_2$	731.1	0.7	85.6
3.D.2.1	Indirect N$_2$O Emissions From Managed Soils – Atmospheric Deposition	N$_2$O	710.2	0.7	86.3
1.A.2.c	Manufacturing Industries and Construction – Chemicals Gaseous Fuels	CO$_2$	528.7	0.5	86.8
4.C.1	Grassland – Grassland Remaining Grassland	CO$_2$	521.3	0.5	87.4
1.A.4.a	Other Sectors – Commercial/Institutional Liquid Fuels	CO$_2$	500.6	0.5	87.9
1.A.1.a	Energy Industries – Public Electricity and Heat Production Solid Fuels	CO$_2$	474.8	0.5	88.3
2.C.3	Metal Industry – Aluminium Production	CO$_2$	449.0	0.5	88.8
2.A.1	Mineral Industry – Cement Production	CO$_2$	448.7	0.5	89.3
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Gaseous Fuels	CO$_2$	445.5	0.5	89.7
3.A.4	Other Livestock – Deer	CH$_4$	418.3	0.4	90.1
3.B.1.1	Option A – Dairy Cattle	CH$_4$	390.1	0.4	90.5
1.A.2.f	Manufacturing Industries and Construction – Non-metallic Minerals Solid Fuels	CO$_2$	382.9	0.4	90.9
3.D.2.2	Indirect N$_2$O Emissions From Managed Soils – Nitrogen Leaching and Run-off	N$_2$O	382.0	0.4	91.3
3.G	Agriculture – Liming	CO$_2$	360.1	0.4	91.7
4.B.1	Cropland – Cropland Remaining Cropland	CO$_2$	358.1	0.4	92.0

CRF category code	IPCC category	Gas	1990 estimate (kt CO$_2$-e)	Level assessment (%)	Cumulative total (%)
	IPCC Tier 1 category level assessment – including LULUCF (net emissions): 1990				
1.A.2.d	Manufacturing Industries and Construction – Pulp, Paper and Print Gaseous Fuels	CO$_2$	348.6	0.4	92.4
1.A.4.b	Other Sectors – Residential Solid Fuels	CO$_2$	344.9	0.3	92.7
1.A.2.g.iii	Other (please specify) – Mining (excluding fuels) and quarrying Liquid Fuels	CO$_2$	331.5	0.3	93.1
1.B.1.a.1	Coal Mining and Handling – Underground Mines	CH$_4$	289.6	0.3	93.4
1.B.2.b.5	Natural Gas – Distribution	CH$_4$	277.5	0.3	93.6
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Liquid Fuels	CO$_2$	265.9	0.3	93.9
5.D	Waste – Wastewater Treatment and Discharge	CH$_4$	240.6	0.2	94.2
1.A.4.a	Other Sectors – Commercial/Institutional Gaseous Fuels	CO$_2$	236.1	0.2	94.4
1.A.3.d	Domestic Navigation – Residual Fuel Oil	CO$_2$	232.9	0.2	94.6
4.C.2	Grassland – Land Converted to Grassland	CO$_2$	232.1	0.2	94.9
3.D.1.1	Direct N$_2$O Emissions From Managed Soils – Inorganic N Fertilisers	N$_2$O	230.3	0.2	95.1
1.B.2.d	Other (please specify) – Geothermal	CO$_2$	228.6	0.2	95.3
3.A.4	Other Livestock – Goats	CH$_4$	196.6	0.2	95.5
1.A.4.b	Other Sectors – Residential Gaseous Fuels	CO$_2$	185.6	0.2	95.7
3.D.1.4	Direct N$_2$O Emissions From Managed Soils – Crop Residues	N$_2$O	175.5	0.2	95.9
1.A.4.b	Other Sectors – Residential Liquid Fuels	CO$_2$	167.4	0.2	96.1
2.B.10	Chemical Industry – Other (please specify)	CO$_2$	152.3	0.2	96.2
1.B.2.b.2	Natural Gas – Production	CH$_4$	143.5	0.1	96.4
1.A.4.a	Other Sectors – Commercial/Institutional Solid Fuels	CO$_2$	142.2	0.1	96.5
1.A.3.b	Transport – Road Transportation Gaseous Fuels	CO$_2$	140.8	0.1	96.7
3.B.1.2	CH$_4$ Emissions – Sheep	CH$_4$	139.6	0.1	96.8
4.A.2	Forest Land – Land Converted to Forest Land	N$_2$O	121.1	0.1	96.9
1.A.2.a	Manufacturing Industries and Construction – Iron and Steel Gaseous Fuels	CO$_2$	116.6	0.1	97.0
1.B.2.c.2.iii	Flaring – Combined	CO$_2$	114.4	0.1	97.2
4.B.2	Cropland – Land Converted to Cropland	CO$_2$	111.4	0.1	97.3
1.A.2.d	Manufacturing Industries and Construction – Pulp, Paper and Print Solid Fuels	CO$_2$	109.5	0.1	97.4
1.B.2.c.1.ii	Venting – Gas	CO$_2$	109.3	0.1	97.5
1.A.4.c	Other Sectors – Agriculture/Forestry/Fishing Gaseous Fuels	CO$_2$	106.2	0.1	97.6
2.G.3	Other Product Manufacture and Use – N$_2$O From Product Uses	N$_2$O	102.4	0.1	97.7
5.D	Waste – Wastewater Treatment and Discharge	N$_2$O	96.5	0.1	97.8
4.C.1	Grassland – Grassland Remaining Grassland	CH$_4$	90.0	0.1	97.9
1.A.3.b	Transport – Road Transportation Liquid Fuels	N$_2$O	89.3	0.1	98.0
2.A.2	Mineral Industry – Lime Production	CO$_2$	82.6	0.1	98.1
1.A.3.c	Transport – Railways Liquid Fuels	CO$_2$	78.4	0.1	98.1
3.B.1.1	Option A – Non-Dairy Cattle	CH$_4$	76.6	0.1	98.2
1.A.3.b	Transport – Road Transportation Liquid Fuels	CH$_4$	72.9	0.1	98.3

IPCC Tier 1 category level assessment – including LULUCF (net emissions): 1990					
CRF category code	IPCC category	Gas	1990 estimate (kt CO_2-e)	Level assessment (%)	Cumulative total (%)
1.B.2.c.2.iii	Flaring – Combined	CH_4	64.6	0.1	98.4
4.E.1	Settlements – Settlements Remaining Settlements	CO_2	64.5	0.1	98.4
1.A.2.f	Manufacturing Industries and Construction – Non-metallic Minerals Gaseous Fuels	CO_2	64.3	0.1	98.5
1.A.2.g.vi	Other (please specify) – Textile and Leather Gaseous Fuels	CO_2	59.2	0.1	98.6
3.B.1.3	CH_4 Emissions – Swine	CH_4	58.6	0.1	98.6
1.B.2.d	Other (please specify) – Geothermal	CH_4	54.8	0.1	98.7
1.A.2.d	Manufacturing Industries and Construction – Pulp, Paper and Print Liquid Fuels	CO_2	52.2	0.1	98.7
1.A.2.g.viii	Other (please specify) – Other (please specify) Liquid Fuels	CO_2	51.7	0.1	98.8
1.A.4.b	Other Sectors – Residential Biomass	CH_4	48.4	0.0	98.8
1.A.2.f	Manufacturing Industries and Construction – Non-metallic Minerals Liquid Fuels	CO_2	47.9	0.0	98.9
1.A.3.a	Domestic Aviation – Aviation Gasoline	CO_2	47.7	0.0	98.9
3.A.4	Other livestock – Horses	CH_4	42.3	0.0	99.0
1.A.2.g.i	Other (please specify) – Manufacturing of Machinery Gaseous Fuels	CO_2	41.9	0.0	99.0

Note: Removals from the LULUCF sector are shown as negatives in this table. The absolute values for those removals were used for the calculations.

Table A1.3.2(b)   Results of the level analysis for 99 per cent of the gross emissions and removals for New Zealand in 1990 included for reference only

IPCC Tier 1 category level assessment – gross emissions (excluding LULUCF): 1990					
CRF category code	IPCC category	Gas	1990 estimate (kt CO_2-e)	Level assessment (%)	Cumulative total (%)
3.A.2	Other (please specify) – Sheep	CH_4	14,361.3	21.8	21.8
1.A.3.b	Transport – Road Transportation Liquid Fuels	CO_2	7,164.6	10.9	32.7
3.A.1	Option A – Dairy Cattle	CH_4	5,951.6	9.0	41.7
3.A.1	Option A – Non-Dairy Cattle	CH_4	5,737.5	8.7	50.5
3.D.1.3	Direct N_2O Emissions From Managed Soils – Urine and Dung Deposited by Grazing Animals	N_2O	5,131.8	7.8	58.3
5.A	Waste – Solid Waste Disposal	CH_4	3,510.9	5.3	63.6
1.A.1.a	Energy Industries – Public Electricity and Heat Production Gaseous Fuels	CO_2	3,011.8	4.6	68.2
1.A.1.c	Energy Industries – Manufacture of Solid Fuels and Other Energy Industries Gaseous Fuels	CO_2	1,720.1	2.6	70.8
2.C.1	Metal Industry – Iron and Steel Production	CO_2	1,306.7	2.0	72.8
1.A.4.c	Other Sectors – Agriculture/Forestry/Fishing Liquid Fuels	CO_2	1,072.3	1.6	74.4
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Solid Fuels	CO_2	938.6	1.4	75.8
2.C.3	Metal Industry – Aluminium Production	PFCs	909.9	1.4	77.2
1.A.3.a	Domestic Aviation – Jet Kerosene	CO_2	892.6	1.4	78.6
1.A.1.b	Energy Industries – Petroleum Refining Liquid Fuels	CO_2	778.9	1.2	79.8

CRF category code	IPCC category	Gas	1990 estimate (kt CO$_2$-e)	Level assessment (%)	Cumulative total (%)
	IPCC Tier 1 category level assessment – gross emissions (excluding LULUCF): 1990				
1.A.2.g.viii	Other (please specify) – Other (please specify) Solid Fuels	CO$_2$	731.1	1.1	80.9
3.D.2.1	Indirect N$_2$O Emissions From Managed Soils – Atmospheric Deposition	N$_2$O	710.2	1.1	81.9
1.A.2.c	Manufacturing Industries and Construction – Chemicals Gaseous Fuels	CO$_2$	528.7	0.8	82.7
1.A.4.a	Other Sectors – Commercial/Institutional Liquid Fuels	CO$_2$	500.6	0.8	83.5
1.A.1.a	Energy Industries – Public Electricity and Heat Production Solid Fuels	CO$_2$	474.8	0.7	84.2
2.C.3	Metal Industry – Aluminium Production	CO$_2$	449.0	0.7	84.9
2.A.1	Mineral Industry – Cement Production	CO$_2$	448.7	0.7	85.6
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Gaseous Fuels	CO$_2$	445.5	0.7	86.3
3.A.4	Other livestock – Deer	CH$_4$	418.3	0.6	86.9
3.B.1.1	Option A – Dairy Cattle	CH$_4$	390.1	0.6	87.5
1.A.2.f	Manufacturing Industries and Construction – Non-Metallic Minerals Solid Fuels	CO$_2$	382.9	0.6	88.1
3.D.2.2	Indirect N$_2$O Emissions From Managed Soils – Nitrogen Leaching and Run-off	N$_2$O	382.0	0.6	88.7
3.G	Agriculture – Liming	CO$_2$	360.1	0.5	89.2
1.A.2.d	Manufacturing Industries and Construction – Pulp, Paper and Print Gaseous Fuels	CO$_2$	348.6	0.5	89.7
1.A.4.b	Other Sectors – Residential Solid Fuels	CO$_2$	344.9	0.5	90.3
1.A.2.g.iii	Other (please specify) – Mining (excluding fuels) and Quarrying Liquid Fuels	CO$_2$	331.5	0.5	90.8
1.B.1.a.1	Coal Mining and Handling – Underground Mines	CH$_4$	289.6	0.4	91.2
1.B.2.b.5	Natural Gas – Distribution	CH$_4$	277.5	0.4	91.6
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Liquid Fuels	CO$_2$	265.9	0.4	92.0
5.D	Waste – Wastewater Treatment and Discharge	CH$_4$	240.6	0.4	92.4
1.A.4.a	Other Sectors – Commercial/Institutional Gaseous Fuels	CO$_2$	236.1	0.4	92.8
1.A.3.d	Domestic Navigation – Residual Fuel Oil	CO$_2$	232.9	0.4	93.1
3.D.1.1	Direct N$_2$O Emissions From Managed Soils – Inorganic N Fertilisers	N$_2$O	230.3	0.3	93.5
1.B.2.d	Other (please specify) – Geothermal	CO$_2$	228.6	0.3	93.8
3.A.4	Other livestock – Goats	CH$_4$	196.6	0.3	94.1
1.A.4.b	Other Sectors – Residential Gaseous Fuels	CO$_2$	185.6	0.3	94.4
3.D.1.4	Direct N$_2$O Emissions From Managed Soils – Crop Residues	N$_2$O	175.5	0.3	94.7
1.A.4.b	Other Sectors – Residential Liquid Fuels	CO$_2$	167.4	0.3	94.9
2.B.10	Chemical Industry – Other (please specify)	CO$_2$	152.3	0.2	95.1
1.B.2.b.2	Natural Gas – Production	CH$_4$	143.5	0.2	95.4
1.A.4.a	Other Sectors – Commercial/Institutional Solid Fuels	CO$_2$	142.2	0.2	95.6
1.A.3.b	Transport – Road Transportation Gaseous Fuels	CO$_2$	140.8	0.2	95.8
3.B.1.2	CH$_4$ Emissions – Sheep	CH$_4$	139.6	0.2	96.0

IPCC Tier 1 category level assessment – gross emissions (excluding LULUCF): 1990					
CRF category code	IPCC category	Gas	1990 estimate (kt CO$_2$-e)	Level assessment (%)	Cumulative total (%)
1.A.2.a	Manufacturing Industries and Construction – Iron and Steel Gaseous Fuels	CO$_2$	116.6	0.2	96.2
1.B.2.c.2.iii	Flaring – Combined	CO$_2$	114.4	0.2	96.3
1.A.2.d	Manufacturing Industries and Construction – Pulp, Paper and Print Solid Fuels	CO$_2$	109.5	0.2	96.5
1.B.2.c.1.ii	Venting – Gas	CO$_2$	109.3	0.2	96.7
1.A.4.c	Other Sectors – Agriculture/Forestry/Fishing Gaseous Fuels	CO$_2$	106.2	0.2	96.8
2.G.3	Other Product Manufacture and Use – N$_2$O from Product Uses	N$_2$O	102.4	0.2	97.0
5.D	Waste – Wastewater Treatment and Discharge	N$_2$O	96.5	0.1	97.1
1.A.3.b	Transport – Road Transportation Liquid Fuels	N$_2$O	89.3	0.1	97.3
2.A.2	Mineral Industry – Lime Production	CO$_2$	82.6	0.1	97.4
1.A.3.c	Transport – Railways Liquid Fuels	CO$_2$	78.4	0.1	97.5
3.B.1.1	Option A – Non-Dairy Cattle	CH$_4$	76.6	0.1	97.6
1.A.3.b	Transport – Road Transportation Liquid Fuels	CH$_4$	72.9	0.1	97.8
1.B.2.c.2.iii	Flaring – Combined	CH$_4$	64.6	0.1	97.8
1.A.2.f	Manufacturing Industries and Construction – Non-Metallic Minerals Gaseous Fuels	CO$_2$	64.3	0.1	97.9
1.A.2.g.vi	Other (please specify) – Textile and Leather Gaseous Fuels	CO$_2$	59.2	0.1	98.0
3.B.1.3	CH$_4$ Emissions – Swine	CH$_4$	58.6	0.1	98.1
1.B.2.d	Other (please specify) – Geothermal	CH$_4$	54.8	0.1	98.2
1.A.2.d	Manufacturing Industries and Construction – Pulp, Paper and Print Liquid Fuels	CO$_2$	52.2	0.1	98.3
1.A.2.g.viii	Other (please specify) – Other (please specify) Liquid Fuels	CO$_2$	51.7	0.1	98.4
1.A.4.b	Other Sectors – Residential Biomass	CH$_4$	48.4	0.1	98.4
1.A.2.f	Manufacturing Industries and Construction – Non-Metallic Minerals Liquid Fuels	CO$_2$	47.9	0.1	98.5
1.A.3.a	Domestic Aviation – Aviation Gasoline	CO$_2$	47.7	0.1	98.6
3.A.4	Other livestock – Horses	CH$_4$	42.3	0.1	98.7
1.A.2.g.i	Other (please specify) – Manufacturing of Machinery Gaseous Fuels	CO$_2$	41.9	0.1	98.7
3.H	Agriculture – Urea Application	CO$_2$	39.2	0.1	98.8
1.B.1.a.2	Coal Mining and Handling – Surface Mines	CH$_4$	38.7	0.1	98.8
3.D.1.2	Direct N$_2$O Emissions From Managed Soils – Organic N Fertilisers	N$_2$O	37.6	0.1	98.9
3.B.2.5	N$_2$O and NMVOC Emissions – Indirect N$_2$O Emissions	N$_2$O	37.5	0.1	98.9
1.A.4.c	Other Sectors – Agriculture/Forestry/Fishing Solid Fuels	CO$_2$	35.1	0.1	99.0

Table A1.3.3(a) Results of the key category trend analysis for 99 per cent of the net emissions and removals for New Zealand in 1990 – 2016

CRF category code	IPCC category	Gas	1990 estimate (kt CO$_2$-e)	2016 estimate (kt CO$_2$-e)	Trend assessment	Contribution to trend (%)	Cumulative total (%)
IPCC Tier 1 category trend assessment – including LULUCF (net emissions)							
4.A.2	Forest Land – Land Converted to Forest Land	CO$_2$	−19,911.5	−13,149.7	0.074	16.7	16.7
3.A.2	Other (please specify) – Sheep	CH$_4$	14,361.3	8,412.6	0.062	14.0	30.7
3.A.1	Option A – Dairy Cattle	CH$_4$	5,951.6	13,623.6	0.054	12.2	42.9
1.A.3.b	Transport – Road Transportation Liquid Fuels	CO$_2$	7,164.6	13,470.5	0.042	9.5	52.4
4.G	Land Use, Land-Use Change and Forestry – Harvested Wood Products	CO$_2$	−2,072.9	−5,946.4	0.028	6.4	58.8
4.C.2	Grassland – Land Converted to Grassland	CO$_2$	232.1	3,070.8	0.022	5.0	63.8
1.A.1.c	Energy Industries – Manufacture of Solid Fuels and Other Energy Industries Gaseous Fuels	CO$_2$	1,720.1	273.3	0.013	3.0	66.8
4.A.1	Forest Land – Forest Land Remaining Forest Land	CO$_2$	−9,143.7	−8,787.5	0.012	2.8	69.6
1.A.2.c	Manufacturing Industries and Construction – Chemicals Gaseous Fuels	CO$_2$	528.7	1,939.5	0.011	2.4	72.0
2.F.1	Product Uses as Substitutes for ODS – Refrigeration and Air Conditioning	HFCs	0.0	1,282.5	0.010	2.3	74.3
3.A.1	Option A – Non-Dairy Cattle	CH$_4$	5,737.5	5,228.7	0.010	2.3	76.5
3.D.1.1	Direct N$_2$O Emissions From Managed Soils – Inorganic N Fertilisers	N$_2$O	230.3	1,332.2	0.008	1.9	78.4
2.C.3	Metal Industry – Aluminium Production	PFCs	909.9	48.7	0.008	1.7	80.2
1.A.1.a	Energy Industries – Public Electricity and Heat Production Gaseous Fuels	CO$_2$	3,011.8	2,586.9	0.007	1.5	81.6
1.A.2.g.viii	Other (please specify) – Other (please specify) Solid Fuels	CO$_2$	731.1	92.0	0.006	1.3	83.0
4.C.1	Grassland – Grassland Remaining Grassland	CO$_2$	521.3	1,306.4	0.006	1.3	84.2
5.A	Waste – Solid Waste Disposal	CH$_4$	3,510.9	3,439.0	0.004	1.0	85.2
3.H	Agriculture – Urea Application	CO$_2$	39.2	574.4	0.004	0.9	86.1
3.B.1.1	Option A – Dairy Cattle	CH$_4$	390.1	930.4	0.004	0.9	87.0
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Solid Fuels	CO$_2$	938.6	1,496.5	0.003	0.8	87.8
1.B.2.d	Other (please specify) – Geothermal	CO$_2$	228.6	659.1	0.003	0.7	88.5
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Gaseous Fuels	CO$_2$	445.5	864.3	0.003	0.6	89.1
1.A.4.b	Other Sectors – Residential Solid Fuels	CO$_2$	344.9	31.8	0.003	0.6	89.8

CRF category code	IPCC category	Gas	1990 estimate (kt CO$_2$-e)	2016 estimate (kt CO$_2$-e)	Trend assessment	Contribution to trend (%)	Cumulative total (%)
3.D.1.3	Direct N$_2$O Emissions From Managed Soils – Urine and Dung Deposited by Grazing Animals	N$_2$O	5,131.8	5,503.3	0.002	0.6	90.3
2.C.1	Metal Industry – Iron and Steel Production	CO$_2$	1,306.7	1,712.1	0.002	0.4	90.7
1.B.1.a.1	Coal Mining and Handling – Underground Mines	CH$_4$	289.6	113.5	0.002	0.4	91.1
3.A.4	Other Livestock – Goats	CH$_4$	196.6	22.7	0.002	0.4	91.5
1.A.1.b	Energy Industries – Petroleum Refining Liquid Fuels	CO$_2$	778.9	690.2	0.002	0.3	91.8
1.A.4.a	Other Sectors – Commercial/Institutional Gaseous Fuels	CO$_2$	236.1	439.6	0.001	0.3	92.1
1.B.2.c.2.iii	Flaring – Combined	CO$_2$	114.4	294.5	0.001	0.3	92.4
1.A.3.b	Transport – Road Transportation Gaseous Fuels	CO$_2$	140.8	0.9	0.001	0.3	92.7
1.A.2.f	Manufacturing Industries and Construction – Non-Metallic Minerals Solid Fuels	CO$_2$	382.9	275.3	0.001	0.3	93.0
1.A.1.b	Energy Industries – Petroleum Refining Gaseous Fuels	CO$_2$	0.0	157.1	0.001	0.3	93.2
1.B.2.c.1.ii	Venting – Gas	CO$_2$	109.3	268.2	0.001	0.3	93.5
1.A.2.g.viii	Other (please specify) – Other (please specify) Liquid Fuels	CO$_2$	51.7	200.4	0.001	0.3	93.7
1.A.2.g.iii	Other (please specify) – Mining (excluding fuels) and Quarrying Liquid Fuels	CO$_2$	331.5	510.5	0.001	0.2	94.0
1.A.4.b	Other Sectors – Residential Gaseous Fuels	CO$_2$	185.6	343.2	0.001	0.2	94.2
1.A.3.a	Domestic Aviation – Jet Kerosene	CO$_2$	892.6	893.7	0.001	0.2	94.4
1.B.2.b.5	Natural Gas – Distribution	CH$_4$	277.5	200.1	0.001	0.2	94.6
1.B.2.d	Other (please specify) – Geothermal	CH$_4$	54.8	172.8	0.001	0.2	94.8
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Liquid Fuels	CO$_2$	265.9	411.2	0.001	0.2	95.0
1.A.4.a	Other Sectors – Commercial/Institutional Liquid Fuels	CO$_2$	500.6	458.5	0.001	0.2	95.2
1.A.4.c	Other Sectors – Agriculture/Forestry/Fishing Liquid Fuels	CO$_2$	1,072.3	1,321.7	0.001	0.2	95.4
3.G	Agriculture – Liming	CO$_2$	360.1	514.4	0.001	0.2	95.6
3.D.2.1	Indirect N$_2$O Emissions From Managed Soils – Atmospheric Deposition	N$_2$O	710.2	910.1	0.001	0.2	95.8
2.F.4	Product Uses as Substitutes for ODS – Aerosols	HFCs	0.0	96.2	0.001	0.2	96.0
2.B.8	Chemical Industry – Petrochemical and Carbon Black Production	CH$_4$	27.6	125.3	0.001	0.2	96.1

IPCC Tier 1 category trend assessment – including LULUCF (net emissions)							
CRF category code	IPCC category	Gas	1990 estimate (kt CO₂-e)	2016 estimate (kt CO₂-e)	Trend assessment	Contribution to trend (%)	Cumulative total (%)
1.A.1.a	Energy Industries – Public Electricity and Heat Production Solid Fuels	CO_2	474.8	445.7	0.001	0.2	96.3
2.A.2	Mineral Industry – Lime Production	CO_2	82.6	176.0	0.001	0.1	96.4
4.A.2	Forest Land – Land Converted to Forest Land	N_2O	121.1	62.4	0.001	0.1	96.6
1.A.4.c	Other Sectors – Agriculture/Forestry/Fishing Solid Fuels	CO_2	35.1	114.7	0.001	0.1	96.7
1.A.2.f	Manufacturing Industries and Construction – Non-Metallic Minerals Liquid Fuels	CO_2	47.9	127.0	0.001	0.1	96.8
3.B.1.2	CH₄ Emissions – Sheep	CH_4	139.6	86.9	0.001	0.1	97.0
1.A.2.d	Manufacturing Industries and Construction – Pulp, Paper and Print Solid Fuels	CO_2	109.5	54.6	0.001	0.1	97.1
3.D.2.2	Indirect N₂O Emissions From Managed Soils – Nitrogen Leaching and Run-off	N_2O	382.0	501.6	0.001	0.1	97.2
4.B.1	Cropland – Cropland Remaining Cropland	CO_2	358.1	340.5	0.001	0.1	97.3
1.A.4.a	Other Sectors – Commercial/Institutional Solid Fuels	CO_2	142.2	99.9	0.000	0.1	97.4
4.B.2	Cropland – Land Converted to Cropland	CO_2	111.4	68.4	0.000	0.1	97.5
2.G.3	Other Product Manufacture and Use – N₂O from Product Uses	N_2O	102.4	59.0	0.000	0.1	97.6
1.A.3.b	Transport – Road Transportation Liquid Fuels	CH_4	72.9	25.8	0.000	0.1	97.7
3.D.1.4	Direct N₂O Emissions From Managed Soils – Crop Residues	N_2O	175.5	252.6	0.000	0.1	97.8
4.C.1	Grassland – Grassland Remaining Grassland	CH_4	90.0	51.9	0.000	0.1	97.9
1.A.3.c	Transport – Railways Liquid Fuels	CO_2	78.4	130.8	0.000	0.1	98.0
1.A.2.g.vi	Other (please specify) – Textile and Leather Gaseous Fuels	CO_2	59.2	30.1	0.000	0.1	98.1
1.A.3.d	Domestic Navigation – Residual Fuel Oil	CO_2	232.9	300.7	0.000	0.1	98.1
1.A.2.a	Manufacturing Industries and Construction – Iron and Steel Gaseous Fuels	CO_2	116.6	95.5	0.000	0.1	98.2
1.A.2.d	Manufacturing Industries and Construction – Pulp, Paper and Print Gaseous Fuels	CO_2	348.6	359.2	0.000	0.1	98.3
1.A.4.c	Other Sectors – Agriculture/Forestry/Fishing Gaseous Fuels	CO_2	106.2	86.7	0.000	0.1	98.3
3.B.2.5	N₂O and NMVOC Emissions – Indirect N₂O Emissions	N_2O	37.5	76.0	0.000	0.1	98.4
1.A.2.g.i	Other (please specify) – Manufacturing of Machinery Gaseous Fuels	CO_2	41.9	15.2	0.000	0.1	98.4

IPCC Tier 1 category trend assessment – including LULUCF (net emissions)							
CRF category code	IPCC category	Gas	1990 estimate (kt CO$_2$-e)	2016 estimate (kt CO$_2$-e)	Trend assessment	Contribution to trend (%)	Cumulative total (%)
2.C.3	Metal Industry – Aluminium Production	CO$_2$	449.0	539.4	0.000	0.1	98.5
2.A.4	Mineral Industry – Other Process Uses of Carbonates	CO$_2$	30.5	64.4	0.000	0.1	98.5
3.B.1.3	CH$_4$ Emissions – Swine	CH$_4$	58.6	37.8	0.000	0.1	98.6
1.A.4.b	Other Sectors – Residential Solid Fuels	CH$_4$	27.3	2.5	0.000	0.1	98.6
1.A.2.d	Manufacturing Industries and Construction – Pulp, Paper and Print Liquid Fuels	CO$_2$	52.2	86.0	0.000	0.0	98.7
3.A.4	Other livestock – Horses	CH$_4$	42.3	22.0	0.000	0.0	98.7
4.C.1	Grassland – Grassland Remaining Grassland	N$_2$O	33.0	13.1	0.000	0.0	98.8
1.B.2.b.2	Natural Gas – Production	CH$_4$	143.5	138.5	0.000	0.0	98.8
1.A.2.g.iii	Other (please specify) – Mining (excluding fuels) and Quarrying Solid Fuels	CO$_2$	19.9	0.0	0.000	0.0	98.9
1.A.3.e	Transport – Other Transportation (please specify) Gaseous Fuels	CO$_2$	5.5	28.5	0.000	0.0	98.9
2.A.1	Mineral Industry – Cement Production	CO$_2$	448.7	486.4	0.000	0.0	98.9
4.D.2	Wetlands – Land Converted to Wetlands	CO$_2$	−20.4	1.1	0.000	0.0	99.0
5.D	Waste – Wastewater Treatment and Discharge	N$_2$O	96.5	130.8	0.000	0.0	99.0

Note: Key categories are those that comprise 95 per cent of the total. Removals from the LULUCF sector are shown as negatives in this table. The absolute values for those removals were used for the calculations.

Table A1.3.3(b)   Results of the key category trend analysis for 99 per cent of the gross emissions and removals for New Zealand in 1990 – 2016

IPCC Tier 1 category trend assessment – gross emissions (excluding LULUCF)							
CRF Category code	IPCC Category	Gas	1990 estimate (kt CO$_2$-e)	2016 estimate (kt CO$_2$-e)	Trend assessment	Contribution to trend (%)	Cumulative total (%)
3.A.2	Other (please specify) – Sheep	CH$_4$	14,361.3	8,412.6	0.093	22.5	22.5
3.A.1	Option A – Dairy Cattle	CH$_4$	5,951.6	13,623.6	0.069	16.7	39.1
1.A.3.b	Transport – Road Transportation Liquid Fuels	CO$_2$	7,164.6	13,470.5	0.052	12.6	51.7
1.A.1.c	Energy Industries – Manufacture of Solid Fuels and Other Energy Industries Gaseous Fuels	CO$_2$	1,720.1	273.3	0.019	4.6	56.3
3.A.1	Option A – Non-Dairy Cattle	CH$_4$	5,737.5	5,228.7	0.017	4.2	60.5
1.A.2.c	Manufacturing Industries and Construction – Chemicals Gaseous Fuels	CO$_2$	528.7	1,939.5	0.014	3.4	63.8
2.F.1	Product Uses as Substitutes for ODS – Refrigeration and Air Conditioning	HFCs	0.0	1,282.5	0.014	3.3	67.1
3.D.1.1	Direct N$_2$O Emissions From Managed Soils – Inorganic N Fertilisers	N$_2$O	230.3	1,332.2	0.011	2.7	69.8

IPCC Tier 1 category trend assessment – gross emissions (excluding LULUCF)							
CRF Category code	IPCC Category	Gas	1990 estimate (kt CO_2-e)	2016 estimate (kt CO_2-e)	Trend assessment	Contribution to trend (%)	Cumulative total (%)
2.C.3	Metal Industry – Aluminium Production	PFCs	909.9	48.7	0.011	2.7	72.5
1.A.1.a	Energy Industries – Public Electricity and Heat Production Gaseous Fuels	CO_2	3,011.8	2,586.9	0.011	2.6	75.1
1.A.2.g.viii	Other (please specify) – Other (please specify) Solid Fuels	CO_2	731.1	92.0	0.008	2.0	77.1
5.A	Waste – Solid Waste Disposal	CH_4	3,510.9	3,439.0	0.008	2.0	79.0
3.D.1.3	Direct N_2O Emissions From Managed Soils – Urine and Dung Deposited by Grazing Animals	N_2O	5,131.8	5,503.3	0.007	1.6	80.7
3.H	Agriculture – Urea Application	CO_2	39.2	574.4	0.006	1.4	82.0
3.B.1.1	Option A – Dairy Cattle	CH_4	390.1	930.4	0.005	1.2	83.2
1.B.2.d	Other (please specify) – Geothermal	CO_2	228.6	659.1	0.004	1.0	84.2
1.A.4.b	Other Sectors – Residential Solid Fuels	CO_2	344.9	31.8	0.004	1.0	85.2
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Solid Fuels	CO_2	938.6	1,496.5	0.004	1.0	86.1
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Gaseous Fuels	CO_2	445.5	864.3	0.004	0.8	87.0
1.A.1.b	Energy Industries – Petroleum Refining Liquid Fuels	CO_2	778.9	690.2	0.003	0.6	87.6
1.B.1.a.1	Coal Mining and Handling – Underground Mines	CH_4	289.6	113.5	0.002	0.6	88.2
3.A.4	Other Livestock – Goats	CH_4	196.6	22.7	0.002	0.5	88.7
1.A.2.f	Manufacturing Industries and Construction – Non-Metallic Minerals Solid Fuels	CO_2	382.9	275.3	0.002	0.5	89.2
1.A.3.a	Domestic Aviation – Jet Kerosene	CO_2	892.6	893.7	0.002	0.4	89.7
1.A.3.b	Transport – Road Transportation Gaseous Fuels	CO_2	140.8	0.9	0.002	0.4	90.1
1.B.2.c.2.iii	Flaring – Combined	CO_2	114.4	294.5	0.002	0.4	90.5
1.A.4.a	Other Sectors – Commercial/Institutional Gaseous Fuels	CO_2	236.1	439.6	0.002	0.4	90.9
1.A.1.b	Energy Industries – Petroleum Refining Gaseous Fuels	CO_2	0.0	157.1	0.002	0.4	91.3
2.C.1	Metal Industry – Iron and Steel Production	CO_2	1,306.7	1,712.1	0.002	0.4	91.7
1.A.4.a	Other Sectors – Commercial/Institutional Liquid Fuels	CO_2	500.6	458.5	0.001	0.4	92.0
1.A.2.g.viii	Other (please specify) – Other (please specify) Liquid Fuels	CO_2	51.7	200.4	0.001	0.4	92.4
1.B.2.c.1.ii	Venting – Gas	CO_2	109.3	268.2	0.001	0.4	92.8

CRF Category code	IPCC Category	Gas	1990 estimate (kt CO$_2$-e)	2016 estimate (kt CO$_2$-e)	Trend assessment	Contribution to trend (%)	Cumulative total (%)
1.B.2.b.5	Natural Gas – Distribution	CH$_4$	277.5	200.1	0.001	0.3	93.1
1.A.1.a	Energy Industries – Public Electricity and Heat Production Solid Fuels	CO$_2$	474.8	445.7	0.001	0.3	93.4
1.A.4.b	Other Sectors – Residential Gaseous Fuels	CO$_2$	185.6	343.2	0.001	0.3	93.7
1.A.2.g.iii	Other (please specify) – Mining (excluding fuels) and Quarrying Liquid Fuels	CO$_2$	331.5	510.5	0.001	0.3	94.0
1.B.2.d	Other (please specify) – Geothermal	CH$_4$	54.8	172.8	0.001	0.3	94.3
2.F.4	Product Uses as Substitutes for ODS – Aerosols	HFCs	0.0	96.2	0.001	0.2	94.5
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Liquid Fuels	CO$_2$	265.9	411.2	0.001	0.2	94.8
2.B.8	Chemical Industry – Petrochemical and Carbon Black Production	CH$_4$	27.6	125.3	0.001	0.2	95.0
3.G	Agriculture – Liming	CO$_2$	360.1	514.4	0.001	0.2	95.2
3.B.1.2	CH$_4$ Emissions – Sheep	CH$_4$	139.6	86.9	0.001	0.2	95.4
2.A.2	Mineral Industry – Lime Production	CO$_2$	82.6	176.0	0.001	0.2	95.6
1.A.2.d	Manufacturing Industries and Construction – Pulp, Paper and Print Solid Fuels	CO$_2$	109.5	54.6	0.001	0.2	95.8
1.A.4.c	Other Sectors – Agriculture/Forestry/Fishing Solid Fuels	CO$_2$	35.1	114.7	0.001	0.2	96.0
1.A.4.a	Other Sectors – Commercial/Institutional Solid Fuels	CO$_2$	142.2	99.9	0.001	0.2	96.2
1.A.2.f	Manufacturing Industries and Construction – Non-metallic Minerals Liquid Fuels	CO$_2$	47.9	127.0	0.001	0.2	96.4
2.G.3	Other Product Manufacture and Use – N$_2$O from Product Uses	N$_2$O	102.4	59.0	0.001	0.2	96.5
1.A.3.b	Transport – Road Transportation Liquid Fuels	CH$_4$	72.9	25.8	0.001	0.2	96.7
3.D.2.1	Indirect N$_2$O Emissions From Managed Soils – Atmospheric Deposition	N$_2$O	710.2	910.1	0.001	0.2	96.8
1.A.2.d	Manufacturing Industries and Construction – Pulp, Paper and Print Gaseous Fuels	CO$_2$	348.6	359.2	0.001	0.1	97.0
2.A.1	Mineral Industry – Cement Production	CO$_2$	448.7	486.4	0.001	0.1	97.1
3.D.2.2	Indirect N$_2$O Emissions From Managed Soils – Nitrogen Leaching and Run-off	N$_2$O	382.0	501.6	0.000	0.1	97.2
1.A.2.a	Manufacturing Industries and Construction – Iron and Steel Gaseous Fuels	CO$_2$	116.6	95.5	0.000	0.1	97.3
3.D.1.4	Direct N$_2$O Emissions From Managed Soils – Crop Residues	N$_2$O	175.5	252.6	0.000	0.1	97.5

IPCC Tier 1 category trend assessment – gross emissions (excluding LULUCF)							
CRF Category code	IPCC Category	Gas	1990 estimate (kt CO₂-e)	2016 estimate (kt CO₂-e)	Trend assessment	Contribution to trend (%)	Cumulative total (%)
1.A.2.g.vi	Other (please specify) – Textile and Leather Gaseous Fuels	CO_2	59.2	30.1	0.000	0.1	97.6
1.A.4.c	Other Sectors – Agriculture/Forestry/Fishing Gaseous Fuels	CO_2	106.2	86.7	0.000	0.1	97.7
1.A.4.c	Other Sectors – Agriculture/Forestry/Fishing Liquid Fuels	CO_2	1,072.3	1,321.7	0.000	0.1	97.8
1.A.3.c	Transport – Railways Liquid Fuels	CO_2	78.4	130.8	0.000	0.1	97.9
3.A.4	Other Livestock – Deer	CH_4	418.3	465.0	0.000	0.1	97.9
1.A.2.g.i	Other (please specify) – Manufacturing of Machinery Gaseous Fuels	CO_2	41.9	15.2	0.000	0.1	98.0
1.B.2.b.2	Natural Gas – Production	CH_4	143.5	138.5	0.000	0.1	98.1
3.B.1.3	CH_4 Emissions – Swine	CH_4	58.6	37.8	0.000	0.1	98.2
3.B.2.5	N₂O and NMVOC Emissions – Indirect N₂O Emissions	N_2O	37.5	76.0	0.000	0.1	98.3
1.A.4.b	Other Sectors – Residential Solid Fuels	CH_4	27.3	2.5	0.000	0.1	98.4
3.A.4	Other Livestock – Horses	CH_4	42.3	22.0	0.000	0.1	98.4
2.A.4	Mineral Industry – Other Process Uses of Carbonates	CO_2	30.5	64.4	0.000	0.1	98.5
1.A.2.g.iii	Other (please specify) – Mining (excluding fuels) and Quarrying Solid Fuels	CO_2	19.9	0.0	0.000	0.1	98.6
1.A.2.d	Manufacturing Industries and Construction – Pulp, Paper and Print Liquid Fuels	CO_2	52.2	86.0	0.000	0.1	98.6
1.A.2.g.vi	Other (please specify) – Textile and leather Solid Fuels	CO_2	23.0	5.3	0.000	0.1	98.7
1.A.3.d	Domestic Navigation – Residual Fuel Oil	CO_2	232.9	300.7	0.000	0.1	98.7
1.A.3.a	Domestic Aviation – Aviation Gasoline	CO_2	47.7	35.0	0.000	0.1	98.8
1.A.3.e	Transport – Other Transportation (please specify) Gaseous Fuels	CO_2	5.5	28.5	0.000	0.1	98.9
5.D	Waste – Wastewater Treatment and Discharge	CH_4	240.6	266.0	0.000	0.1	98.9
3.B.1.1	Option A – Non-Dairy Cattle	CH_4	76.6	70.1	0.000	0.1	99.0
1.A.2.g.iii	Other (please specify) – Mining (excluding fuels) and Quarrying Gaseous Fuels	CO_2	10.7	33.3	0.000	0.1	99.0

Note: Key categories are those that comprise 95 per cent of the total.

Annex 1: References

IPCC. 2003. Penman J, Gytarsky M, Hiraishi T, Krug T, Kruger D, Pipatti R, Buendia L, Miwa K, Ngara T, Tanabe K, Wagner F (eds). *Good Practice Guidance for Land-Use, Land-Use Change and Forestry.* IPCC National Greenhouse Gas Inventories Programme. Japan: Published for the IPCC by the Institute for Global Environmental Strategies.

IPCC. 2006. Eggleston HS, Buendia L, Miwa K, Ngara T, Tanabe K (eds). *2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 1. General Guidance and Reporting.* IPCC National Greenhouse Gas Inventories Programme. Japan: Published for the IPCC by the Institute for Global Environmental Strategies.

Annex 2: Uncertainty analysis

Uncertainty estimates are an essential element of a complete emissions inventory. The purpose of uncertainty information is to help prioritise efforts to improve the accuracy of inventories in the future and guide decisions on methodological choice (IPCC, 2006).

New Zealand has followed Approach 1 for uncertainty analysis, as required by the inventory reporting guidelines under United Nations Framework Convention on Climate Change (UNFCCC, 2013) and Intergovernmental Panel on Climate Change (IPCC) methodological guidelines (IPCC, 2006). Uncertainties in the categories are combined to provide uncertainty estimates for the entire inventory in any year and the uncertainty in the overall inventory trend over time. Land Use, Land-Use Change and Forestry (LULUCF) sector categories have been included using the absolute value of any removals of carbon dioxide (CO_2) (table A2.1.1). Table A2.1.2 calculates the uncertainty only in emissions, that is, excluding LULUCF removals.

A2.1 Approach 1 uncertainty calculation

The uncertainty in activity data and emission and/or removal factors shown in tables A2.1.1 and A2.1.2 are equal to half the 95 per cent confidence interval divided by the mean and expressed as a percentage. The reason for halving the 95 per cent confidence interval is that the value corresponds to the familiar plus or minus value when uncertainties are loosely quoted as 'plus or minus x per cent'.

Where uncertainty is highly asymmetrical, the larger percentage difference between the mean and the confidence limit is entered. Where only the total uncertainty is known for a category, then:

- if uncertainty is correlated across years, the uncertainty is entered as the emission or the removal factor uncertainty and as zero in the activity data uncertainty

- if uncertainty is not correlated across years, the uncertainty is entered as the uncertainty in the activity data and as zero in the emission or the removal factor uncertainty.

In Approach 1, uncertainties in the trend are estimated using two sensitivities.

- Type A sensitivity is the change in the difference of total emissions between the base year and the current year, expressed as a percentage. Further, this change results from a 1 per cent increase in emissions of a given source category and a greenhouse gas in both the base year and the current year.

- Type B sensitivity is the change in the difference of total emissions between the base year and the current year, expressed as a percentage. Further, this change results from a 1 per cent increase in emissions of a given source category and gas in the current year only.

Uncertainties that are fully correlated between years are associated with Type A sensitivities, and uncertainties that are not correlated between years are associated with Type B sensitivities.

In tables A2.1.1 and A2.1.2, the figure labelled 'Uncertainty in the trend' is an estimate of the total uncertainty in the trend in emissions since the base year. This is expressed as the number of percentage points in the 95 per cent confidence interval in the per cent change in emissions since the base year. The total uncertainty in the trend is calculated by combining the contribution of emissions factor uncertainty and activity data uncertainty to the trend across all categories using equation 3.1 (IPCC, 2006).

The values for individual categories are an estimate of the uncertainty introduced into the trend by the category in question.

IPCC source category	Gas	1990 emissions or absolute value of removals (kt CO₂-e)	2016 emissions or absolute value of removals (kt CO₂-e)	Activity data uncertainty (%)	Emission or removal factor uncertainty (%)	Combined uncertainty (%)	Combined uncertainty as a per cent of the national total in 2016 (%)	Type A sensitivity (%)	Type B sensitivity (%)	Uncertainty in the trend in national total introduced by emission or removal factor uncertainty (%)	Uncertainty in trend in national total introduced by activity data uncertainty (%)	Uncertainty introduced into the trend in the national total (%)	Emission/ removal factor quality indicator	Activity data quality indicator
Energy – Liquid fuels	CO_2	11,789.99	18,928.69	1.5	0.5	1.6	0.3	0.1	0.2	0.0	0.4	0.4	R	M
Energy – Solid fuels	CO_2	3,211.03	2,617.39	1.2	2.2	2.5	0.1	0.0	0.0	0.0	0.0	0.1	M	M
Energy – Gaseous fuels	CO_2	7,054.90	7,372.50	−0.7	2.6	2.7	0.2	0.0	0.1	0.0	−0.1	0.1	M	M
Energy – Fugitive – geothermal	CO_2	228.58	659.15	5.0	5.0	7.1	0.0	0.0	0.0	0.0	0.0	0.1	M	D
Energy – Fugitive – venting/flaring	CO_2	229.84	577.55	−0.7	2.6	2.7	0.0	0.0	0.0	0.0	0.0	0.0	M	M
Energy – Fugitive – oil and gas activities	CO_2	0.21	0.20	5.0	100.0	100.1	0.0	0.0	0.0	0.0	0.0	0.0	D	D
Energy – Fugitive – transmission and distribution	CO_2	1.46	1.25	−0.7	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	D	M
IPPU – Mineral industry	CO_2	561.87	726.79	2.0	7.0	7.3	0.0	0.0	0.0	0.0	0.0	0.0	D	M
IPPU – Chemical industry	CO_2	175.40	191.34	2.0	6.0	6.3	0.0	0.0	0.0	0.0	0.0	0.0	D	D
IPPU – Metal industry	CO_2	1,757.51	2,251.52	5.0	7.0	8.6	0.2	0.0	0.0	0.0	0.2	0.2	D	D
IPPU – Non-energy products from fuels and solvent use	CO_2	30.34	46.54	20.0	50.0	53.9	0.0	0.0	0.0	0.0	0.0	0.0	D	D
Agriculture – Liming	CO_2	360.06	514.41	3.4	50.0	50.1	0.2	0.0	0.0	0.1	0.0	0.1	D	R
Agriculture – Urea application	CO_2	39.19	574.39	10.0	50.0	51.0	0.3	0.0	0.0	0.3	0.1	0.3	D	R
LULUCF – Forest land	CO_2	29,055.28	21,937.24	5.9	41.6	42.1	8.3	−0.1	0.2	−4.6	1.9	5.0	M	M
LULUCF – Cropland	CO_2	469.44	408.97	5.5	68.9	69.1	0.3	0.0	0.0	−0.1	0.0	0.1	M	M
LULUCF – Grassland	CO_2	753.34	4,377.16	5.1	49.6	49.8	2.0	0.0	0.0	1.8	0.3	1.8	M	M
LULUCF – Wetlands	CO_2	10.95	19.96	30.6	0.3	30.6	0.0	0.0	0.0	0.0	0.0	0.0	M	M
LULUCF – Settlements	CO_2	67.74	78.86	18.4	95.3	97.1	0.1	0.0	0.0	0.0	0.0	0.0	M	M
LULUCF – Other land	CO_2	12.32	33.97	22.0	63.5	67.2	0.0	0.0	0.0	0.0	0.0	0.0	M	M

IPCC source category	Gas	1990 emissions or absolute value of removals (kt CO₂-e)	2016 emissions or absolute value of removals (kt CO₂-e)	Activity data uncertainty (%)	Emission or removal factor uncertainty (%)	Combined uncertainty (%)	Combined uncertainty as a per cent of the national total in 2016 (%)	Type A sensitivity (%)	Type B sensitivity (%)	Uncertainty in the trend in national total introduced by emission or removal factor uncertainty (%)	Uncertainty in trend in national total introduced by activity data uncertainty (%)	Uncertainty introduced into the trend in the national total (%)	Emission/removal factor quality indicator	Activity data quality indicator
LULUCF – Harvested wood products	CO₂	2,072.91	5,946.38	15.0	67.4	69.0	3.7	0.0	0.1	2.5	1.3	2.8	M	M
Waste – Incineration and open burning of waste	CO₂	13.18	1.21	50.0	40.0	64.0	0.0	0.0	0.0	0.0	0.0	0.0	D	D
Energy – Liquid fuels	CH₄	82.24	33.89	1.5	50.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	D	M
Energy – Solid fuels	CH₄	36.40	16.70	1.2	50.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	D	M
Energy – Gaseous fuels	CH₄	9.04	4.40	−0.7	50.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	D	M
Energy – Biomass	CH₄	66.60	78.90	50.0	50.0	70.7	0.0	0.0	0.0	0.0	0.1	0.1	D	D
Energy – Fugitive – geothermal	CH₄	54.79	172.83	5.0	5.0	7.1	0.0	0.0	0.0	0.0	0.0	0.0	D	D
Energy – Fugitive – venting/processing	CH₄	66.06	76.10	−0.7	50.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	D	M
Energy – Fugitive – coal mining	CH₄	328.23	171.80	1.2	50.0	50.0	0.1	0.0	0.0	−0.1	0.0	0.1	D	M
Energy – Fugitive – transmission and distribution	CH₄	279.96	205.96	−0.7	100.0	100.0	0.2	0.0	0.0	−0.1	0.0	0.1	D	M
Energy – Fugitive – oil and gas activities	CH₄	143.52	138.55	−0.7	100.0	100.0	0.1	0.0	0.0	0.0	0.0	0.0	D	D
Energy – Fugitive – oil transportation and storage	CH₄	4.40	5.12	5.0	50.0	50.2	0.0	0.0	0.0	0.0	0.0	0.0	D	D
IPPU – Chemical industry	CH₄	27.60	125.28	2.0	80.0	80.0	0.1	0.0	0.0	0.1	0.0	0.1	D	D
Agriculture – Enteric fermentation	CH₄	26,718.21	27,782.94	3.9	15.5	16.0	4.0	0.0	0.3	−0.4	1.6	1.6	M	M
Agriculture – Manure management	CH₄	686.08	1,147.44	5.0	20.0	20.6	0.2	0.0	0.0	0.1	0.1	0.1	M	M
Agriculture – Burning of residues	CH₄	22.62	19.91	6.0	20.0	20.9	0.0	0.0	0.0	0.0	0.0	0.0	D	R
LULUCF	CH₄	117.70	99.60	30.0	41.6	51.3	0.0	0.0	0.0	0.0	0.0	0.0	M	M

IPCC source category	Gas	1990 emissions or absolute value of removals (kt CO₂-e)	2016 emissions or absolute value of removals (kt CO₂-e)	Activity data uncertainty (%)	Emission or removal factor uncertainty (%)	Combined uncertainty (%)	Combined uncertainty as a per cent of the national total in 2016 (%)	Type A sensitivity (%)	Type B sensitivity (%)	Uncertainty in the trend in national total introduced by emission or removal factor uncertainty (%)	Uncertainty in trend in national total introduced by activity data uncertainty (%)	Uncertainty introduced into the trend in the national total (%)	Emission/ removal factor quality indicator	Activity data quality indicator
Waste – Solid waste disposal	CH₄	3,510.86	3,438.98	97.0	40.0	104.9	3.2	0.0	0.0	−0.2	4.8	4.8	M	R
Waste – Wastewater treatment and discharge	CH₄	240.55	266.03	10.0	40.0	41.2	0.1	0.0	0.0	0.0	0.0	0.0	D	R
Waste – Incineration and open burning of waste	CH₄	0.01	0.00	50.0	100.0	111.8	0.0	0.0	0.0	0.0	0.0	0.0	D	D
Energy – Liquid fuels	N₂O	140.77	175.30	1.5	50.0	50.0	0.1	0.0	0.0	0.0	0.0	0.0	D	M
Energy – Solid fuels	N₂O	14.99	12.11	1.2	50.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	D	M
Energy – Gaseous fuels	N₂O	5.53	3.68	−0.7	50.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	D	M
Energy – Biomass	N₂O	36.59	55.75	50.0	50.0	70.7	0.0	0.0	0.0	0.0	0.0	0.0	D	D
Energy – Fugitive – venting/flaring	N₂O	0.06	0.15	5.0	100.0	100.1	0.0	0.0	0.0	0.0	0.0	0.0	D	D
IPPU – Other product manufacture and use	N₂O	102.45	58.99	15.0	0.0	15.0	0.0	0.0	0.0	0.0	0.0	0.0	R	R
Agriculture – Agricultural soils	N₂O	6,697.45	8,593.30	11.4	54.2	55.4	4.3	0.0	0.1	0.5	1.4	1.5	M	M
Agriculture – Manure management	N₂O	53.49	90.83	5.0	100.0	100.1	0.1	0.0	0.0	0.0	0.0	0.0	R	R
Agriculture – Burning of residues	N₂O	4.77	4.12	6.0	20.0	20.9	0.0	0.0	0.0	0.0	0.0	0.0	D	R
LULUCF	N₂O	179.10	91.44	30.0	41.6	51.3	0.0	0.0	0.0	0.0	0.0	0.1	M	M
Waste – Wastewater treatment and discharge	N₂O	96.45	130.75	10.0	90.0	90.6	0.1	0.0	0.0	0.0	0.0	0.0	D	R
Waste – Incineration and open burning of waste	N₂O	1.57	1.23	50.0	100.0	111.8	0.0	0.0	0.0	0.0	0.0	0.0	D	D
IPPU – Product uses as substitutes for ODS	HFCs	0.00	1,386.98	44.0	0.0	44.0	0.5	0.0	0.0	0.0	0.9	0.9	R	R
IPPU – Aluminium production	PFCs	909.95	48.69	5.0	30.0	30.4	0.0	0.0	0.0	−0.3	0.0	0.3	M	M

IPCC source category	Gas	1990 emissions or absolute value of removals (kt CO₂-e)	2016 emissions or absolute value of removals (kt CO₂-e)	Activity data uncertainty (%)	Emission or removal factor uncertainty (%)	Combined uncertainty (%)	Combined uncertainty as a per cent of the national total in 2016 (%)	Type A sensitivity (%)	Type B sensitivity (%)	Uncertainty in the trend in national total introduced by emission or removal factor uncertainty (%)	Uncertainty in trend in national total introduced by activity data uncertainty (%)	Uncertainty introduced into the trend in the national total (%)	Emission/ removal factor quality indicator	Activity data quality indicator
IPPU – Product uses as substitutes for ODS	PFCs	0.00	0.00	35.0	0.0	35.0	0.0	0.0	0.0	0.0	0.0	0.0	R	R
IPPU – Metal industry	SF₆	2.74	0.00	100.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	R	R
IPPU – Other product manufacture and use	SF₆	17.24	17.29	36.0	45.0	57.6	0.0	0.0	0.0	0.0	0.0	0.0	R	R
Total emissions/ removals		**98,553.56**	**111,720.48**		**Uncertainty in the year**		**11.4%**		**Uncertainty in the trend**			**8.055%**		

Note:　D = default; M = measurements; R = national referenced information.

IPCC source category	Gas	1990 emissions or absolute value of removals, Gg CO₂-e	2016 emissions or absolute value of removals, Gg CO₂-e	Activity data uncertainty (%)	Emission or removal factor uncertainty (%)	Combined uncertainty (%)	Combined uncertainty as a per cent of the national total in 2016 (%)	Type A sensitivity (%)	Type B sensitivity (%)	Uncertainty in the trend in national total introduced by emission or removal factor uncertainty (%)	Uncertainty in trend in national total introduced by activity data uncertainty (%)	Uncertainty introduced into the trend in the national total (%)	Emission/removal factor quality indicator	Activity data quality indicator
Energy – Liquid fuels	CO₂	11,789.99	18,928.69	1.5	0.5	1.6	0.4	0.1	0.2	0.0	0.5	0.5	R	R
Energy – Solid fuels	CO₂	3,211.03	2,617.39	1.2	2.2	2.5	0.1	0.0	0.0	0.0	0.1	0.1	R	R
Energy – Gaseous fuels	CO₂	7,054.90	7,372.50	–0.7	2.6	2.7	0.3	0.0	0.1	0.0	–0.1	0.1	R	R
Energy – Fugitive – geothermal	CO₂	228.58	659.15	5.0	5.0	7.1	0.1	0.0	0.0	0.0	0.1	0.1	D	D
Energy – Fugitive – venting/flaring	CO₂	229.84	577.55	–0.7	2.6	2.7	0.0	0.0	0.0	0.0	0.0	0.0	R	R
Energy – Fugitive – oil and gas activities	CO₂	0.21	0.20	5.0	100.0	100.1	0.0	0.0	0.0	0.0	0.0	0.0	D	D
Energy – Fugitive – transmission and distribution	CO₂	1.46	1.25	–0.7	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	R	R
IPPU – Mineral industry	CO₂	561.87	726.79	2.0	7.0	7.3	0.1	0.0	0.0	0.0	0.0	0.0	D	D
IPPU – Chemical industry	CO₂	175.40	191.34	2.0	6.0	6.3	0.0	0.0	0.0	0.0	0.0	0.0	D	D
IPPU – Metal industry	CO₂	1,757.51	2,251.52	5.0	7.0	8.6	0.2	0.0	0.0	0.0	0.2	0.2	D	D
IPPU – Non-energy products from fuels and solvent use	CO₂	30.34	46.54	20.0	50.0	53.9	0.0	0.0	0.0	0.0	0.0	0.0	D	D
Agriculture – Liming	CO₂	360.06	514.41	3.4	50.0	50.1	0.3	0.0	0.0	0.1	0.0	0.1	D	R
Agriculture – Urea application	CO₂	39.19	574.39	10.0	50.0	51.0	0.4	0.0	0.0	0.4	0.1	0.4	D	R
Waste – Incineration and open Burning of waste	CO₂	13.18	1.21	50.0	40.0	64.0	0.0	0.0	0.0	0.0	0.0	0.0	D	D
Energy – Liquid fuels	CH₄	82.24	33.89	1.5	50.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	D	D
Energy – Solid fuels	CH₄	36.40	16.70	1.2	50.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	D	D
Energy – Gaseous fuels	CH₄	9.05	4.40	–0.7	50.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	D	D
Energy – Biomass	CH₄	66.60	78.90	50.0	50.0	70.7	0.1	0.0	0.0	0.0	0.1	0.1	D	D
Energy – Fugitive – geothermal	CH₄	54.79	172.83	5.0	5.0	7.1	0.0	0.0	0.0	0.0	0.0	0.0	D	D

IPCC source category	Gas	1990 emissions or absolute value of removals, Gg CO₂-e	2016 emissions or absolute value of removals, Gg CO₂-e	Activity data uncertainty (%)	Emission or removal factor uncertainty (%)	Combined uncertainty (%)	Combined uncertainty as a per cent of the national total in 2016 (%)	Type A sensitivity (%)	Type B sensitivity (%)	Uncertainty in the trend in national total introduced by emission or removal factor uncertainty (%)	Uncertainty in trend in national total introduced by activity data uncertainty (%)	Uncertainty introduced into the trend in the national total (%)	Emission/removal factor quality indicator	Activity data quality indicator
Energy – Fugitive – venting/processing	CH₄	66.06	76.10	–0.7	50.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	R	R
Energy – Fugitive – coal mining	CH₄	328.23	171.80	1.2	50.0	50.0	0.1	0.0	0.0	–0.2	0.0	0.2	R	R
Energy – Fugitive – transmission and distribution	CH₄	279.97	205.96	–0.7	100.0	100.0	0.3	0.0	0.0	–0.2	0.0	0.2	R	R
Energy – Fugitive – oil and gas activities	CH₄	143.52	138.55	–0.7	100.0	100.0	0.2	0.0	0.0	–0.1	0.0	0.1	D	D
Energy – Fugitive – oil transportation and storage	CH₄	4.40	5.12	5.0	50.0	50.2	0.0	0.0	0.0	0.0	0.0	0.0	D	D
IPPU – Chemical industry	CH₄	27.60	125.28	2.0	80.0	80.0	0.1	0.0	0.0	0.1	0.0	0.1	D	D
Agriculture – Enteric fermentation	CH₄	26,718.21	27,782.94	3.9	15.5	16.0	5.6	–0.1	0.4	–1.0	1.9	2.2	M	M
Agriculture – Manure management	CH₄	686.08	1,147.44	5.0	20.0	20.6	0.3	0.0	0.0	0.1	0.1	0.1	M	M
Agriculture – Burning of residues	CH₄	22.62	19.91	6.0	20.0	20.9	0.0	0.0	0.0	0.0	0.0	0.0	D	R
Waste – Solid waste disposal	CH₄	3,510.86	3,438.98	97.0	40.0	104.9	4.6	0.0	0.0	–0.5	6.0	6.0	M	R
Waste – Wastewater treatment and discharge	CH₄	240.55	266.03	10.0	40.0	41.2	0.1	0.0	0.0	0.0	0.0	0.0	D	R
Waste – Incineration and open burning of waste	CH₄	0.01	0.00	50.0	100.0	111.8	0.0	0.0	0.0	0.0	0.0	0.0	D	D
Energy – Liquid fuels	N₂O	140.77	175.30	1.5	50.0	50.0	0.1	0.0	0.0	0.0	0.0	0.0	D	D
Energy – Solid fuels	N₂O	14.99	12.11	1.2	50.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	D	D
Energy – Gaseous fuels	N₂O	5.53	3.68	–0.7	50.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	D	D
Energy – Biomass	N₂O	36.59	55.75	50.0	50.0	70.7	0.1	0.0	0.0	0.0	0.1	0.1	D	D
Energy – Fugitive – venting and flaring	N₂O	0.06	0.15	5.0	100.0	100.1	0.0	0.0	0.0	0.0	0.0	0.0	D	D

IPCC source category	Gas	1990 emissions or absolute value of removals, Gg CO$_2$-e	2016 emissions or absolute value of removals, Gg CO$_2$-e	Activity data uncertainty (%)	Emission or removal factor uncertainty (%)	Combined uncertainty (%)	Combined uncertainty as a per cent of the national total in 2016 (%)	Type A sensitivity (%)	Type B sensitivity (%)	Uncertainty in the trend in national total introduced by emission or removal factor uncertainty (%)	Uncertainty in trend in national total introduced by activity data uncertainty (%)	Uncertainty introduced into the trend in the national total (%)	Emission/ removal factor quality indicator	Activity data quality indicator
IPPU – Other product manufacture and use	N$_2$O	102.45	58.99	15.0	0.0	15.0	0.0	0.0	0.0	0.0	0.0	0.0	D	D
Agriculture – Agricultural soils	N$_2$O	6,697.45	8,593.30	11.4	54.2	55.4	6.0	0.0	0.1	0.5	1.8	1.8	R	R
Agriculture – Manure management	N$_2$O	53.49	90.83	5.0	100.0	100.1	0.1	0.0	0.0	0.0	0.0	0.0	M	M
Agriculture – Burning of residues	N$_2$O	4.77	4.12	6.0	20.0	20.9	0.0	0.0	0.0	0.0	0.0	0.0	R	R
Waste – Wastewater treatment and discharge	N$_2$O	96.45	130.75	30.0	41.6	51.3	0.1	0.0	0.0	0.0	0.1	0.1	D	R
Waste – Incineration and open burning of waste	N$_2$O	1.57	1.23	50.0	100.0	111.8	0.0	0.0	0.0	0.0	0.0	0.0	D	D
IPPU – Product uses as substitutes for ODS	HFCs	0.00	1,386.98	44.0	0.0	44.0	0.8	0.0	0.0	0.0	1.1	1.1	R	R
IPPU – Aluminium production	PFCs	909.95	48.69	5.0	30.0	30.4	0.0	0.0	0.0	−0.5	0.0	0.5	M	M
IPPU – Product uses as substitutes for ODS	PFCs	0.00	0.00	35.0	0.0	35.0	0.0	0.0	0.0	0.0	0.0	0.0	R	R
IPPU – Metal industry	SF$_6$	2.74	0.00	100.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	R	R
IPPU – Other product manufacture and use	SF$_6$	17.24	17.29	36.0	45.0	57.6	0.0	0.0	0.0	0.0	0.0	0.0	R	R
Total emissions		65,814.8	78,726.9		Uncertainty in the year		9.5%		Uncertainty in the trend			14.2%		

Note: D = default; M = measurements; R = national referenced information.

Annex 2: References

IPCC. 2006. Eggleston HS, Buendia L, Miwa K, Ngara T, Tanabe K (eds). *2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 1. General Guidance and Reporting.* IPCC National Greenhouse Gas Inventories Programme. Japan: Published for the IPCC by the Institute for Global Environmental Strategies.

UNFCCC. 2013. FCCC/CP/2013/Add.3. *Guidelines for the preparation of national communications by Parties included in Annex I to the Convention, Part I: UNFCCC reporting guidelines on annual greenhouse gas inventories (addendum to Decision 24/CP.19).*

Annex 3: Detailed methodological information for other sectors

A3.1 Supplementary information for the Agriculture sector

A3.1.1 Livestock population data

2016 Agricultural Production census and survey

Details of the Agricultural Production census and survey are included to provide an understanding of the livestock statistics process and uncertainty values. The information here is provided by Statistics New Zealand, with full details available from the Statistics New Zealand website (www.stats.govt.nz/information-releases/agricultural-production-statistics-june-2016-final).

The target population for the 2016 Agricultural Production survey was all businesses that were engaged in agricultural production activity (including livestock, cropping, horticulture and forestry) or that owned land that was intended for agricultural activity during the year ended 30 June 2016. The response rate, or the estimated proportion of eligible businesses that responded to the 2016 Agricultural Production survey, was 79.0 per cent. These businesses represent 81 per cent of the total estimated value of agricultural operations. Statistics New Zealand imputes by randomly selecting data from the same population (i.e., 'hot deck' procedure) for values for farmers and growers who did not return a completed questionnaire. The imputation levels of recent Agricultural Production surveys are provided in table A3.1.1.

Sampling error arises from selecting a sample of businesses and weighting the results rather than taking a complete enumeration (i.e., census). Non-sampling error arises from biases in the patterns of response and non-response, inaccuracies in reporting by respondents and errors in the recording and classification of data. Statistics New Zealand adopts procedures to detect and minimise these types of errors, but they may still occur and are not easy to quantify.

Table A3.1.1   **Imputation levels and sampling errors for recent Agricultural Production surveys**

Statistic	Proportion of total estimate imputed (%)		Relative sampling errors at 95% confidence interval (%)	
Survey year	**2015**	**2016**	**2015**	**2016**
Ewe hoggets put to ram	15	22	3	3
Breeding ewes, two tooth and over	18	21	2	2
Total number of sheep	**18**	**21**	**2**	**2**
Lambs born to ewe hoggets	16	22	3	3
Lambs born to ewes	18	21	2	2
Total number of lambs	**18**	**21**	**2**	**2**
Dairy cows and heifers, in milk or calf	25	29	4	5
Total number of dairy cattle	**25**	**29**	**3**	**5**
Calves born alive to beef heifers and/or cows	27	28	3	4
Beef cows and heifers (in calf) one to two years	20	22	4	7
Beef cows and heifers (in calf) two years and over	17	20	4	3

Statistic	Proportion of total estimate imputed (%)		Relative sampling errors at 95% confidence interval (%)	
Survey year	2015	2016	2015	2016
Total number of beef cattle	**19**	**21**	**2**	**3**
Calves born alive to dairy heifers and/or cows	18	22	2	4
Female deer mated	11	16	5	7
Total number of deer	12	16	5	6
Fawns born on farm and alive at four months	11	17	5	7
Breeding sows (one year and over)	13	9	12	5
Mated gilts	7	7	4	5
Total pigs	**10**	**7**	**2**	**2**
Piglets weaned on the farm	8	7	1	1
Area of wheat harvested	22	24	6	11
Area of barley harvested	20	26	10	9
Area of maize grain harvested	17	18	9	10

Livestock characterisation in New Zealand's Tier 2 modelling

The delineation of the major livestock categories in New Zealand's Tier 2 livestock nutritional and energy requirements modelling (see table A3.1.2) are taken from population data collected by the Agricultural Production census and survey and the Ministry for Primary Industries slaughter statistics.

Table A3.1.2   Characterisation of major livestock subcategories (dairy cattle, non-dairy cattle, sheep and deer) in New Zealand's Tier 2 livestock modelling

Livestock category	Subcategory
Dairy cattle	
Dairy cattle categories	Milking cows and heifers
	Growing females less than one year
	Growing females one to two years
	Breeding bulls
Dairy data: geographical regions based on regional council areas	Northland
	Auckland
	Waikato
	Bay of Plenty
	Gisborne
	Hawke's Bay
	Taranaki
	Manawatu–Wanganui
	Wellington
	Tasman
	Nelson
	Marlborough
	West Coast
	Canterbury
	Otago
	Southland
Non-dairy (beef) cattle categories	Breeding growing cows 0 to one year
	Breeding growing cows one to two years
	Breeding growing cows two to three years

Livestock category	Subcategory
	Breeding mature cows
	Breeding bulls – mixed age
	Slaughter heifers 0 to one year
	Slaughter heifers one to two years
	Slaughter steers 0 to one year
	Slaughter steers one to two years
	Slaughter bulls 0 to one year
	Slaughter bulls one to two years
Sheep categories	Dry ewes
	Mature breeding ewes
	Growing breeding sheep
	Growing non-breeding sheep
	Wethers
	Lambs
	Rams
Deer categories	Breeding hinds
	Hinds less than one year
	Hinds one to two years
	Stags less than one year
	Stags one to two years
	Stags two to three years
	Mixed age and breeding stags

A3.1.2 Key parameters and emission factors used in the Agriculture sector

For the major livestock categories, milk yield varies over the course of a year, which affects energy requirements, intake and emissions. table A3.1.3 shows the proportions that are used to calculate milk yield for different months over the course of a year.

Table A3.1.3 **Proportion of annual milk yield each month for major livestock categories**

Month	Dairy cattle	Non-dairy cattle	Sheep	Deer
July	0.0088	0.0000	0.0000	0.0000
August	0.0578	0.0000	0.0000	0.0000
September	0.1213	0.1670	0.1639	0.0000
October	0.1503	0.1670	0.2541	0.0000
November	0.1425	0.1670	0.2459	0.1000
December	0.1282	0.1670	0.2541	0.2583
January	0.1109	0.1670	0.0820	0.2583
February	0.0900	0.1670	0.0000	0.2333
March	0.0851	0.0000	0.0000	0.1500
April	0.0654	0.0000	0.0000	0.0000
May	0.0335	0.0000	0.0000	0.0000
June	0.0061	0.0000	0.0000	0.0000

Source: Suttie (2012) and Pickering and Fick (2015)

Note: All values presented in the table are rounded to four decimal places for presentation purposes and precise values are available upon request.

Table A3.1.4   Emission factors for Tier 1 enteric fermentation livestock and manure management

Emission factor	Emission type	Source	Parameter value (kg CH$_4$/head/yr)
EF$_{GOATS}$	Enteric fermentation – goats	Lassey (2011)	8.1[53]
EF$_{HORSES}$	Enteric fermentation – horses	IPCC (2006), table 10.10	18
EF$_{MULES}$	Enteric fermentation – mules and asses	IPCC (2006), table 10.10	10
EF$_{SWINE}$	Enteric fermentation – swine	Hill (2012)	1.06
EF$_{ALPACA}$	Enteric fermentation – alpaca	IPCC (2006), table 10.10	8
MM$_{GOATS}$	Manure management – goats	IPCC (2006), table 10.15	0.20
MM$_{HORSES}$	Manure management – horses	IPCC (2006), table 10.15	2.34
MM$_{MULES}$	Manure management – mules and asses	IPCC (2006), table 10.15	1.1
MM$_{SWINE}$	Manure management – swine	Hill (2012); IPCC (2000)	5.94
MM$_{BROILERS}$	Manure management – broilers	Fick et al. (2011)	0.022
MM$_{LAYERS}$	Manure management – layer hens	Fick et al. (2011)	0.016
MM$_{OTHER\ POULTRY}$	Manure management – other poultry	IPCC (1996), table 4.5	0.117
MM$_{ALPACA}$	Manure management – alpaca	New Zealand 1990 sheep value[54]	0.097

Table A3.1.5   Emission factors for New Zealand's agriculture nitrous oxide emissions

Emission factor	Emissions	Source	Parameter value
EF$_1$ (kg N$_2$O-N/kg N)	Direct emissions from nitrogen input to soil	Kelliher and de Klein (unpublished)	0.0100
EF$_{1-UREA}$ (kg N$_2$O-N/kg N)	Direct emissions from nitrogen input to soil from urea fertiliser	van der Weerden et al. (2016)	0.0059
EF$_{1-DAIRY}$ (kg N$_2$O-N/kg N)	Direct emissions from nitrogen input to soil from dairy cattle manure	van der Weerden et al. (2016)	0.0025
EF$_2$ (kg N$_2$O-N/ha-yr)	Direct emissions from organic soil mineralisation due to cultivation	IPCC (2006), table 11.1	8.0000
EF$_{3SSD}$ (kg N$_2$O-N/kg N excreted)	Direct emissions from waste in the solid waste and dry lot animal waste management systems	IPCC (2000), table 4.12	0.0200
EF$_{3\ (PRP\ URINE)}$ (kg N$_2$O-N/kg N excreted)	Direct emissions from urine in the pasture, range and paddock animal waste management systems for cattle, sheep and deer, and direct emissions from manure waste in the pasture, range and paddock animal waste management systems for all other species	Carran et al. (1995); Muller et al. (1995); de Klein et al. (2003)	0.0100
EF$_{3(PRP\ DUNG)}$ (kg N$_2$O-N/kg N excreted)	Direct emissions from dung in the pasture, range and paddock animal waste management systems for cattle, sheep and deer	Luo et al. (2009)	0.0025
EF$_{3OTHER}$ (kg N$_2$O-N/kg N excreted)	Direct emissions from waste in other animal waste management systems	IPCC (2000), table 4.13	0.0050
EF$_{3POULTRY}$ (kg N$_2$O-N/kg N excreted)	Direct emissions from waste in other animal waste management systems – poultry specific	Fick et al. (2011)	0.0010
EF$_4$ (kg N$_2$O-N/kg NH$_x$-N)	Indirect emissions from volatising nitrogen	IPCC (2006), table 11.3	0.0100
EF$_5$ (kg N$_2$O-N/kg N leached and run-off)	Indirect emissions from leaching nitrogen	IPCC (2006), table 11.3	0.0075

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[53]   Value is for 2016. In 1990, the value was EF 7.4 kg CH$_4$/head/year. Values for the intermediate years between 1990 and 2009 and for 2010–14 are interpolated and extrapolated based on an assumption that the dairy goat population has remained in a near constant state over time.

[54]   As was reported in the 2010 submission, that is, the first year that alpacas were included in *New Zealand's Greenhouse Gas Inventory* (Ministry for the Environment, 2010).

Table A3.1.6   Parameter values for New Zealand's agriculture nitrous oxide emissions

Parameter (fraction)	Fraction of the parameter	Source	Parameter value
Frac$_{GASF}$ (kg NH$_3$-N + NO$_x$-N/kg of synthetic fertiliser N applied)	Total synthetic fertiliser emitted as NO$_x$ or NH$_3$	IPCC (2006) verified by Sherlock et al. (2008)	0.1
Frac$_{GASM}$ (kg NH$_3$-N + NO$_x$-N/kg of N excreted by livestock)	Total nitrogen emitted as NO$_x$ or NH$_3$	Sherlock et al. (2008)	0.1
Frac$_{LEACH(-H)}$ (kg N/kg fertiliser or manure N)	Nitrogen input to soils that is lost through leaching and run-off	Thomas et al. (unpublished, 2005)	0.07
Frac$_{BURN}$ (kg N/kg crop-N)	Crop residue burned in fields	Thomas et al. (2008), table 14	Crop specific survey data
Frac$_{BURNL}$ (kg N/kg legume-N)	Legume crop residue burned in fields	Thomas et al. (2008) Practice does not occur in New Zealand	0
Frac$_{RENEW}$	Fraction of land undergoing pasture renewal	Thomas et al. (2014)	Year-specific
Frac$_{REMOVE}$	Fraction of nitrogen in above-ground residues removed for bedding, feed or construction	Thomas et al. (2014) Practice does not occur in New Zealand	0
Frac$_{FUEL}$ (N/kg N excreted)	Livestock nitrogen excretion in excrements burned for fuel	Practice does not occur in New Zealand	0

Some of the parameters used to calculate *Nitrous oxide emissions from crop residue returned to soil* and emissions from *Field burning of agricultural residues* are summarised below in table A3.1.7. These values are taken from research conducted by Thomas et al. (2008, 2011).

Table A3.1.7   Parameter values for New Zealand's cropping emissions

Crop	HI	dmf	AG$_N$	Root Shoot ratio R$_{BG}$	BG$_N$
Wheat	0.41	0.86	0.005	0.1	0.009
Barley	0.46	0.86	0.005	0.1	0.009
Oats	0.3	0.86	0.005	0.1	0.009
Maize grain	0.5	0.86	0.007	0.1	0.007
Field seed peas	0.5	0.21	0.02	0.1	0.015
Lentils	0.5	0.86	0.02	0.1	0.015
Peas fresh and process	0.45	0.86	0.03	0.1	0.015
Potatoes	0.9	0.22	0.02	0.1	0.01
Onions	0.8	0.11	0.02	0.1	0.01
Sweet corn	0.55	0.24	0.009	0.1	0.007
Squash	0.8	0.2	0.02	0.1	0.01
Herbage seeds	0.11	0.85	0.015	0.1	0.01
Legume seeds	0.09	0.85	0.04	0.1	0.01
Brassica seeds	0.2	0.85	0.01	0.1	0.008

Source: Thomas et al. (2008, 2011)

Note: AG$_N$ = above-ground nitrogen residue; BG$_N$ = below-ground nitrogen residue; dmf = dry-matter conversion factor; HI = harvest index; R$_{BG}$ = ratio of below-ground residues to the harvest yield.

A3.2 Supplementary information for the LULUCF sector

A3.2.1 Annual land-use change summary

This section contains a summary of the annual land-use change from 1990 to 2016 (see table A3.2.1).

Table A3.2.1   **Annual land-use changes** (units in 000s hectares)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
From Natural Forest										
To Pre - 1990 Planted Forest	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Post - 1989 Forest	-	-	-	-	-	-	-	-	-	-
Cropland - perennial	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cropland - annual	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grassland - high producing	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Grassland - low producing	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Grassland - with woody biomass	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Wetland - open water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wetland - vegetative non forest	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Settlements	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
From Pre - 1990 Planted Forest										
To Natural Forest	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Post - 1989 Forest	-	-	-	-	-	-	-	-	-	-
Cropland - perennial	-	-	-	-	-	-	-	-	-	-
Cropland - annual	-	-	-	-	-	-	-	-	-	-
Grassland - high producing	-	-	-	-	-	-	-	-	-	-
Grassland - low producing	-	-	-	-	-	-	-	-	-	-
Grassland - with woody biomass	-	-	-	-	-	-	-	-	-	-
Wetland - open water	-	-	-	-	-	-	-	-	-	-
Wetland - vegetative non forest	-	-	-	-	-	-	-	-	-	-
Settlements	-	-	-	-	-	-	-	-	-	-
Other land	-	-	-	-	-	-	-	-	-	-
From Post - 1989 Forest										
To Natural Forest	-	-	-	-	-	-	-	-	-	-
Pre - 1990 Planted Forest	-	-	-	-	-	-	-	-	-	-
Cropland - perennial	-	-	-	-	-	-	-	-	-	-
Cropland - annual	-	-	-	-	-	-	-	-	-	-
Grassland - high producing	-	-	-	-	-	-	-	-	-	-
Grassland - low producing	-	-	-	-	-	-	-	-	-	-
Grassland - with woody biomass	-	-	-	-	-	-	-	-	-	-
Wetland - open water	-	-	-	-	-	-	-	-	-	-
Wetland - vegetative non forest	-	-	-	-	-	-	-	-	-	-
Settlements	-	-	-	-	-	-	-	-	-	-
Other land	-	-	-	-	-	-	-	-	-	-
From Cropland - perennial										
To Natural Forest	-	-	-	-	-	-	-	-	-	-
Pre - 1990 Planted Forest	-	-	-	-	-	-	-	-	-	-
Post - 1989 Forest	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cropland - annual	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Grassland - high producing	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Grassland - low producing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grassland - with woody biomass	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wetland - open water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wetland - vegetative non forest	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Settlements	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
From Cropland - annual										
To Natural Forest	-	-	-	-	-	-	-	-	-	-
Pre - 1990 Planted Forest	-	-	-	-	-	-	-	-	-	-
Post - 1989 Forest	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cropland - perennial	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Grassland - high producing	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Grassland - low producing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grassland - with woody biomass	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wetland - open water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wetland - vegetative non forest	-	-	-	-	-	-	-	-	-	-
Settlements	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
From Grassland - high producing										
To Natural Forest	-	-	-	-	-	-	-	-	-	-
Pre - 1990 Planted Forest	-	-	-	-	-	-	-	-	-	-
Post - 1989 Forest	2.7	2.6	8.1	9.9	15.7	11.9	13.5	10.4	8.4	6.6
Cropland - perennial	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
Cropland - annual	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Grassland - low producing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grassland - with woody biomass	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.9	0.9	0.9
Wetland - open water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wetland - vegetative non forest	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Settlements	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Other land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
From Natural Forest										
To Pre - 1990 Planted Forest	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	0.1	0.1
Post - 1989 Forest	-	-	-	-	-	-	-	-	-	-
Cropland - perennial	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	-
Cropland - annual	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	-
Grassland - high producing	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.2	0.5
Grassland - low producing	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	0.5	1.1
Grassland - with woody biomass	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.9
Wetland - open water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	0.0
Wetland - vegetative non forest	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	0.0
Settlements	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
From Pre - 1990 Planted Forest										
To Natural Forest	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0
Post - 1989 Forest	-	-	-	-	-	-	-	-	-	-
Cropland - perennial	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	-	0.0
Cropland - annual	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.0
Grassland - high producing	1.4	1.3	0.9	2.0	4.5	9.2	11.5	15.3	1.1	1.4
Grassland - low producing	0.7	0.7	0.6	0.9	1.7	2.9	3.7	4.9	2.5	3.7
Grassland - with woody biomass	0.2	0.2	0.2	0.3	0.5	0.9	1.2	1.5	0.3	0.9
Wetland - open water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wetland - vegetative non forest	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	-
Settlements	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.0	0.0
Other land	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.0	0.0
From Post - 1989 Forest										
To Natural Forest	-	-	-	-	-	-	-	-	-	-
Pre - 1990 Planted Forest	-	-	-	-	-	-	-	-	-	-
Cropland - perennial	-	-	0.0	0.0	0.0	0.0	0.0	0.0	-	0.0
Cropland - annual	-	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
Grassland - high producing	-	-	0.5	1.6	1.5	1.7	1.4	3.4	0.6	0.5
Grassland - low producing	-	-	0.1	0.4	0.4	0.5	0.4	0.9	0.4	1.9
Grassland - with woody biomass	-	-	0.0	0.2	0.1	0.2	0.1	0.3	0.1	0.2
Wetland - open water	-	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
Wetland - vegetative non forest	-	-	0.0	0.0	0.0	0.0	0.0	0.0	-	-
Settlements	-	-	0.0	0.0	0.0	0.0	0.0	0.0	-	0.0
Other land	-	-	0.0	0.0	0.0	0.0	0.0	0.0	-	0.0
From Cropland - perennial										
To Natural Forest	-	-	-	-	-	-	-	-	-	-
Pre - 1990 Planted Forest	-	-	-	-	-	-	-	-	-	-
Post - 1989 Forest	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	-
Cropland - annual	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	-	-
Grassland - high producing	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	-	-
Grassland - low producing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	-
Grassland - with woody biomass	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	-
Wetland - open water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	-
Wetland - vegetative non forest	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	-
Settlements	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	-
Other land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	-
From Cropland - annual										
To Natural Forest	-	-	-	-	-	-	-	-	-	-
Pre - 1990 Planted Forest	-	-	-	-	-	-	-	-	-	-
Post - 1989 Forest	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cropland - perennial	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.1	0.1
Grassland - high producing	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0
Grassland - low producing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	-
Grassland - with woody biomass	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wetland - open water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
Wetland - vegetative non forest	-	-	-	-	-	-	-	-	-	-
Settlements	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	-
From Grassland - high producing										
To Natural Forest	-	-	-	-	-	-	-	-	-	-
Pre - 1990 Planted Forest	-	-	-	-	-	-	-	-	0.0	0.0
Post - 1989 Forest	5.7	5.2	3.9	3.7	2.3	1.6	1.1	1.1	0.4	0.8
Cropland - perennial	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	0.4	0.4
Cropland - annual	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	0.0	0.0
Grassland - low producing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3
Grassland - with woody biomass	0.9	0.9	0.7	0.7	0.7	0.7	0.7	0.7	0.2	0.2
Wetland - open water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3
Wetland - vegetative non forest	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Settlements	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.1	0.1
Other land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1

		2010	2011	2012	2013	2014	2015	2016
From Natural Forest								
To	Pre - 1990 Planted Forest	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	Post - 1989 Forest	-	-	-	-	-	-	-
	Cropland - perennial	-	-	-	-	-	-	-
	Cropland - annual	0.0	-	-	0.0	0.0	-	-
	Grassland - high producing	0.3	0.1	0.1	0.2	0.1	0.2	0.2
	Grassland - low producing	0.7	0.4	0.3	0.2	0.1	0.7	0.7
	Grassland - with woody biomass	0.7	0.2	0.2	0.1	0.1	-	-
	Wetland - open water	-	0.0	-	-	-	-	-
	Wetland - vegetative non forest	-	-	0.0	-	-	-	-
	Settlements	0.0	0.0	0.0	-	-	-	-
	Other land	0.1	0.1	0.1	0.1	0.1	-	-
From Pre - 1990 Planted Forest								
To	Natural Forest	0.0	0.0	0.0	-	-	-	-
	Post - 1989 Forest	-	-	-	-	-	-	-
	Cropland - perennial	-	-	-	0.0	0.0	-	-
	Cropland - annual	0.0	0.0	0.0	0.1	0.0	-	-
	Grassland - high producing	1.9	1.8	1.6	5.0	5.9	2.1	2.3
	Grassland - low producing	4.5	3.2	5.8	1.4	1.6	2.0	1.2
	Grassland - with woody biomass	0.8	0.6	0.2	0.4	0.2	-	-
	Wetland - open water	0.0	0.0	-	0.0	0.0	-	-
	Wetland - vegetative non forest	-	-	-	-	-	-	-
	Settlements	0.0	0.0	0.0	0.0	0.0	-	-
	Other land	0.0	0.1	0.0	0.0	0.0	-	-
From Post - 1989 Forest								
To	Natural Forest	-	-	-	-	-	-	-
	Pre - 1990 Planted Forest	-	-	-	-	-	-	-
	Cropland - perennial	-	-	-	-	-	-	-
	Cropland - annual	0.0	0.0	-	0.1	0.0	-	-
	Grassland - high producing	0.5	0.6	0.4	1.6	0.5	0.4	0.3
	Grassland - low producing	0.9	1.0	0.6	0.3	0.2	0.5	0.3
	Grassland - with woody biomass	0.2	0.2	0.1	0.1	0.1	-	-
	Wetland - open water	-	0.0	0.0	-	-	-	-
	Wetland - vegetative non forest	-	-	-	-	-	-	-
	Settlements	0.0	0.0	0.0	-	0.0	-	-
	Other land	0.0	0.0	0.0	0.0	0.0	-	-
From Cropland - perennial								
To	Natural Forest	-	-	-	-	-	-	-
	Pre - 1990 Planted Forest	-	-	-	-	-	-	-
	Post - 1989 Forest	-	-	-	-	-	-	-
	Cropland - annual	-	-	-	-	-	-	-
	Grassland - high producing	-	-	-	-	-	-	-
	Grassland - low producing	-	-	-	-	-	-	-
	Grassland - with woody biomass	-	-	-	-	-	-	-
	Wetland - open water	-	-	-	-	-	-	-
	Wetland - vegetative non forest	-	-	-	-	-	-	-
	Settlements	-	-	-	-	-	-	-
	Other land	-	-	-	-	-	-	-
From Cropland - annual								
To	Natural Forest	-	-	-	-	-	-	-
	Pre - 1990 Planted Forest	-	-	-	-	-	-	-
	Post - 1989 Forest	0.0	0.0	0.0	-	-	-	-
	Cropland - perennial	0.1	0.1	0.1	-	-	-	-
	Grassland - high producing	0.0	0.0	0.0	-	-	-	-
	Grassland - low producing	-	-	-	-	-	-	-
	Grassland - with woody biomass	0.0	0.0	0.0	-	-	-	-
	Wetland - open water	0.1	0.1	0.1	-	-	-	-
	Wetland - vegetative non forest	-	-	-	-	-	-	-
	Settlements	0.0	0.0	0.0	-	-	-	-
	Other land	-	-	-	-	-	-	-
From Grassland - high producing								
To	Natural Forest	-	-	-	-	-	-	-
	Pre - 1990 Planted Forest	0.0	0.0	0.0	-	-	-	-
	Post - 1989 Forest	1.1	2.2	1.9	0.7	0.7	0.5	0.6
	Cropland - perennial	0.4	0.4	0.4	0.4	0.4	0.4	0.4
	Cropland - annual	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Grassland - low producing	0.3	0.3	0.3	0.0	0.0	0.0	0.0
	Grassland - with woody biomass	0.2	0.2	0.2	0.1	0.1	0.1	0.1
	Wetland - open water	0.3	0.3	0.3	0.3	0.3	0.3	0.3
	Wetland - vegetative non forest	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Settlements	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	Other land	0.1	0.1	0.1	0.1	0.1	0.1	0.1

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
From Grassland - low producing										
To Natural Forest	-	-	-	-	-	-	-	-	-	-
Pre - 1990 Planted Forest	-	-	-	-	-	-	-	-	-	-
Post - 1989 Forest	8.4	8.2	25.7	31.4	49.7	37.5	42.8	32.8	26.7	21.0
Cropland - perennial	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Cropland - annual	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grassland - high producing	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.7	4.7	4.7
Grassland - with woody biomass	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.8	3.8	3.8
Wetland - open water	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Wetland - vegetative non forest	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Settlements	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Other land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
From Grassland - with woody biomass										
To Natural Forest	-	-	-	-	-	-	-	-	-	-
Pre - 1990 Planted Forest	-	-	-	-	-	-	-	-	-	-
Post - 1989 Forest	3.2	3.1	9.8	12.0	18.9	14.4	16.1	12.4	10.3	8.2
Cropland - perennial	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cropland - annual	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grassland - high producing	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.2	1.2	1.2
Grassland - low producing	1.6	1.6	1.6	1.6	1.6	1.6	1.6	2.0	2.0	2.0
Wetland - open water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wetland - vegetative non forest	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Settlements	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
From Wetland - open water										
To Natural Forest	-	-	-	-	-	-	-	-	-	-
Pre - 1990 Planted Forest	-	-	-	-	-	-	-	-	-	-
Post - 1989 Forest	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cropland - perennial	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cropland - annual	-	-	-	-	-	-	-	-	-	-
Grassland - high producing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grassland - low producing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grassland - with woody biomass	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wetland - vegetative non forest	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Settlements	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
From Wetland - vegetative non forest										
To Natural Forest	-	-	-	-	-	-	-	-	-	-
Pre - 1990 Planted Forest	-	-	-	-	-	-	-	-	-	-
Post - 1989 Forest	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cropland - perennial	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cropland - annual	-	-	-	-	-	-	-	-	-	-
Grassland - high producing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grassland - low producing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grassland - with woody biomass	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wetland - open water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Settlements	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
From Settlements										
To Natural Forest	-	-	-	-	-	-	-	-	-	-
Pre - 1990 Planted Forest	-	-	-	-	-	-	-	-	-	-
Post - 1989 Forest	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cropland - perennial	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cropland - annual	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grassland - high producing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grassland - low producing	-	-	-	-	-	-	-	-	-	-
Grassland - with woody biomass	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wetland - open water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wetland - vegetative non forest	-	-	-	-	-	-	-	-	-	-
Other land	-	-	-	-	-	-	-	-	-	-
From Other land										
To Natural Forest	-	-	-	-	-	-	-	-	-	-
Pre - 1990 Planted Forest	-	-	-	-	-	-	-	-	-	-
Post - 1989 Forest	0.1	0.1	0.3	0.3	0.5	0.4	0.4	0.3	0.3	0.2
Cropland - perennial	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cropland - annual	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grassland - high producing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grassland - low producing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grassland - with woody biomass	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Wetland - open water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wetland - vegetative non forest	-	-	-	-	-	-	-	-	-	-
Settlements	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
From Grassland - low producing										
To Natural Forest	-	-	-	-	-	-	-	-	-	-
Pre - 1990 Planted Forest	-	-	-	-	-	-	-	-	0.0	0.0
Post - 1989 Forest	18.1	16.5	12.4	11.7	7.3	5.2	3.6	3.5	1.5	3.4
Cropland - perennial	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1
Cropland - annual	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grassland - high producing	4.7	4.7	4.4	4.4	4.4	4.4	4.4	4.4	5.9	5.9
Grassland - with woody biomass	3.8	3.8	3.2	3.2	3.2	3.2	3.2	3.2	1.2	1.2
Wetland - open water	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0
Wetland - vegetative non forest	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Settlements	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0
Other land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
From Grassland - with woody biomass										
To Natural Forest	-	-	-	-	-	-	-	-	-	-
Pre - 1990 Planted Forest	-	-	-	-	-	-	-	-	0.0	0.0
Post - 1989 Forest	7.2	6.5	5.0	4.7	3.0	2.1	1.4	1.5	0.9	1.3
Cropland - perennial	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cropland - annual	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grassland - high producing	1.2	1.2	1.1	1.1	1.1	1.1	1.1	1.1	0.9	0.9
Grassland - low producing	2.0	2.0	1.6	1.6	1.6	1.6	1.6	1.6	2.6	2.6
Wetland - open water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wetland - vegetative non forest	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Settlements	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
From Wetland - open water										
To Natural Forest	-	-	-	-	-	-	-	-	-	-
Pre - 1990 Planted Forest	-	-	-	-	-	-	-	-	-	-
Post - 1989 Forest	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	-
Cropland - perennial	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	-
Cropland - annual	-	-	-	-	-	-	-	-	-	-
Grassland - high producing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	-
Grassland - low producing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	-
Grassland - with woody biomass	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	-
Wetland - vegetative non forest	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	-
Settlements	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	-
Other land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	-
From Wetland - vegetative non forest										
To Natural Forest	-	-	-	-	-	-	-	-	-	-
Pre - 1990 Planted Forest	-	-	-	-	-	-	-	-	-	-
Post - 1989 Forest	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cropland - perennial	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	-
Cropland - annual	-	-	-	-	-	-	-	-	-	-
Grassland - high producing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grassland - low producing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grassland - with woody biomass	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	-
Wetland - open water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Settlements	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	-
Other land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
From Settlements										
To Natural Forest	-	-	-	-	-	-	-	-	-	-
Pre - 1990 Planted Forest	-	-	-	-	-	-	-	-	-	-
Post - 1989 Forest	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	-
Cropland - perennial	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	-
Cropland - annual	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	-
Grassland - high producing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	-
Grassland - low producing	-	-	-	-	-	-	-	-	-	-
Grassland - with woody biomass	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	-
Wetland - open water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	-
Wetland - vegetative non forest	-	-	-	-	-	-	-	-	-	-
Other land	-	-	-	-	-	-	-	-	-	-
From Other land										
To Natural Forest	-	-	-	-	-	-	-	-	-	-
Pre - 1990 Planted Forest	-	-	-	-	-	-	-	-	0.0	0.0
Post - 1989 Forest	0.2	0.2	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0
Cropland - perennial	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	-
Cropland - annual	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	-
Grassland - high producing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grassland - low producing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grassland - with woody biomass	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0
Wetland - open water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wetland - vegetative non forest	-	-	-	-	-	-	-	-	-	-
Settlements	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

	2010	2011	2012	2013	2014	2015	2016
From Grassland - low producing							
To Natural Forest	-	-	-	-	-	-	-
Pre - 1990 Planted Forest	0.0	0.0	0.0	-	-	-	-
Post - 1989 Forest	4.8	9.6	8.2	3.0	3.0	2.3	3.5
Cropland - perennial	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Cropland - annual	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grassland - high producing	5.9	5.9	5.9	5.6	5.6	5.6	5.6
Grassland - with woody biomass	1.2	1.2	1.2	0.8	0.8	0.8	0.8
Wetland - open water	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wetland - vegetative non forest	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Settlements	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other land	0.1	0.1	0.1	0.1	0.1	0.1	0.1
From Grassland - with woody biomass							
To Natural Forest	-	-	-	-	-	-	-
Pre - 1990 Planted Forest	0.0	0.0	0.0	-	-	-	-
Post - 1989 Forest	1.4	2.2	3.3	1.1	1.1	0.9	1.0
Cropland - perennial	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cropland - annual	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grassland - high producing	0.9	0.9	0.9	0.8	0.8	0.8	0.8
Grassland - low producing	2.6	2.6	2.6	2.1	2.1	2.1	2.1
Wetland - open water	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wetland - vegetative non forest	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Settlements	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other land	0.0	0.0	0.0	0.0	0.0	0.0	0.0
From Wetland - open water							
To Natural Forest	-	-	-	-	-	-	-
Pre - 1990 Planted Forest	-	-	-	-	-	-	-
Post - 1989 Forest	-	-	-	-	-	-	-
Cropland - perennial	-	-	-	-	-	-	-
Cropland - annual	-	-	-	-	-	-	-
Grassland - high producing	-	-	-	-	-	-	-
Grassland - low producing	-	-	-	-	-	-	-
Grassland - with woody biomass	-	-	-	-	-	-	-
Wetland - vegetative non forest	-	-	-	-	-	-	-
Settlements	-	-	-	-	-	-	-
Other land	-	-	-	-	-	-	-
From Wetland - vegetative non forest							
To Natural Forest	-	-	-	-	-	-	-
Pre - 1990 Planted Forest	-	-	-	-	-	-	-
Post - 1989 Forest	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cropland - perennial	-	-	-	-	-	-	-
Cropland - annual	-	-	-	-	-	-	-
Grassland - high producing	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grassland - low producing	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grassland - with woody biomass	-	-	-	-	-	-	-
Wetland - open water	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Settlements	-	-	-	-	-	-	-
Other land	0.0	0.0	0.0	0.0	0.0	0.0	0.0
From Settlements							
To Natural Forest	-	-	-	-	-	-	-
Pre - 1990 Planted Forest	-	-	-	-	-	-	-
Post - 1989 Forest	-	-	-	-	-	-	-
Cropland - perennial	-	-	-	-	-	-	-
Cropland - annual	-	-	-	-	-	-	-
Grassland - high producing	-	-	-	-	-	-	-
Grassland - low producing	-	-	-	-	-	-	-
Grassland - with woody biomass	-	-	-	-	-	-	-
Wetland - open water	-	-	-	-	-	-	-
Wetland - vegetative non forest	-	-	-	-	-	-	-
Other land	-	-	-	-	-	-	-
From Other land							
To Natural Forest	-	-	-	-	-	-	-
Pre - 1990 Planted Forest	0.0	0.0	0.0	-	-	-	-
Post - 1989 Forest	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cropland - perennial	-	-	-	-	-	-	-
Cropland - annual	-	-	-	-	-	-	-
Grassland - high producing	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grassland - low producing	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grassland - with woody biomass	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wetland - open water	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wetland - vegetative non forest	-	-	-	-	-	-	-
Settlements	0.0	0.0	0.0	0.0	0.0	0.0	0.0

A3.2.2   Natural forest yield table

This section contains the natural forest yield table used for this submission.

Table A3.2.2   Pre-1990 natural forest – regenerating shrubland yield table (tonnes C ha⁻¹)

Year	Above-ground biomass	Below-ground biomass	Dead wood	Litter	Total biomass
1990	37.47	9.37	5.35	6.58	58.77
1991	38.53	9.63	5.43	6.58	60.17
1992	39.59	9.9	5.5	6.58	61.57
1993	40.65	10.16	5.57	6.58	62.96
1994	41.7	10.43	5.64	6.58	64.35
1995	42.76	10.69	5.71	6.58	65.74
1996	43.82	10.96	5.78	6.58	67.14
1997	44.88	11.22	5.85	6.58	68.53
1998	45.94	11.48	5.92	6.58	69.92
1999	46.99	11.75	5.99	6.58	71.31
2000	48.05	12.01	6.06	6.58	72.7
2001	49.11	12.28	6.13	6.58	74.1
2002	50.17	12.54	6.2	6.58	75.49
2003	51.22	12.81	6.27	6.58	76.88
2004	52.28	13.07	6.34	6.58	78.27
2005	53.34	13.34	6.41	6.58	79.67
2006	54.4	13.6	6.48	6.58	81.06
2007	55.46	13.86	6.55	6.58	82.45
2008	56.51	14.13	6.62	6.58	83.84
2009	57.57	14.39	6.69	6.58	85.23
2010	58.63	14.66	6.76	6.58	86.63
2011	59.69	14.92	6.83	6.58	88.02
2012	60.74	15.19	6.9	6.58	89.41
2013	61.8	15.45	6.97	6.58	90.8
2014	62.86	15.71	7.04	6.58	92.19
2015	63.92	15.97	7.11	6.58	93.58
2016	64.98	16.23	7.18	6.58	94.97

A3.2.3   Uncertainty analysis for the LULUCF sector

This section contains the disaggregated uncertainty analysis for the Land Use, Land-Use Change and Forestry (LULUCF) sector. This additional information has been provided as a result of the review of New Zealand's 2010 inventory (2012 submission). One of the recommendations of that review was that New Zealand provides "a detailed disaggregated assessment of uncertainty, as well as the aggregated uncertainty associated with the LULUCF sector, consistent with the IPCC [Intergovernmental Panel on Climate Change] good practice guidance for LULUCF". This information is now provided in table A3.2.3.

Table A3.2.3   Uncertainty analysis for the LULUCF sector

IPCC category	Gas	1990 emissions or removals (kt CO₂-e)	2016 emissions or removals (kt CO₂-e)	Activity data uncertainty (%)	Emission factor / estimation parameter uncertainty (biomass) (%)	Emission factor / estimation parameter uncertainty (mineral soil) (%)	Combined uncertainty (%)	Contribution to variance by category in 2014 (%)	Type A sensitivity (%)	Type B sensitivity (%)	Uncertainty in trend in LULUCF emissions introduced by emission factor / estimation parameter uncertainty (%)	Uncertainty in trend in LULUCF emissions introduced by activity data uncertainty (%)	Uncertainty introduced into the trend in total LULUCF emissions (%)	Emission factor quality indicator	Activity data quality indicator
Pre-1990 natural forest remaining pre-1990 natural forest	CO₂	6,165.9	6,139.3	5.0	126.6	7.9	126.7	34.2	4.9	20.4	6.2	0.3	6.2	M	M
Land converted to pre-1990 natural forest	CO₂	168.2	14.9	5.0	126.6	7.9	90.6	0.1	−0.4	0.0	−0.5	0.0	0.5	M	M
Pre-1990 planted forest remaining pre-1990 planted forest	CO₂	−4,726.2	1,912.7	5.0	11.4	12.3	404.2	33.9	18.2	6.3	2.1	1.3	2.4	M	M
Land converted to pre-1990 planted forest	CO₂	28,424.8	−1,758.3	5.0	11.4	12.3	26.7	2.1	−76.5	−5.8	−8.7	−5.4	10.3	M	M
Post-1989 forest remaining post-1989 forest	CO₂	0.0	0.0	8.0	29.2	10.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	M	M
Land converted to post-1989 planted forest	CO₂	−78.3	15,628.7	8.0	29.2	10.4	28.6	19.6	52.1	51.9	15.2	5.9	16.3	M	M
G-WB remaining G-WB	CO₂	−69.1	−55.8	83.0	75.0	7.3	86.8	0.2	0.0	−0.2	0.0	0.0	0.0	M	M
Land converted to G-WB	CO₂	409.9	108.7	83.0	75.0	7.3	92.4	0.4	−0.7	0.4	−0.5	−0.8	0.9	M	M
G-HP remaining G-HP	CO₂	−1,130.5	−1,114.4	8.0	75.0	5.8	90.4	4.4	−0.9	−3.7	−0.6	−0.1	0.7	M	M
Land converted to G-HP	CO₂	283.6	−1,743.6	8.0	75.0	5.8	15.6	1.2	−6.5	−5.8	−4.9	−0.7	4.9	M	M
G-LP remaining G-LP	CO₂	−229.0	−159.4	8.0	75.0	7.3	90.4	0.6	0.0	−0.5	0.0	0.0	0.0	M	M

IPCC category	Gas	1990 emissions or removals (kt CO₂-e)	2016 emissions or removals (kt CO₂-e)	Activity data uncertainty (%)	Emission factor / estimation parameter uncertainty (biomass) (%)	Emission factor / estimation parameter uncertainty (mineral soil) (%)	Combined uncertainty (%)	Contribution to variance by category in 2014 (%)	Type A sensitivity (%)	Type B sensitivity (%)	Uncertainty in trend in LULUCF emissions introduced by emission factor / estimation parameter uncertainty (%)	Uncertainty in trend in LULUCF emissions introduced by activity data uncertainty (%)	Uncertainty introduced into the trend in total LULUCF emissions (%)	Emission factor quality indicator	Activity data quality indicator
Land converted to G-LP	CO₂	−27.2	−1,412.6	8.0	75.0	7.3	11.5	0.7	−4.6	−4.7	−3.5	−0.5	3.5	M	M
Cropland – perennial remaining cropland – perennial	CO₂	−80.7	−74.6	8.0	75.0	14.1	90.4	0.3	0.0	−0.2	0.0	0.0	0.0	M	M
Land converted to cropland – perennial	CO₂	−46.5	−0.7	8.0	75.0	14.1	9,422.8	0.3	0.1	0.0	0.1	0.0	0.1	M	M
Cropland – annual remaining cropland – annual	CO₂	−269.5	−259.8	8.0	75.0	9.7	90.4	1.0	−0.2	−0.9	−0.1	0.0	0.1	M	M
Land converted to cropland – annual	CO₂	−72.6	−73.9	8.0	75.0	9.7	30.9	0.1	−0.1	−0.2	0.0	0.0	0.0	M	M
Wetland – open water remaining wetlands – open water	CO₂	0.0	0.0	33.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	M	M
Land converted to wetland – open water	CO₂	20.9	−2.0	33.0	0.0	0.0	251.2	0.0	−0.1	0.0	0.0	0.0	0.0	M	M
Wetland – vegetative non-forest remaining wetland – vegetative non-forest	CO₂	0.0	−18.4	33.0	75.0	12.3	95.9	0.1	−0.1	−0.1	0.0	0.0	0.1	M	M
Land converted to wetland – vegetative non-forest	CO₂	−0.6	0.5	33.0	75.0	12.3	15.7	0.0	0.0	0.0	0.0	0.0	0.0	M	M

IPCC category	Gas	1990 emissions or removals (kt CO₂-e)	2016 emissions or removals (kt CO₂-e)	Activity data uncertainty (%)	Emission factor / estimation parameter uncertainty (biomass) (%)	Emission factor / estimation parameter uncertainty (mineral soil) (%)	Combined uncertainty (%)	Contribution to variance by category in 2014 (%)	Type A sensitivity (%)	Type B sensitivity (%)	Uncertainty in trend in LULUCF emissions introduced by emission factor / estimation parameter uncertainty (%)	Uncertainty in trend in LULUCF emissions introduced by activity data uncertainty (%)	Uncertainty introduced into the trend in total LULUCF emissions (%)	Emission factor quality indicator	Activity data quality indicator
Settlements remaining settlements	CO₂	−64.5	−64.5	22.0	75.0	95.0	92.6	0.3	−0.1	−0.2	0.0	0.0	0.0	M	M
Land converted to settlements	CO₂	−3.2	−14.4	22.0	75.0	95.0	98.0	0.1	0.0	0.0	0.0	0.0	0.0	M	M
Other land remaining other land	CO₂	0.0	0.0	22.0	75.0	70.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	M	M
Land converted to other land	CO₂	−10.9	−34.0	22.0	75.0	70.7	28.8	0.0	−0.1	−0.1	−0.1	0.0	0.1	M	M
Harvested wood products	CO₂	1,728.2	5,946.4	15.0	67.4	–	68.2	17.8	15.4	19.7	10.4	3.3	10.9	M	M
LULUCF CH₄ (CO₂-e)	CO₂-e	−93.2	−99.6	30.0	41.6	–	51.3	0.2	−0.1	−0.3	0.0	0.0	0.1	R	R
LULUCF N₂O (CO₂-e)	CO₂-e	−177.1	−91.2	30.0	41.6	–	51.3	0.2	0.1	−0.3	0.1	0.1	0.1	R	R

Note: G-HP = high producing grassland; G-LP = low producing grassland; G-WB = grassland with woody biomass; M = measurements; R = national referenced information.

A3.2.4 LUCAS Data Management System

The Land Use Carbon Analysis System (LUCAS) Data Management System stores, manages and archives data for international greenhouse gas reporting for the LULUCF sector. These systems are used for managing the land-use spatial databases, plot and reference data, and for combining the two sets of data to calculate the numbers required for reporting under the United Nations Framework Convention on Climate Change (the Convention) and the Kyoto Protocol (see figure A3.2.1).

The data collected is stored and manipulated within three systems: the Geospatial System, the Gateway, and the Calculation and Reporting Application.

The main objectives of these systems are to:

- provide a transparent system for data storage and carbon calculations
- provide a repository for the versioning and validation of plot measurements and land use data
- calculate carbon stocks, emissions and removals per hectare for land uses and carbon pools based on the plot and spatial data collected
- calculate biomass burning emissions by land use based on area and emission factors stored in the Gateway
- produce the outputs required for the LULUCF sector reporting under the Convention and the Kyoto Protocol
- archive all inputs and outputs used in reporting.

The module 'Joint Calculations' refers to the process New Zealand uses to estimate national average carbon values by carbon pool for each land-use category and subcategory.

The Joint Calculation process is performed within the Calculation and Reporting Application. Within the Joint Calculations interface, the user selects the appropriate area data and emission factors. The results of the calculations are carbon gains, losses and net change for all land-use subcategories whether in a conversion state or land remaining land, by year, by carbon pool, and stratified by North Island or South Island.

Figure A3.2.1   New Zealand's LUCAS data management system
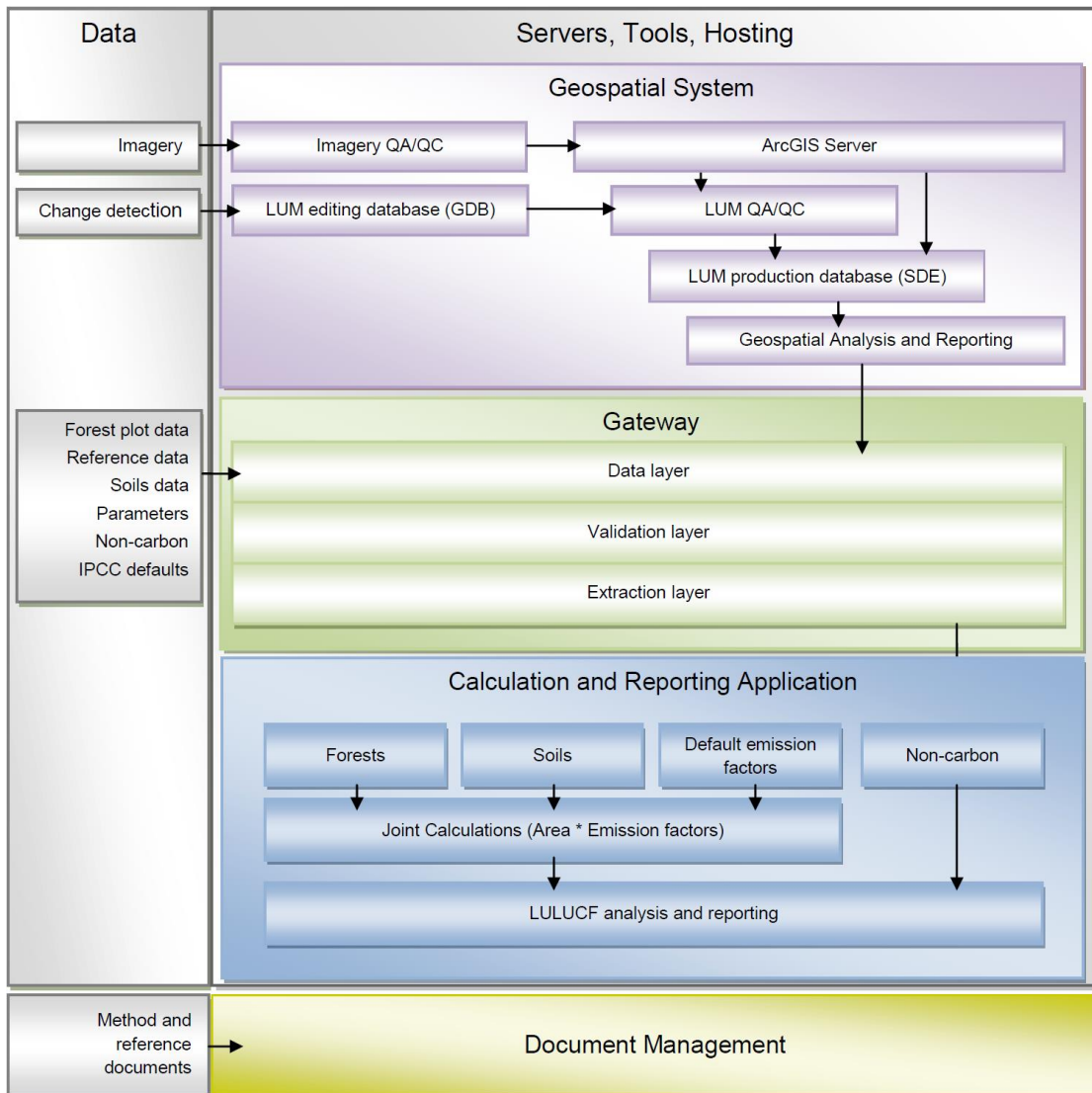
Note: LUM = land use map; QA/QC = quality assurance/quality control. Joint calculations are described below.

Geospatial System

The Geospatial System consists of hardware and specific applications designed to meet LULUCF reporting requirements. The hardware largely comprises servers for spatial database storage, management, versioning and running web-mapping applications. The core components of the Geospatial System are outlined in figure A3.2.2.

Figure A3.2.2   New Zealand's Geospatial System components
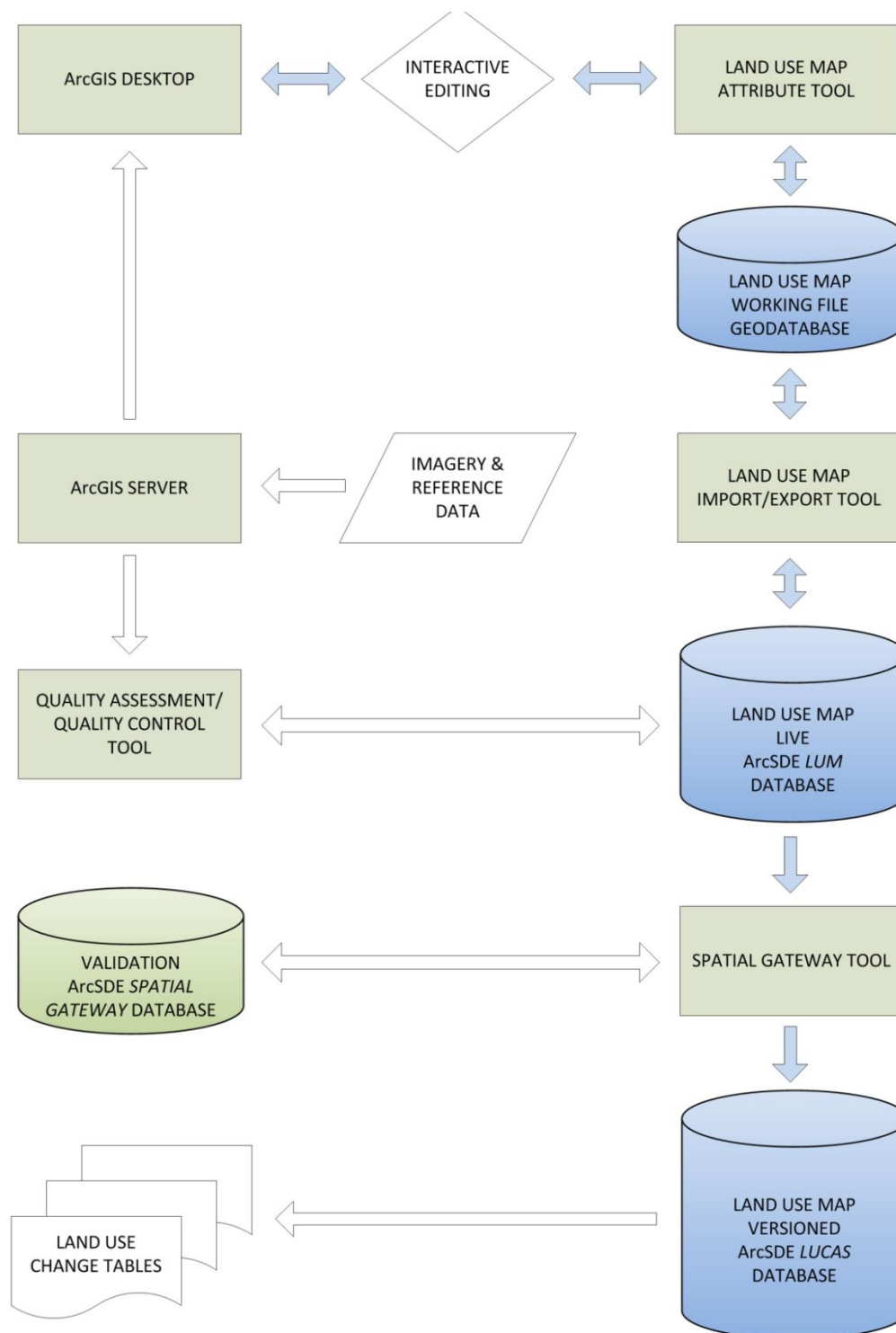
Note: Blue indicates land use mapping data flow. LUCAS = Land Use Carbon Analysis System; LUM = land use map.

Land use mapping functionality

The land use mapping (LUM) functionality of the Geospatial System largely involves the editing and maintenance of time-stamped land use mapping data. The five main components within the LUM functionality are:

- LUM Import/Export Tool – which provides functionality for managing the importing and exporting of LUM information in to and out of the database

- LUM Attribute Tool – an extension to the standard ArcGIS Desktop software that facilitates maintenance and updates to the LUM data by external contractors

- LUM Database – a non-versioned GIS database for interim LUM data and related quality assurance and control observation data

- Spatial Gateway Tool – which is used to validate and version data from the LUM database prior to loading into the LUCAS Geospatial Database. Spatial Gateway rules are stored in the Spatial Gateway Database

- LUCAS Geospatial Database – which stores final versioned geospatial data sets that are used to generate land-use change data.

LUCAS Management Studio

The LUCAS Management Studio (see figure A3.2.3) is the package of applications used to store activity data and calculate and report New Zealand's emissions and removals for LULUCF. The LUCAS Gateway is a data warehouse with the purpose of storing, versioning and validating activity data and emission factors. The Calculation and Reporting Application sources all data from the Gateway and calculates and outputs New Zealand's emissions and removals for LULUCF for land remaining land and land converted to another land use, by pool and year.

Figure A3.2.3   LUCAS Management Studio
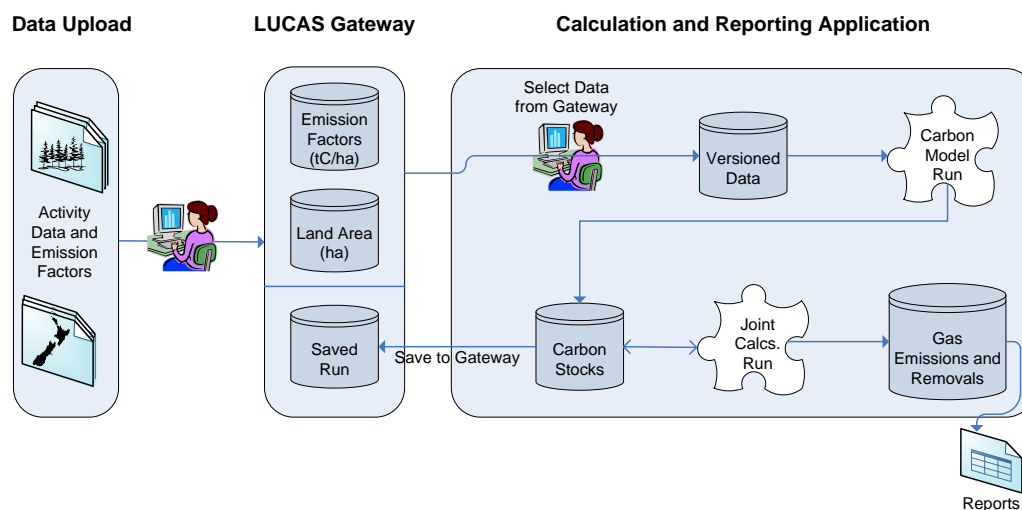
LUCAS Gateway

The LUCAS Gateway enables the storage of activity data such as: field plot data, land use area, biomass burning and other data, such as Intergovernmental Panel on Climate Change (IPCC) defaults, needed by the Calculation and Reporting Application.

The LUCAS Gateway provides a viewing, querying and editing interface to the source (plot, land use area, carbon and non-carbon) data. It also stores any published or saved results from running the Calculation and Reporting Application.

All activity data and emission factors are stored within the Gateway database (see figure A3.2.4). It contains the following key components.

- A data and results layer contains all activity data (natural, planted forest, soils, default carbon, non-carbon, land use areas, land-use change and reference tables). The user has the ability to create a 'snapshot' in time (a data set archiving system) of the data held in the Gateway. This enables users of the Calculation and Reporting Application to select from a range of data snapshots and ensures past results can be replicated over time.

- A validation layer allows users to judge the suitability of data for use in the Calculation and Reporting Application calculations, subsequent to passing primary validation. Where records are deemed not acceptable for use within published reports, they are tagged as 'invalid' in the LUCAS Gateway database.

- An audit trail provides a history of any changes to the database tables within the Gateway.

- Versioning at a number of levels ensures any changes to data, schema or the database itself are logged and versioned, while providing the user with the ability to track what changes have been applied and roll back to a previous version if required. The results of saved or published reports within the Calculation and Reporting Application are also stored within the Gateway for repeatability and reference.

- Primary data validation, both during data capture and during import of the data into the Gateway, ensures only data that has passed acceptability criteria is available for a publishable Calculation and Reporting Application run.

- Hosting and application support provides hosting services, system security, backup and restore, daily maintenance and monitoring for the Gateway and Calculation and Reporting Application.

Figure A3.2.4   LUCAS Gateway database
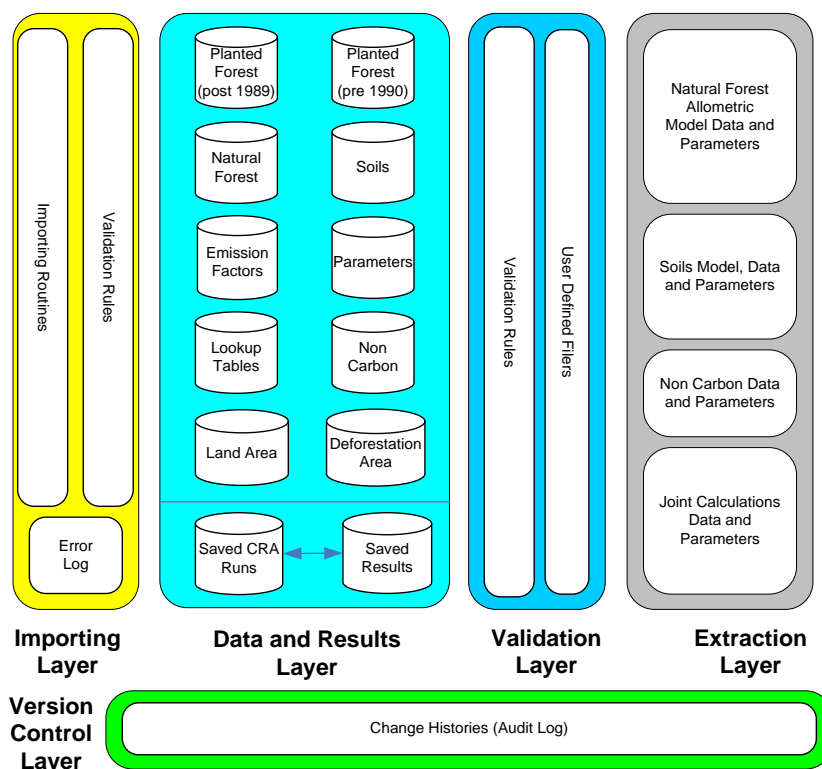
Calculation and Reporting Application

The Calculation and Reporting Application enables users to import carbon and non-carbon data from the Gateway and, by running the various modules, determine emissions and removals by New Zealand's forests, cropland, grassland and other land use types. This information, combined with land area data, enables New Zealand to meet its reporting requirements under the Convention and Kyoto Protocol.

The Calculation and Reporting Application allows for the inclusion of other data sets, models and calculations without the complete redesign of the applications. All models, data and results are versioned, and the Calculation and Reporting Application allows the user to alter specific key values within a model or calculation (parameters) without the intervention of a programmer or technical support officer. The Calculation and Reporting Application is deployed as a client-based application that sources the required data from the Gateway.

The Calculation and Reporting Application comprises four modules: natural forest, soils, non-carbon, and joint calculations. Any of these modules can be run independently or as a group. The results are provided as 'views' to the user at the completion of the run.

To activate the module, the user selects the module to run within the Calculation and Reporting Application, the version of the data set to be used, the model version and other calculation parameters. The natural forest and soil carbon modules use R statistical language as the base program language, while the non-carbon module and joint calculations module are developed in C Sharp programming language (C#).

Within the joint calculations module, the user has the option of using the carbon results from running the modules or using default carbon estimates (based on published reports) stored within the Gateway. The joint calculations module combines the carbon estimates with the land use area to calculate carbon stock and change following the methodology set out in section 2.3 of volume 4 of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006). The results represent carbon stock and change for every 'from' and 'to' land use combination outlined by the IPCC since 1990.

On completion of running a module, the results can be saved or published back to the Gateway. This provides a versioned and auditable record of the results used for reporting. If the results are saved or published, other information, such as the time created, the user's identification and the module-particular parameters that were used, is also saved for tracking and audit control.

The Calculation and Reporting Application is maintained and supported by Interpine Forestry Limited, a New Zealand-based company that specialises in forestry inventories and related information technology development. Interpine Forestry Limited also provides support services, such as database and application backups, day-to-day issue resolution and enhancement projects to the Gateway or Calculation and Reporting Application as required.

Any changes to the data or table structure within the Gateway, or to people accessing the Gateway or Calculation and Reporting Application, are tracked via audit logs. For any changes to the data within the Gateway, the person making the change, the date, reason for change and the version are logged and reports are made available to the users for review.

Document management

All reference material, including scientific reports containing information on methodologies or emission factors used in the production of the LULUCF and Kyoto Protocol estimates, is archived on the Ministry for the Environment's document management store, Te Puna.

The emission factors and area estimates just for published runs are also archived within the Gateway and can be accessed via the Gateway or the Calculation and Reporting Application.

Annex 3: References

Some references may be downloaded directly from the following webpage: www.mpi.govt.nz/news-and-resources/statistics-and-forecasting/greenhouse-gas-reporting/agriculture-greenhouse-gas-inventory-reports.

The Ministry for Primary Industries is progressively making reports used for the inventory available on this page, provided copyright permits.

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Annex 4: Methodology and data collection for estimating emissions from fossil fuel combustion

New Zealand emission factors are based on gross calorific value. Energy activity data and emission factors in New Zealand are conventionally reported in gross (higher heating value) terms, with some minor exceptions. The convention adopted by New Zealand to convert gross calorific value to net calorific value follows the Organisation for Economic Co-operation and Development and International Energy Agency assumptions:

Net calorific value = 0.95 × gross calorific value for coal and liquid fuels

Net calorific value = 0.90 × gross calorific value for gas

Net calorific value = 0.80 × gross calorific value for wood

Emission factors for gas, coal, biomass and liquid fuels used by New Zealand are shown in tables A4.1–A4.4. Where Intergovernmental Panel on Climate Change (IPCC) default emission factors are used, a net-to-gross factor as above is used to account for New Zealand activity data representing gross energy figures:

Gross EF = Net EF × Factor

Table A4.1   Gross carbon dioxide emission factors used for New Zealand's energy sector in 2016

	Emission factor (t CO_2/TJ)	Emission factor (t C/TJ)	Source
Gas			
Maui	52.30	14.2	1
Kapuni	53.56	14.6	1
McKee	54.45	14.9	2
Kaimiro	68.14	18.6	2
Ngatoro	68.14	18.6	2
TAWN	52.72	14.4	2
Mangahewa	54.44	14.7	2
Turangi	54.79	14.8	2
Pohokura	54.72	14.9	1
Rimu/Kauri	52.23	14.2	2
Maari	53.22	14.5	2
Weighted Average	53.96	14.7	
Kapuni LTS	85.54	23.3	1
Methanol – Mixed Feed – to 94	62.44	17.0	2
Methanol – LTS – to 94	83.97	22.9	2
Liquid fuels			
Crude oil	69.67	19.0	4
Regular petrol	66.58	18.2	3
Petrol – premium	66.79	18.2	3
Diesel (10 parts (sulphur) per million)	69.69	19.0	3
Jet kerosene	68.53	18.7	3

	Emission factor (t CO$_2$/TJ)	Emission factor (t C/TJ)	Source
Av gas	65.89	18.0	3
LPG	60.43	16.5	6
Heavy fuel oil	73.63	20.1	3
Light fuel oil	72.91	19.9	3
Bitumen (asphalt)	76.94	21.0	3
Biomass			
Biogas	49.17	13.4	4
Wood (industrial)	89.47	24.4	4
Bioethanol	64.20	17.5	5
Biodiesel	67.26	17.0	4
Wood (residential)	89.47	24.4	4
Coal			
All sectors excl. electricity (sub-bituminous)	92.00	25.1	6
All sectors (bituminous)	89.10	24.3	6
All sectors (lignite)	93.10	25.4	6

1. New Zealand Emissions Trading Scheme data.
2. Specific gas field operator.
3. Refining NZ.
4. IPCC Guidelines (2006).
5. *New Zealand Energy Information Handbook* (Eng et al., 2008).
6. *Review of Default Emissions Factors in Draft Stationary Energy and Industrial Processes Regulations: Coal* (CRL Energy, 2009).

Table A4.2   Consumption-weighted average emission factors used for New Zealand's sub-bituminous coal-fired electricity generation for 1990 to 2016

Year	Emission factor (t CO$_2$/TJ)
1990	91.20
1991	91.24
1992	91.29
1993	91.33
1994	91.38
1995	91.42
1996	91.47
1997	91.51
1998	91.56
1999	91.60
2000	91.64
2001	91.69
2002	91.73
2003	91.78
2004	91.82
2005	91.87
2006	91.91
2007	92.43
2008	92.31
2009	92.39
2010 onwards	92.20

Table A4.3   Methane emission factors used for New Zealand's energy sector for 1990 to 2016

	Emission factor (t CH$_4$/PJ)	Source
Natural gas		
Electricity industries	0.9	IPCC 2006 (table 2.2)
Commercial	4.50	IPCC 2006 (table 2.4)
Residential	4.50	IPCC 2006 (table 2.5)
Domestic transport (CNG)	82.80	IPCC 2006 (table 3.2.2)
Other stationary (mainly industrial)	0.9	IPCC 2006 (table 2.3)
Liquid fuels		
Stationary sources		
Electricity – residual oil	2.85	IPCC 2006 (table 2.2)
Industrial (including refining) – residual oil	2.85	IPCC 2006 (table 2.3)
Industrial – LPG	0.95	IPCC 2006 (table 2.3)
Commercial – residual oil	9.50	IPCC 2006 (table 2.4)
Commercial – distillate oil	9.50	IPCC 2006 (table 2.4)
Commercial – LPG	4.75	IPCC 2006 (table 2.4)
Residential – distillate oil	9.50	IPCC 2006 (table 2.5)
Residential – LPG	4.75	IPCC 2006 (table 2.5)
Agriculture – stationary	2.85	IPCC 2006 (table 2.5)
Mobile sources		
LPG	58.9	IPCC 2006 (table 3.2.2)
Petrol	28.05	IPCC 2006 (table 3.2.2)
Diesel	3.71	IPCC 2006 (table 3.2.2)
Navigation (fuel oil and diesel)	6.65	IPCC 2006 (table 3.5.3)
Aviation fuel/kerosene	0.48	IPCC 2006 (table 3.6.5)
Coal		
Electricity generation	0.95	IPCC 2006 (table 2.2)
Industry	9.50	IPCC 2006 (table 2.3)
Commercial	9.50	IPCC 2006 (table 2.4)
Residential	285.00	IPCC 2006 (table 2.5)
Biomass		
Wood/wood waste	24	IPCC 2006 (table 2.3)
Wood – fireplaces	240.00	IPCC 2006 (table 2.5) wood – residential
Bioethanol	18.00	IPCC 2006 (table 3.2.2) – ethanol, cars, Brazil
Biodiesel	18.00	IPCC 2006 (table 3.2.2) – ethanol, cars, Brazil
Gas biomass	0.9	IPCC 2006 (table 2.2)

Table A4.4   Nitrous oxide emission factors used for New Zealand's energy sector for 1990 to 2016

	Emission factor (t N$_2$O/PJ)	Source
Natural gas		
Electricity generation	0.09	IPCC 2006 (table 2.2)
Commercial	0.09	IPCC 2006 (table 2.4)
Residential	0.09	IPCC 2006 (table 2.5)
Domestic transport (CNG)	2.70	IPCC 2006 (table 3.2.2)
Other stationary (mainly industrial)	0.09	IPCC 2006 (table 2.3)
Liquid fuels		
Stationary sources		
Electricity – residual oil	0.57	IPCC 2006 (table 2.2)
Electricity – distillate oil	0.57	IPCC 2006 (table 2.2)

	Emission factor (t N₂O/PJ)	Source
Industrial (including refining) – residual oil	0.57	IPCC 2006 (table 2.2)
Industrial – distillate oil	0.57	IPCC 2006 (table 2.3)
Commercial – residual oil	0.57	IPCC 2006 (table 2.4)
Commercial – distillate oil	0.57	IPCC 2006 (table 2.4)
Residential (all oil)	0.57	IPCC 2006 (table 2.5)
LPG (all uses)	0.095	IPCC 2006 (tables 2.2 – 2.5)
Agriculture – stationary	0.38	Tier 2, diesel engines – agriculture
Mobile sources		
LPG	0.19	IPCC 2006 (table 3.22)
Petrol	7.6	IPCC 2006 (table 3.2.2)
Diesel	3.71	IPCC 2006 (table 3.2.2)
Fuel oil (ships)	1.90	IPCC 2006 (table 3.5.3)
Aviation fuel/kerosene	1.90	IPCC 2006 (table 3.6.5)
Coal		
Electricity generation	1.43	IPCC 2006 (table 2.2)
Industry	1.43	IPCC 2006 (table 2.3)
Commercial	1.43	IPCC 2006 (table 2.4)
Residential	1.43	IPCC 2006 (table 2.5)
Biomass		
Wood (all uses)	3.20	IPCC 2006 (table 2.5) wood/wood waste
Gas biomass	0.09	IPCC 2006 (table 2.5)

A4.1   Emissions from liquid fuels

A4.1.1   Activity data and uncertainties

The *Delivery of Petroleum Fuels by Industry Survey* is conducted by the Ministry of Business, Innovation and Employment (MBIE). Because it is a census, there is no sampling error. The only possible sources of error are non-sample errors (such as respondent error and processing error). The 2016 statistical difference for liquid fuels in the balance table of the publication *Energy in New Zealand* (MBIE, 2017) was 1.5 per cent. This is used as the activity data uncertainty for liquid fuels in 2016.

A4.1.2   Emission factors and uncertainties

The carbon dioxide (CO_2) emission factors are described in table A4.1. Table A4.5 shows a complete time series of gross calorific values, while table A4.6 shows a complete time series of carbon content of liquid fuels. This information is supplied by the Refining NZ and is used in the calculation of annual emission factors for liquid fuels.

A 2009 consultant report (Hale and Twomey, Unpublished) to the Ministry for the Environment estimates the uncertainty of CO_2 emission factors for liquid fuels at ±0.5 per cent. The uncertainty for methane and nitrous oxide emission factors is ±50.0 per cent because almost all emission factors are IPCC defaults.

Table A4.5   Gross calorific values (MJ/kg) for liquid fuels for 1990 to 2016

	Premium petrol	Regular petrol	Diesel	Jet kerosene	Av gas	Heavy fuel oil	Light fuel oil	Power station fuel oil	Bitumen (asphalt)
1990	47.24	47.22	45.76	46.37	47.30	43.07	44.12	42.71	41.30
1991	47.17	47.17	45.73	46.38	47.30	43.02	44.07	42.70	41.30
1992	47.18	47.14	45.75	46.41	47.30	43.03	44.14	42.72	41.30
1993	47.09	47.14	45.74	46.36	47.30	43.01	44.13	42.75	41.31
1994	47.10	47.11	45.75	46.34	47.30	43.03	44.16	42.70	41.30
1995	47.07	47.14	45.59	46.31	47.30	43.03	44.01	42.69	41.30
1996	46.91	47.14	45.54	46.26	47.30	43.00	43.98	42.68	41.30
1997	46.93	47.17	45.58	46.32	47.30	42.92	43.92	42.56	41.30
1998	46.89	47.12	45.64	46.27	47.30	43.06	44.02	42.79	41.27
1999	46.92	47.13	45.56	46.29	47.30	43.09	43.93	42.79	41.28
2000	46.91	47.12	45.58	46.22	47.30	43.07	43.90	42.74	41.27
2001	46.92	47.15	45.64	46.25	47.30	43.08	43.96	42.76	41.27
2002	46.90	47.16	45.62	46.29	47.30	43.03	43.84	42.79	41.26
2003	46.87	47.11	45.61	46.23	47.30	43.06	43.79	42.77	41.27
2004	46.91	47.10	45.59	46.25	47.30	43.04	43.90	42.79	41.30
2005	46.95	47.10	45.73	46.28	47.30	43.11	43.94	42.78	41.30
2006	46.97	47.09	45.79	46.23	47.30	42.93	43.68	42.65	41.30
2007	46.97	47.10	45.77	46.23	47.30	42.97	43.72	42.66	41.30
2008	46.93	47.06	45.72	46.19	47.30	42.86	43.72	42.56	41.30
2009	46.95	47.03	45.72	46.17	47.30	42.89	43.75	42.56	41.29
2010	46.96	47.03	45.69	46.17	47.30	42.95	43.70	42.62	41.29
2011	46.96	47.04	45.69	46.19	47.30	42.89	43.72	42.61	41.27
2012	46.98	47.03	45.66	46.18	47.30	43.03	43.71	42.72	41.27
2013	46.99	47.05	45.71	46.23	47.30	43.05	43.84	42.72	41.26
2014	46.95	47.02	45.71	46.23	47.30	42.94	43.73	42.64	41.26
2015	46.96	47.03	45.67	46.19	47.30	42.98	43.70	42.65	41.28
2016	46.96	47.03	45.67	46.19	47.30	42.98	43.71	42.65	41.28

Table A4.6   Carbon content (per cent mass) for liquid fuels for 1990 to 2016

	Premium petrol	Regular petrol	Diesel	Jet kerosene	Av gas	Heavy fuel oil	Light fuel oil	Power station fuel oil	Bitumen (asphalt)
1990	84.87	84.92	86.28	85.92	85.00	86.22	86.67	86.03	86.57
1991	85.04	85.04	86.33	85.89	85.00	86.26	86.30	86.04	86.57
1992	85.03	85.13	86.29	85.84	85.00	86.25	86.18	86.03	86.57
1993	85.25	85.13	86.32	85.94	85.00	86.27	86.20	86.00	86.56
1994	85.21	85.19	86.30	85.99	85.00	86.25	86.13	86.04	86.57
1995	85.30	85.13	86.63	86.05	85.00	86.25	86.39	86.05	86.57
1996	85.66	85.13	86.73	86.16	85.00	86.28	86.45	86.05	86.57
1997	85.63	85.04	86.64	86.04	85.00	86.35	86.55	86.16	86.58
1998	85.72	85.17	86.52	86.14	85.00	86.22	86.39	85.97	86.63
1999	85.65	85.15	86.69	86.10	85.00	86.20	86.53	85.96	86.63
2000	85.67	85.16	86.64	86.25	85.00	86.22	86.58	86.01	86.63

	Premium petrol	Regular petrol	Diesel	Jet kerosene	Av gas	Heavy fuel oil	Light fuel oil	Power station fuel oil	Bitumen (asphalt)
2001	85.65	85.09	86.53	86.18	85.00	86.21	86.49	85.98	86.64
2002	85.68	85.06	86.57	86.10	85.00	86.25	86.68	85.96	86.66
2003	85.76	85.19	86.58	86.23	85.00	86.23	86.76	85.98	86.63
2004	85.66	85.22	86.62	86.20	85.00	86.24	86.58	85.97	86.58
2005	85.58	85.22	86.62	86.12	85.00	86.18	86.52	85.97	86.57
2006	85.54	85.25	86.57	86.24	85.00	86.34	86.93	86.08	86.57
2007	85.54	85.23	86.61	86.24	85.00	86.30	86.87	86.07	86.57
2008	85.63	85.32	86.70	86.32	85.00	86.39	86.87	86.16	86.57
2009	85.56	85.38	86.72	86.36	85.00	86.37	86.83	86.16	86.60
2010	85.54	85.40	86.77	86.35	85.00	86.31	86.90	86.11	86.59
2011	85.55	85.37	86.78	86.32	85.00	86.37	86.87	86.12	86.64
2012	85.51	85.38	86.84	86.34	85.00	86.25	86.89	86.02	86.63
2013	85.49	85.35	86.73	86.22	85.00	86.24	86.68	86.02	86.65
2014	85.57	85.42	86.74	86.23	85.00	86.33	86.87	86.10	86.65
2015	85.54	85.40	86.81	86.33	85.00	86.30	86.90	86.09	86.62
2016	85.54	85.40	86.81	86.33	85.00	86.30	86.90	86.09	86.62

Table A4.7   **Emission factors for European gasoline and diesel vehicles – COPERT IV model (European Environment Agency, 2007)**

	N_2O emission factors (mg/km)				CH_4 emission factors (mg/km)			
	Urban		Rural	Highway	Urban		Rural	Highway
	Cold	Hot			Cold	Hot		
Passenger car								
Gasoline								
pre-Euro	10	10	6.5	6.5	201	131	86	41
Euro 1	38	22	17	8	45	26	16	14
Euro 2	24	11	4.5	2.5	94	17	13	11
Euro 3	12	3	2	1.5	83	3	2	4
Euro 4	6	2	0.8	0.7	57	2.87	2.69	5.08
Diesel								
pre-Euro	0	0	0	0	22	28	12	8
Euro 1	0	2	4	4	18	11	9	3
Euro 2	3	4	6	6	6	7	3	2
Euro 3	15	9	4	4	3	3	0	0
Euro 4	15	9	4	4	1.1	1.1	0	0
LPG								
pre-ECE	0	0	0	0	80	80	35	25
Euro 1	38	21	13	8	80	80	35	25
Euro 2	23	13	3	2	80	80	35	25
Euro 3 and later	9	5	2	1	80	80	35	25
Light duty vehicles								
Gasoline								
pre-Euro	10	10	6.5	6.5	201	131	86	41
Euro 1	122	52	52	52	45	26	16	14
Euro 2	62	22	22	22	94	17	13	11
Euro 3	36	5	5	5	83	3	2	4
Euro 4	16	2	2	2	57	2	2	0

| | N$_2$O emission factors (mg/km) | | | | CH$_4$ emission factors (mg/km) | | | |
| | Urban | | Rural | Highway | Urban | | Rural | Highway |
	Cold	Hot			Cold	Hot		
Diesel								
pre-Euro	0	0	0	0	22	28	12	8
Euro 1	0	2	4	4	18	11	9	3
Euro 2	3	4	6	6	6	7	3	2
Euro 3	15	9	4	4	3	3	0	0
Euro 4	15	9	4	4	1.1	1.1	0	0
Heavy duty truck and bus								
Gasoline – all technologies	6	6	6	6	140	140	110	70
Diesel								
GVW<16t	30	30	30	30	85	85	23	20
GVW>16t	30	30	30	30	175	175	80	70
Urban busses and coaches	30	30	30	30	175	175	80	70
CNG								
pre Euro 4					5,400	5,400	5,400	5,400
Euro 4 and later					900	900	900	900
Power two wheeler								
Gasoline								
<50 cm^3	1	1	1	1	219	219	219	219
>50 cm^3 2 stroke	2	2	2	2	150	150	150	150
>50 cm^3 4 stroke	2	2	2	2	200	200	200	200

A4.2   Emissions from solid fuels

A4.2.1   Activity data and uncertainties

The *New Zealand Quarterly Statistical Return of Coal Production and Sales* conducted by MBIE has near coverage of the sector, meaning that sampling error is small. The only other possible sources of error are non-sample errors (such as respondent error and processing error). The 2016 statistical difference for solid fuels in the balance table of the publication *Energy in New Zealand* (MBIE, 2017) was 1.2 per cent. This is used as the activity data uncertainty for solid fuels in 2016.

A4.2.2   Emission factors and uncertainties

The estimated uncertainty in CO_2 emission factors for solid fuels is ±2.2 per cent. This is based on the difference between the range of updated emission factors for the three different ranks of coal used in New Zealand. The uncertainty for methane and nitrous oxide emission factors is ±50.0 per cent because almost all emission factors are IPCC defaults.

A4.3   Emissions from gaseous fuels

A4.3.1   Activity data

Through the various surveys and information collected by MBIE, it has full coverage of the natural gas sector. This means that there is no sampling error in natural gas statistics and the

only possible sources of error include those such as respondent error and processing error. The 2016 statistical difference for gaseous fuels in the balance table of the publication *Energy in New Zealand* (MBIE, 2017) was −0.7 per cent. This is used as the activity data uncertainty for gaseous fuels in 2015.

A4.3.2 Emission factors

The estimated uncertainty in CO_2 emission factors for gaseous fuels is ±2.4 per cent. This is based on the difference between the range of emission factors for three large gas fields in New Zealand. Together, these gas fields made up over 65 per cent of New Zealand's total gas supply in 2013. The uncertainty for methane and nitrous oxide emission factors is ±50.0 per cent as almost all emission factors are IPCC defaults.

A4.4 Energy balance

Detailed and up-to-date energy balance tables for New Zealand are available online: www.mbie.govt.nz/info-services/sectors-industries/energy/energy-data-modelling/statistics/energy-balances.

Further information can be found within the publication *Energy in New Zealand*, also available online: www.mbie.govt.nz/info-services/sectors-industries/energy/energy-data-modelling/publications/energy-in-new-zealand.

A4.5 Carbon dioxide reference approach for the Energy sector

A4.5.1 Estimation of carbon dioxide using the IPCC reference approach

The reference approach uses a country's energy supply data to calculate the CO_2 emissions from the combustion of fossil fuels using the apparent consumption equation. The apparent consumption in the reference approach is derived from production, import and export data. This information is included as a check for combustion-related emissions calculated from the sectoral approach.

The apparent consumption for primary fuels in the reference approach is obtained from 'calculated' energy-use figures (see annex 2 and section A4.4). These are derived as a residual figure from an energy balance equation comprising production, imports, exports, stock change and international transport on the supply side according to the IPCC Guidelines (IPCC, 2006).

The majority of the CO_2 emission factors for the reference approach are specific to New Zealand. Most emission factors for liquid fuels are based on annual carbon content and the gross calorific value data provided by New Zealand's only oil refinery, Refining NZ. Where this data is not available, an IPCC default is used. The natural gas emission factor is based on a production-derived, weighted average of emission factors from all gas production fields. The CO_2 emission factors for solid fuels were updated for the 2014 inventory submission following analysis to verify default emission factors used for the New Zealand Emissions Trading Scheme. For more information on this improvement, see chapter 3, section 3.3.2.

Solid fuels in iron and steel manufacture

As mentioned in chapter 3, section 3.2.3, some of the coal production activity data in the reference approach is used in steel production. The Industrial Processes and Product Use sector

accounts for the CO_2 emissions from this coal in the sectoral approach, as recommended by the IPCC Guidelines (IPCC, 2006); therefore they are not included in common reporting format table 1.AA *Fuel combustion – sectoral approach*.

For simplicity, all feedstock carbon is excluded from the reference approach according to the IPCC Guidelines (IPCC, 2006). Without taking into account the use of by-product gases, this can create some discrepancies between the reference and sectoral approaches.

A4.5.2 Comparison of the IPCC reference approach with the New Zealand sectoral methodology

For 2015, CO_2 emissions estimated in the sectoral approach were 0.7 per cent lower than those estimated in the reference approach. Figure A4.1 shows the results for the two approaches for the period 1990–2015.

In some years, differences exist between the reference and sectoral approaches. Much of this is due to the statistical differences found in the energy balance tables (MBIE, 2017) that are used as the basis for the reference and sectoral approach. Since 2000, the standard of national energy data has improved significantly, due to increased resources and focus. In 2008, Statistics New Zealand delegated responsibility for the collection and analysis of national energy data to MBIE. Before 2008, various energy statistics were collected by Statistics New Zealand or MBIE. The change resulted in a more consistent and transparent approach to energy data collection because one agency collected data across the supply chain.

Figure A4.1   Reference and sectoral approach carbon dioxide by fuel type (kt CO_2)
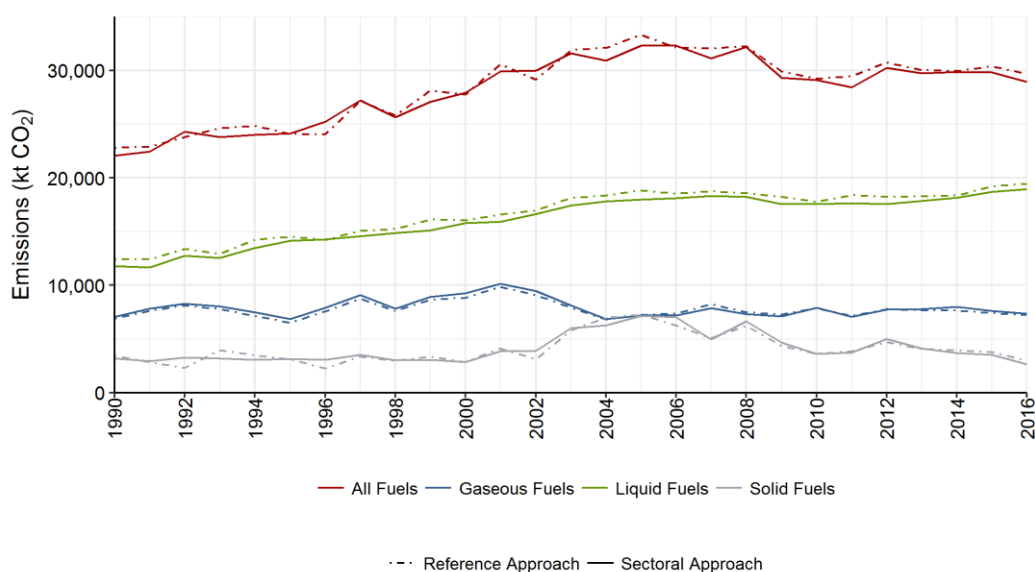
Sources of differences

- For gaseous fuels, the field-specific emission factors are used for natural gas supplied for industrial processes, while the reference approach uses an average emission factor.

- For liquid fuels, the energy balance is mass balanced but not carbon balanced. The fuel category 'other oil' is an aggregation of several fuel types, and so it is difficult to quantify a reliable carbon emission factor for the reference approach.

- In the sectoral approach, sector- or even plant-specific calorific values are used to calculate energy consumption, whereas in the reference approach, average (country-specific) calorific values are applied.

Annex 4: References

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Annex 5: Supplementary information for the KP-LULUCF sector

Annex 5.1: Technical corrections to the FMRL

A5.1.1 Introduction

For the second commitment period, reporting on *Forest management* under the Kyoto Protocol is mandatory. Accounting for *Forest management* during the second commitment period is relative to a forest management reference level (FMRL) (Decision 2/CMP.7, UNFCCC, 2012).

New Zealand's FMRL, first submitted in 2009 and revised in 2011, is set at 11.15 million tonnes carbon dioxide equivalent (Mt CO_2-e) per year for the period 2013 to 2020 (New Zealand Government, 2011). This value was constructed using a business-as-usual projection of pre-1990 planted forest growth and harvest for the period 2013 to 2020. It was based on yield tables and statistics on the area in each age class of pre-1990 planted forest from the National Exotic Forest Description (NEFD) as at 2009 (Ministry for Primary Industries, 2014).

The 2011 FMRL included the following assumptions:

- pre-1990 natural forests were in steady state

- no pre-1990 planted forest deforestation would occur between 2013 and 2020 (pre-1990 natural forests were excluded from the analyses; post-1989 forest deforestation is reported under Article 3.3 – *Deforestation*)

- between 2013 and 2020, 2,000 hectares per year would be converted to non-forest land, and the equivalent forest would be planted elsewhere (i.e., 2,000 hectares per year would be reported as carbon equivalent forest (CEF) and be accounted for under *Forest management*)

- while harvest of post-1989 planted forest will increase over the period, pre-1990 planted forests will still make up a substantial proportion of total forest harvest

- all carbon was instantly emitted at the time of harvest (emissions and removals by the *Harvested wood products* pool were not considered)

- no allowance was made for the impacts of potential natural disturbances beyond background levels captured in the carbon stock yield tables.

It also reflected the following New Zealand legislation (and amendments) and current policies:

- the Forest Act 1949, which regulates the removal of timber from natural indigenous forests

- the South Island Landless Natives Act 1906, which transferred 17,000 hectares of natural indigenous forest to South Island Māori. The harvesting of this forest is also subject to the Resource Management Act 1991

- the Climate Change Response Act 2002, which makes owners of pre-1990 forest who deforest liable for the emissions associated with that activity

- the New Zealand's biofuels policy of the time (under which it was thought most feedstock for biofuel was likely to be derived from non-forest sources).

It was thought that this legislation and these policies would prevent any significant deforestation of pre-1990 forests, and that the New Zealand Emissions Trading Scheme would encourage harvest in pre-1990 planted forests over post-1989 forest.

The 2011 FMRL was determined by modelling the pre-1990 planted forest estate using a Forestry-Oriented Linear Programming Interpreter (FOLPI). As mentioned above, the model developed in FOLPI was based on an age-class distribution of pre-1990 planted forest as at 2009 from the NEFD, and simulated expected harvesting and replanting of this forest. Some additional modelling of decay of residues from harvest events was also carried out in MS Excel.

Since the 2011 FMRL was submitted, supplementary guidance has been prepared that describes the circumstances that would trigger a technical correction to the FMRL (IPCC, 2014). Changes to policies that impact harvest rate (as listed above) cannot be corrected for, but corrections can be made to reflect changes to the method for reporting against the FMRL and to address recommendations made by United Nations Framework Convention on Climate Change (UNFCCC) expert review teams (ERTs).

A technical assessment of New Zealand's reference level submission was carried out by an ERT in 2011 (UNFCCC, 2011). The ERT noted a number of items for New Zealand to address through either the provision of additional data or through applying technical corrections. These included (UNFCCC, 2011, pp 6–10):

- maintaining consistency in the fraction of harvested biomass instantaneously oxidised when estimating emissions from harvest in the FMRL and in reporting against it (paragraph 21);

- ensuring consistency between the National Inventory Report (NIR) and the FMRL and, therefore, the updating of the current FMRL when new data/information becomes available (paragraph 22);

- making efforts to disaggregate gains and losses by biomass pool (paragraph 35);

- providing further information on how forest owners will be able to move from historic/current harvesting practice to the longer rotation length projected in the FOLPI model (paragraph 36);

- explaining in more detail how the difference in both harvested areas and harvesting age as calculated by FOLPI could be achieved (paragraph 36);

- comparing the results provided in its submission with a rerun of the FOLPI model in which the harvesting of over-mature forests (over 32 years of age) is constrained, and modify the reference level accordingly if necessary (paragraph 36);

- if estimates for natural forests are included in future NIR submissions, making a technical adjustment of the FMRL (paragraph 37);

- agreeing that in the future a technical correction should be made to incorporate the Harvested wood product (HWP) pool (paragraph 38).

A5.1.2 Technical corrections required

For the 2016 submission, the following technical corrections were made to meet IPCC guidance and address recommendations by the UNFCCC ERT. These aimed to:

1. ensure consistency between the method used for greenhouse gas reporting of *Forest management* and that used to calculate the FMRL (Kyoto Protocol Supplement, IPCC, 2014, sections 2.7.5.2 and 2.7.6). This involves making changes to:

   a. align forest area estimates

   b. align CEF emissions calculation methods

   c. include over planting estimates (pre-1990 natural forest conversions to pre-1990 planted forest)

   d. include non-carbon emissions

2. include an estimate for pre-1990 natural forest emissions following completion of the re-measurement of the pre-1990 natural forest inventory and subsequent analysis

3. address new elements of Decision 2/CMP.7 including:

   a. accounting for *Harvested wood products*

   b. the application of the natural disturbances provision.

No additional technical corrections have been made for the 2018 submission, though the reporting of the technical corrections included in the 2016 submission has been improved.

Addressing methodological inconsistencies between the 2011 FMRL and Forest management reporting

The first step taken to calculate technical corrections to the FMRL was to replicate the FMRL as submitted in 2011, applying the same policy assumptions, but using the reporting system and historical data that are used to report on *Forest management* in the inventory.

This technical correction addresses two of the findings of the technical assessment (listed above) by:

1. maintaining consistency in the fraction of harvested biomass instantaneously oxidised

2. ensuring consistency between the emissions reported in the inventory for *Forest management* and the FMRL.

This is achieved by using the harvest and deforestation data from 1990 to 2008 from the 2013 inventory (Ministry for the Environment, 2015) as the starting point for the revised projections. Harvesting and deforestation areas for 2009 to 2020, sourced from the Ministry for Primary Industries, are the same as those used for the 2011 FMRL (2009 was the first year of projected data within New Zealand's 2011 FMRL submission).

Minor adjustments were made to this data as outlined below:

- alignment of forest area estimate to match it to the area of forest that is included under the definition of forest used for UNFCCC reporting

- pre-1990 harvesting data (average harvest age) from 2009 to 2020 have been altered from that used in the 2011 FMRL. The average age at harvest has been adjusted down to 28 years, to address the issue raised by the ERT in its technical assessment of the 2011 FMRL. The area of harvest, however, has been kept the same

- the age-class distribution (as at 2013, based on the 2013 inventory) needed to be altered to ensure enough area was present to maintain the 2011 FMRL harvest rate assumptions. While the result of forcing the harvest profile to match the 2011 FMRL creates an improbable age class, it has limited impact on emissions as average age harvested each year is maintained. The creation of a more realistic age class is an issue New Zealand will look to correct in future technical corrections

- changes to CEF reporting to reflect updated guidance for this reporting released after the 2011 FMRL submission.

Aligning forest area estimates

The 2011 FMRL submission was based on data derived from the NEFD (Ministry for Primary Industries, 2014). The NEFD is an annual survey of forest owners that represents the 'net stocked area' of the planted production forest estate established with the primary intention of producing wood or fibre. The Land Use and Carbon Analysis System (LUCAS) that is used for reporting emissions for *Forest management* in the inventory uses complete wall-to-wall mapping to estimate forest area. This means LUCAS maps to a 'gross stocked area' where

harvested areas, skid sites, forest roads and unstocked gullies are included in the mapped forest area. This gross stocked area is also the basis for the national sampling system used for deriving emission factors for the *Forest land* use classes. For modelling emissions for reporting under the UNFCCC, LUCAS has isolated the net stocked area from the mapped gross stocked area so the modelled area is compatible between the two data sources (LUCAS and NEFD). The LUCAS gross stocked area of pre-1990 planted forest area is 1.47 million hectares as at 2009. The LUCAS net stocked area is estimated to be 1.25 million hectares (a 12.4 per cent difference). This compares with 1.14 million hectares from the NEFD as at 2009. Because the 2011 FMRL did not take into account differences in the data sources due to the two purposes for which the data are collected, a technical correction is required to correct the original NEFD-based FMRL to the LUCAS mapped area estimates used for reporting for *Forest management*.

The need for this adjustment extends to estimates of the area of CEF and deforestation, meaning these original net stocked area values need to have an unstocked area component added to them (the same adjustment of 12.4 per cent is used). The harvest areas, however, remain unchanged because both approaches harvest a net stocked area.

The area reported under *Forest management* will change each year because emissions from deforestation will be reported under Article 3.3 – *Deforestation* instead. This means that, every year, a technical correction will be required to remove this area and the associated emissions from both *Forest management* reporting and the FMRL.

Harvest data

Pre-1990 planted forest harvesting uses projections from 2009 to 2020 at an average age of (approximately) 28 years (see table A5.1.1). This is to address the issue raised by the ERT that harvest ages in the projection were older than those observed historically and there were no policies in place that would influence rotation length or change the average harvest ages of planted forests. While the average harvest ages used for the technical correction do not match, the harvest areas match the 2011 FMRL harvest areas.

Table A5.1.1   Pre-1990 planted forest data used to estimate emissions for the technically corrected FMRL

Year	Pre-1990 planted forest deforestation (kha)	Pre-1990 planted forest harvested (kha)	Pre-1990 planted forest harvest average age (years)
1990	–	19.369	28.0
1991	–	19.883	28.0
1992	–	22.639	28.0
1993	–	23.275	28.0
1994	–	25.000	28.0
1995	–	29.275	28.0
1996	–	31.250	28.0
1997	–	32.175	28.0
1998	–	31.575	28.0
1999	–	34.075	28.0
2000	2.305	35.551	28.0
2001	2.225	39.371	28.0
2002	1.616	46.149	28.0
2003	3.137	40.428	28.0
2004	6.777	33.867	28.0
2005	13.186	27.198	28.0
2006	16.596	27.036	28.0
2007	22.022	22.175	28.0
2008	4.103	37.243	28.0

Year	Pre-1990 planted forest deforestation (kha)	Pre-1990 planted forest harvested (kha)	Pre-1990 planted forest harvest average age (years)
2009	2.389	29.218	27.8
2010	2.383	33.086	28.4
2011	2.396	37.479	28.2
2012	2.378	41.354	27.8
2013	2.378	46.112	27.7
2014	2.247	50.021	27.8
2015	2.247	49.697	28.0
2016	2.247	49.724	28.1
2017	2.247	50.018	28.5
2018	2.247	49.967	28.9
2019	2.247	45.817	29.8
2020	2.247	43.817	28.9

Carbon equivalent forests

The method used to calculate the emissions from the application of CEF in the 2011 FMRL was inconsistent with the provisions of Decision 2/CMP.7 (UNFCCC, 2012) and the guidance for reporting (Kyoto Protocol Supplement, IPCC, 2014). The correct method for calculating emissions for CEF is to model the events by applying the same methods as would apply to deforestation and afforestation events but report all emissions (and removals) under *Forest management*.

Carbon equivalent forest harvested and converted

The estimate for carbon equivalent forests harvested and converted (CEF_{hc}) included in the technical correction uses projections of land-use change from 2009 to 2020 at an average age of (approximately) 28 years and at the rate of 2,247 hectares per annum (the net stocked area from the 2011 FMRL of 2,000 hectares, plus an unstocked proportion of 247 hectares, which contains a much lower carbon stock as explained above under 'Aligning forest area estimates').

Carbon equivalent forest newly established

Carbon equivalent forest newly established (CEF_{ne}) land is replanted at an equivalent annual area (2,000 hectares net stocked area plus 247 hectares that is unstocked), and the post-1989 planted forest yield table is applied to the net stocked area. The post-1989 planted forest yield table is deemed appropriate because the new forest is established on *Grassland* and the history of this newly planted land is most similar to post-1989 planted forest land.

In the technical correction to the FMRL, CEF land is modelled as going to and coming from the three *Grassland* types (low producing grassland, high producing grassland and with woody biomass) in equal amounts. Soil emissions resulting from conversion and establishment of CEF land are also now included in the FMRL.

Overplanting

The 2011 FMRL did not model emissions from overplanting that occurs on *Forest management* land. This activity occurs when pre-1990 natural forest is converted to planted forest. The system used for national greenhouse gas reporting for the sector reports the area and emissions associated with that practice within the *Forest management* category. To maintain consistency with *Forest management* reporting, a technical correction needed to be applied. This technical correction results in the addition of 0.039 kilotonnes carbon dioxide (kt CO_2) emissions to the annual estimate of emissions in the FMRL.

Non-carbon emissions

Non-carbon emissions were not included in the 2011 FMRL submission, therefore, a technical correction is required to include these emissions. Non-carbon emissions are estimated based on the average controlled burning from 1990 to 2009 and the minimum historic level for wildfire.

Controlled burning

Emissions from the burning of pre-1990 planted forest harvest residues are now included. The harvest rate is as per the FMRL, and the proportion burned is that applied to the LULUCF *Forest land remaining forest land* category during the first commitment period of the Kyoto Protocol.

Burning of residues associated with conversions of pre-1990 natural forest to pre-1990 planted forest are included, and are assumed to occur at same rate as reported during the first commitment period.

Wildfire emissions

Wildfires are hard to predict and are influenced by inter-annual climatic conditions and regional drought. To estimate emissions from wildfire, the minimum annual historic level that occurred between 1990 and 2009, the calibration period, is applied. This approach is taken to be consistent with New Zealand's background level of natural disturbance.

Nitrous oxide emissions

It is assumed that there are no nitrous oxide emissions from fertilisation of forests within the FMRL. These are minor and captured within the Agriculture sector.

Natural disturbance

Emissions from natural disturbance events were not originally considered in the calculation of the 2011 FMRL. New Zealand has reported its intention to apply the natural disturbance provision, and, for *Forest management*, the background level has been set at the minimum historic level. This is included in the estimate of the non-carbon emissions as described above.

However, emissions from, and associated with, salvage logging cannot be excluded from accounting during the second commitment period.[55] This means that when developing the natural disturbance background level, historical emissions from natural disturbances should exclude these emissions. New Zealand has not excluded these emissions from the historic data used to calculate its background level of natural disturbance emissions under its technically corrected FMRL. If New Zealand applies the provision to exclude emissions from natural disturbances from its accounting, the background level will then be adjusted to remove these salvage logging emissions.

Pre-1990 natural forest

Emissions and removals by pre-1990 natural forest were not included in the 2011 FMRL submission. As pre-1990 natural forest is now included in New Zealand's reporting of emissions for *Forest management* land, a technical correction is required. The rate of carbon change used for this technical correction is consistent with that reported from 1990 to 2013 in the 2015 inventory.

When projections of pre-1990 natural forest emissions are incorporated into the technically corrected FMRL, the area under *Forest management* is reduced to factor in the projected deforestation of these forests. This deforested land will be reported under Article 3.3 –

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[55] Paragraph 33(c) of annex to Decision 2/CMP.7 contained in document FCCC/KP/CMP/2011/10/Add.1, p. 18.

Deforestation. The business-as-usual projection of pre-1990 natural forest deforestation is based on the historical rate seen between 1990 and 2009.

Harvested wood products

Emissions and removals for the harvested wood product pool were not included in the 2011 FMRL submission. The technical correction for this uses the same spreadsheet model used for New Zealand's *Forest management* reporting with minor modifications in order to enable reporting to 2020. The technical correction made reflects that there were no government policies either in place, or being planned, that would increase wood use and/or domestic production between 2013 and 2020.

In order to estimate emissions from harvested wood products from 2013 to 2020, the activity data time series was investigated for trends from 1990 to 2009. Production of products with relatively flat trends through the time series (i.e., pulp and paper) was held at 2009 rates between 2009 and 2020, and products whose production had been increasing over the period (i.e., panels and sawn wood) were increased at the projected rate of population increase (1 per cent; sourced from Statistics New Zealand). Changes in the harvesting rate between 2013 and 2020 have no impact on the production of domestic harvested wood products because wood that is not processed in New Zealand is assumed to be exported.

Exported raw materials are now included in the accounting as a result of research on the use and discard rate of harvested wood products produced from raw materials of New Zealand origin. As harvested wood products produced from exported raw materials are now accounted for, a technical correction will be required. This is planned for the next submission.

Harvested wood products from pre-1990 natural forest are excluded. The volume produced from the harvesting of pre-1990 natural forests is less than 0.1 per cent of New Zealand's total harvest volume (Ministry for Primary Industries, 2015).

A5.1.3 Technical corrections and their impact

The impacts of the technical corrections made in 2014 on the FMRL are summarised in table A5.1.3. No additional technical corrections were made for the 2016 reporting year, as described in chapter 11, section 11.3.4.

Table A5.1.2   Summary of the technical corrections to the FMRL

	Emissions (Mt CO$_2$-e yr^{-1})
FMRL	**11.15**
Technical corrections	
Addressing methodological inconsistencies	−6.82
Additional elements:	
Non-carbon (including natural disturbance)	0.01
Pre-1990 natural forest	−6.08
Harvested wood products	−4.36
Sum of technical corrections	**−17.25**
FMRL$_{corr}$	**−6.10**

Note: FMRL = forest management reference level; FMRL$_{corr}$ = technically corrected forest management reference level. Annual changes are presented in table A5.1.3.

Figure A5.1.1 and table A5.1.3 provide a breakdown of the various components of the technical corrections over the time series.

Figure A5.1.1   Technical corrections to the FMRL by category
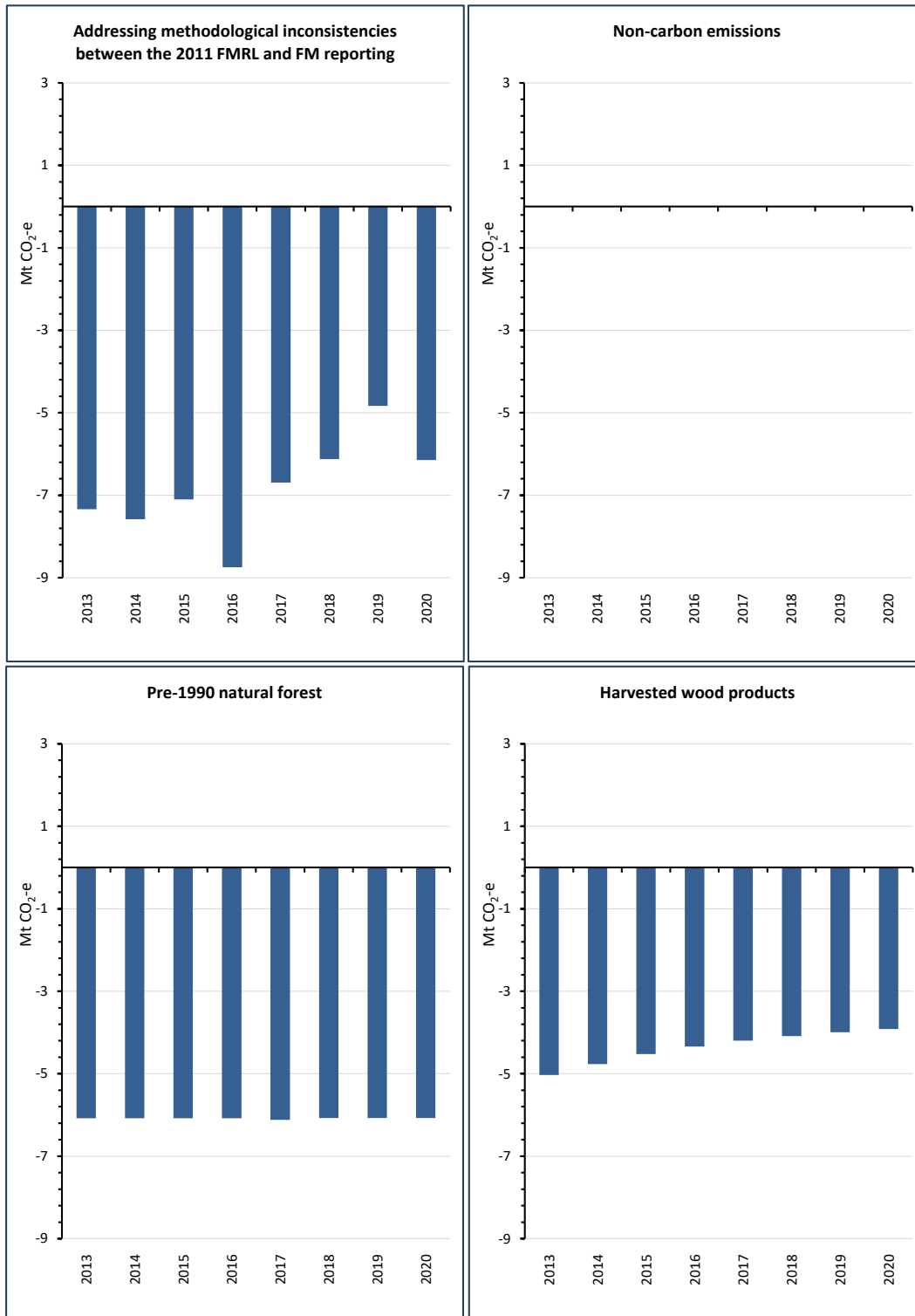
Note: Non-carbon emissions are 0.013 Mt CO₂-e per year, which is too small to display at this scale. FM = forest management; FMRL = forest management reference level.

Figure A5.1.2 provides a comparison of recalculated estimates with previous estimates. This illustrates the time-series consistency of the estimates.

Figure A5.1.2   Comparison of the 2011 FMRL, technical corrections to ensure consistency with Forest management reporting, and total of technical corrections over the period to 2020
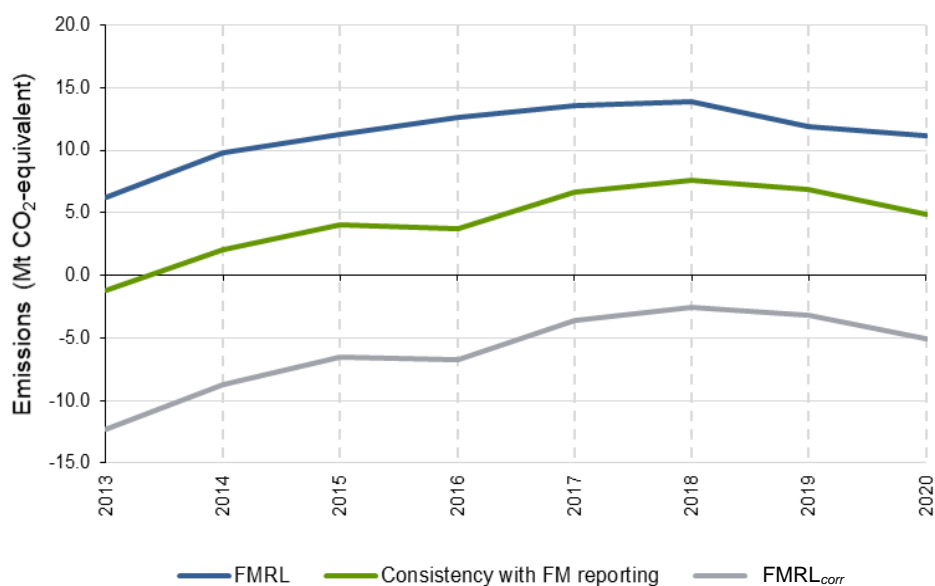
Note: FM = forest management; FMRL = forest management reference level; FMRL$_{corr}$ = technically corrected forest management reference level.

Table A5.1.3   Contribution of each source to the FMRL$_{corr}$

Addressing methodological inconsistencies between the 2011 FMRL and Forest management reporting	2013	2014	2015	2016	2017	2018	2019	2020	Annual average
				(Mt CO$_2$-e)					
Pre-1990 planted forest growth and harvesting – biomass	–2.96	0.30	2.29	1.96	5.01	6.00	5.38	3.54	**2.69**
Pre-1990 planted forest – soil	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	**0.01**
Carbon equivalent forests – biomass	1.75	1.73	1.72	1.69	1.64	1.54	1.49	1.35	**1.61**
Carbon equivalent forests – soil	–0.00	–0.00	–0.00	–0.01	–0.01	–0.01	–0.01	–0.01	**–0.01**
Overplanting (conversion of pre-1990 natural forest to pre-1990 planted forest) – biomass	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	**0.03**
Overplanting – soils	–0.00	–0.00	–0.00	–0.00	–0.00	–0.00	–0.00	–0.00	**0.00001**
Recalculated FMRL									**4.33**
Additional elements									
Non-carbon emissions (including natural disturbance)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	**0.01**
Pre-1990 natural forest – biomass	–6.08	–6.08	–6.08	–6.08	–6.12	–6.08	–6.08	–6.08	**–6.08**
Harvested wood products pool	–5.03	–4.76	–4.52	–4.34	–4.20	–4.09	–3.99	–3.92	**–4.36**
FMRL$_{corr}$	**–12.27**	**–8.76**	**–6.55**	**–6.72**	**–3.63**	**–2.58**	**–3.17**	**–5.08**	**–6.10**

Note: FMRL = forest management reference level; FMRL$_{corr}$ = technically corrected forest management reference level.

Annex 5.2: Natural disturbance

New Zealand has chosen the minimum historical level approach for calculating its background level for natural disturbances for both *Afforestation and reforestation* and *Forest management*.

Types of natural disturbances New Zealand intends to exclude from the accounting are:

- wildfires
- invertebrate and vertebrate pests and diseases
- extreme weather events
- geological disturbances.

In all cases except fire, New Zealand assumes a zero baseline between 1990 and 2009. While other natural disturbance events occurred throughout the calibration period, assumptions were made for the purposes of calculating the background level.

For planted forests reported under *Afforestation and reforestation* and *Forest management*, salvage logging is considered to take place in all disturbed forests.

In the case of pre-1990 natural forests, the ground plot measurement programme captures emissions from natural disturbances implicitly, and the emissions from natural disturbance events, apart from wildfires, cannot be separated from other disturbance events. The stock change estimates reported for natural forests include background levels of small scale natural disturbance events.
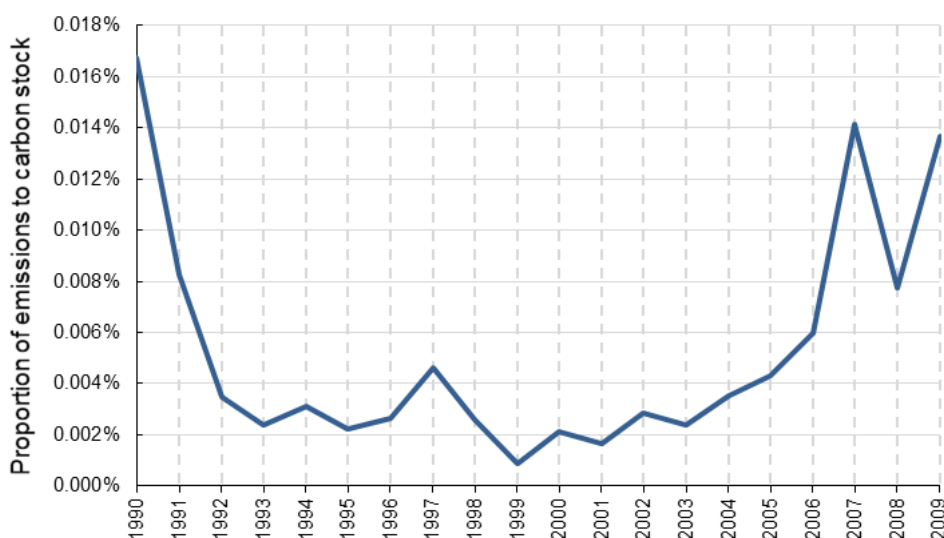
Only direct oxidation of biomass in wildfires is considered for the purposes of calculating a background level of natural disturbance for both *Afforestation and reforestation* and *Forest management* lands, regardless of forest type. The data used are as reported under the United Nations Framework Convention on Climate Change for the period 1990–2009 (see chapter 6, section 6.11.5).

A5.2.1   Afforestation and reforestation

New Zealand may choose to apply the provision for the treatment of natural disturbance emissions to its *Afforestation and reforestation* accounting (Ministry for the Environment, 2015). Due to the nature of *Afforestation and reforestation* accounting and reporting methods, the background level of carbon dioxide emissions from natural disturbance is already captured implicitly within the reported estimates. New Zealand separately estimates and reports the non-carbon emissions from natural disturbances. The background level is set by calculating the minimum non-carbon emissions that occurred from natural disturbances during the calibration period (1990–2009) (figure A5.2.1). However, the post-1989 forest area and carbon stock increase through the calibration period. Therefore, the background level is selected as the year in the calibration period with the minimum emissions from natural disturbance in proportion to total carbon stock. The minimum proportion from the calibration period is then multiplied by the carbon stock in post-1989 forest for each year in the reporting period (2013–20). This approach provides the background level and corrects for the increasing area and age (and therefore carbon stock exposed to natural disturbance) in post-1989 forests.

The *Afforestation and reforestation* background level for 2016 was 0.408 kilotonnes carbon dioxide equivalent (kt CO_2-e).

Avoiding the expectation of net credits or net debits for the application of the natural disturbance provision: Afforestation and reforestation

The background level is selected as the year in the calibration period with the minimum emissions from natural disturbance in proportion to total carbon stock. The minimum proportion from the calibration period is then multiplied by the carbon stock in post-1989 forest for each year in the reporting period (2013 to 2020). This approach is taken because:

- a trend is observed in natural disturbance emissions during the calibration period for *Afforestation and reforestation*. Emissions from natural disturbances have been increasing throughout the calibration period as the age of these forests and, therefore, biomass increase through time. It is expected that this trend will continue during the second commitment period. The calibration period was used to obtain an annual emissions value by proportion of carbon stocks and the minimum then used to calculate the background level for the 2013 year onwards, based on the carbon stocks of *Afforestation and reforestation* lands in each year

- gross:net accounting applies to *Afforestation and reforestation* activities. Emissions from natural disturbances occurring during any year of the commitment period, which fall below the background level, are not excluded from the accounting. Emissions from natural disturbances that are greater than the background level in any year of the commitment period are able to be excluded from the accounting if a Party chooses

- the background level has been set at the minimum historical level so there is an expectation that emissions will exceed the background level every year during the commitment period. If emissions from natural disturbances are greater than the background level, they can be excluded from the accounting and there is no expectation of net debits arising. If emissions are less than the background level in any year of the commitment period, all emissions from natural disturbance will still be accounted for. There is no expectation of net debits in this scenario. Under gross:net accounting for *Afforestation and reforestation* activities, it would not be possible to expect net credits when applying this approach to the exclusion of emissions from natural disturbances from accounting.

A5.2.2 Forest management

The background level of natural disturbance for *Forest management* was calculated as 2.27 kt CO_2-e (figure A5.2.2).

Figure A5.2.2   **Emissions from natural disturbance during the calibration period on Forest management land**
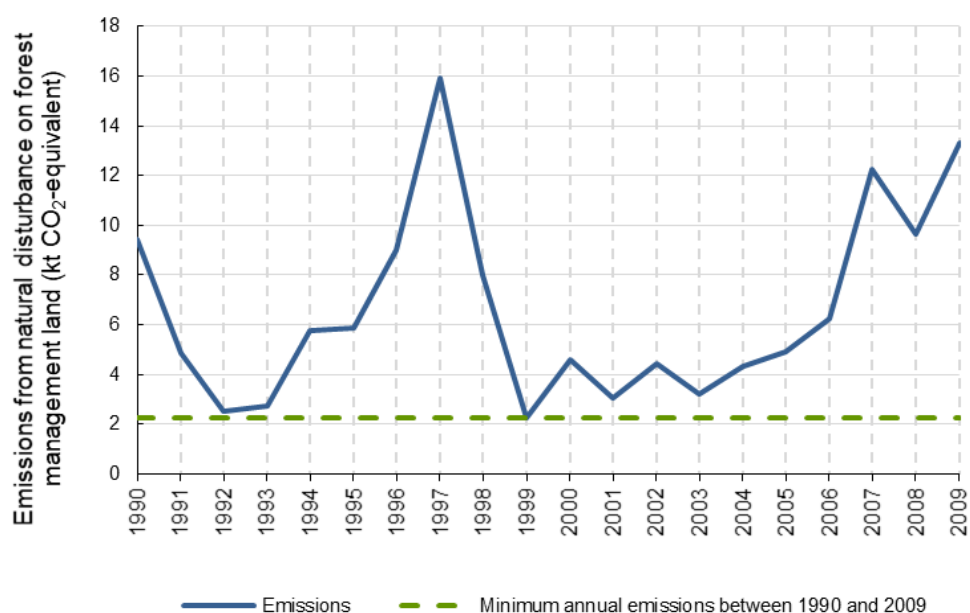
Avoiding the expectation of net credits or net debits for the application of the natural disturbance provision: Forest management

The background level has been set at the minimum annual emissions value of the historical time series because:

- there is no observed trend in natural disturbance emissions during the calibration period for *Forest management* and none can be expected during the second commitment period

- the background level of emissions for *Forest management*, to be included in the FMRL via a technical correction, is equal to the minimum annual emissions value estimated during the calibration period

- any emissions from natural disturbances during the commitment period that fall below the background level are not excluded from the accounting. During the commitment period, emissions from natural disturbances that are above the background level are, subject to New Zealand's discretion, able to be excluded from the accounting

- the accounting for *Forest management* is against a projected business-as-usual FMRL. The background level is included implicitly within the FMRL, and any emissions greater than the background level can be excluded from the accounting. When applying this approach, therefore, there is no expectation of net debits. In setting the background level to the minimum across the calibration period, emissions are expected to exceed this level every year. Therefore, there is no expectation that emissions will be less than the background level and, therefore, there is no expectation of net credits.

Annex 5.3: Carbon equivalent forests

Information on carbon equivalent forests is provided in aggregated form in CRF table 4(KP-I)B.1.2. Details of each application that make up the reported estimates are provided in table A5.3.1.

Table A5.3.1   Breakdown of carbon equivalent forests by domestic scheme application

Scheme ID	Management type	2014	2015	2016
CEF – 2	Newly Established (Ha)	–	–	–
	Harvested and Converted (Ha)	–	37.62	106.29
	Net change (tC)	–	−7.97	−22.49
CEF – 3	Newly Established (Ha)	–	–	407.49
	Harvested and Converted (Ha)	38.81	367.32	0.98
	Net change (tC)	−9.08	−85.86	0.55
CEF – 4	Newly Established (Ha)	–	–	53.79
	Harvested and Converted (Ha)	–	–	24.06
	Net change (tC)	–	–	−4.75
CEF – 8	Newly Established (Ha)	–	–	52.57
	Harvested and Converted (Ha)	–	–	52.19
	Net change (tC)	–	–	−11.54
CEF – 9	Newly Established (Ha)	–	–	24.47
	Harvested and Converted (Ha)	–	2.63	21.83
	Net change (tC)	–	−0.62	−5.07
CEF – 11	Newly Established (Ha)	–	–	–
	Harvested and Converted (Ha)	–	20.60	384.15
	Net change (tC)	–	−5.15	−67.27
CEF – 12	Newly Established (Ha)	–	–	152.35
	Harvested and Converted (Ha)	–	–	151.95
	Net change (tC)	–	–	−35.33
CEF – 13	Newly Established (Ha)	–	–	106.04
	Harvested and Converted (Ha)	–	1.71	103.67
	Net change (tC)	–	−0.40	−24.10
CEF – 14	Newly Established (Ha)	–	–	–
	Harvested and Converted (Ha)	–	4.23	138.57
	Net change (tC)	–	−0.87	−26.13
CEF – 15	Newly Established (Ha)	–	–	–
	Harvested and Converted (Ha)	–	–	37.68
	Net change (tC)	–	–	−7.97
CEF – 17	Newly Established (Ha)	–	–	–
	Harvested and Converted (Ha)	–	–	6.83
	Net change (tC)	–	–	−1.82
CEF – 18	Newly Established (Ha)	–	–	–
	Harvested and Converted (Ha)	–	10.01	112.30
	Net change (tC)	–	−2.00	−23.78
CEF – 19	Newly Established (Ha)	–	–	–
	Harvested and Converted (Ha)	–	2.83	10.45
	Net change (tC)	–	−0.59	−2.23
CEF – 20	Newly Established (Ha)	–	–	–
	Harvested and Converted (Ha)	–	7.40	–
	Net change (tC)	–	−1.90	0.00
CEF – 21	Newly Established (Ha)	–	–	–
	Harvested and Converted (Ha)	–	7.80	80.44
	Net change (tC)	–	−1.52	−17.90
TOTAL	**Newly Established (Ha)**	**–**	**–**	**796.72**
	Harvested and Converted (Ha)	**38.81**	**462.15**	**1,231.40**
	Net change (tC)	**−9.08**	**−106.88**	**−249.83**

Note: CEF = carbon equivalent forest; Ha = hectares; tC = tonnes carbon.

Annex 5: References

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Annex 6: Additional information on the inventory system and completeness

A6.1 Quality assurance and quality control processes

The quality assurance and quality control (QA/QC) processes have a significant role in the preparation of the inventory, to ensure the core principles of transparency, accuracy, completeness, comparability and consistency are achieved. Table A6.1.1 describes the key QA/QC processes used in the preparation of the inventory. These processes are under continual review and improvement to ensure they are fit for purpose.
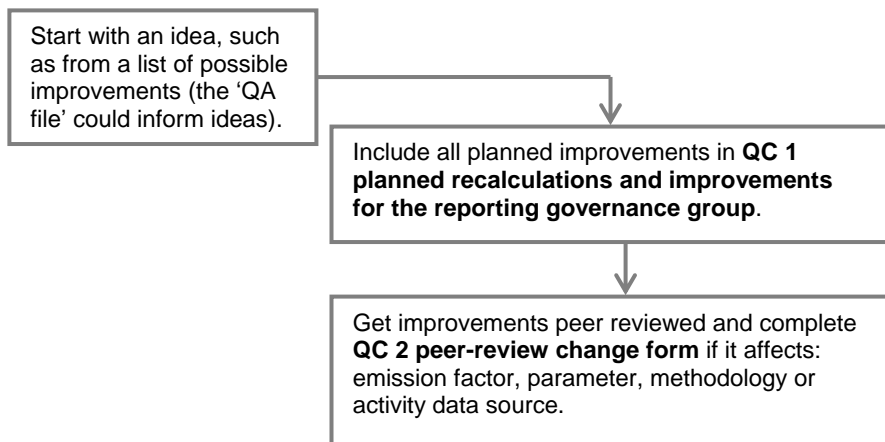
Table A6.1.1   Quality assurance and quality control processes used in preparation of the inventory

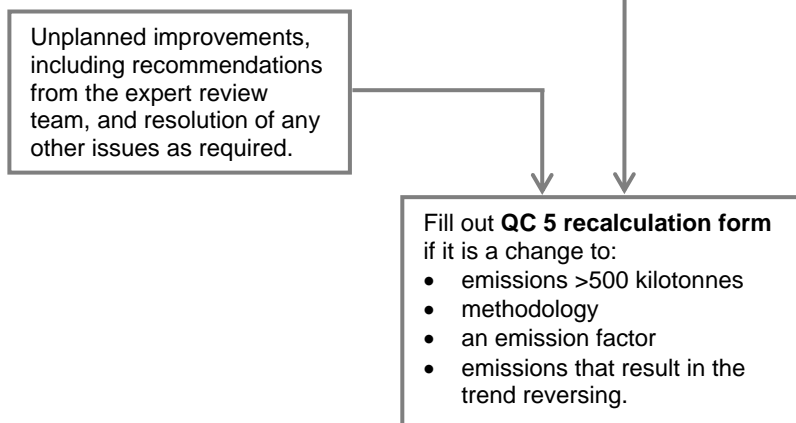| ID	QA/QC process or activity description
QA file	All external reviews of the whole or part of the inventory are documented in the QA file. Reviews are performed by qualified personnel, and the review records are included in the submission of the inventory to the United Nations Framework Convention on Climate Change. These reviews act as a source of ideas for inventory improvements.
QC 1	Planned recalculations and improvements are approved by the reporting governance group that oversees all climate change reporting by the New Zealand Government. The role of this group is further described in chapter 1.
QC 2	Planned improvements are peer reviewed prior to being implemented, when they affect the emission factor, parameter, methodology or activity data source. This is superseded in sectors that have a dedicated panel.
QC 3	Tier 1 checklist QC sheets are completed to ensure transparency, accuracy, completeness, comparability and consistency principles are met. Examples are included in the submission of the inventory.
QC 4	The chapter text for each sector is peer reviewed and follows the checklist provided to ensure that the peer review is comprehensive and consistent.
QC 5	Recalculations that exceed a certain threshold (see figure A6.1.1) are analysed and clearly documented. This includes changes resulting from planned improvements, errors, recommendations from the expert review team, and changes to guidelines.
QC 6	Automated checks are performed in the common reporting format web tool to ensure completeness of the entire time series.
QC 7	All chapters in the inventory are approved by members of the reporting governance group that oversees all climate change reporting by the New Zealand Government.
QC 8	Data flow and QC processes are documented and mapped for each sector and the maps are updated as required. These maps identify when QC is happening in the process, to what data, the type of check and who is responsible.
QC 9	The diagram of the data improvement process depicts the process to approve data improvements via a panel. This also applies to the Agriculture sector and the Land Use, Land-Use Change and Forestry sector.
QC 10	New for the 2018 submission, the reporting governance group manager signs off that each data-quality standard has been met. The updated common reporting format QC tools provide evidence that the data standards are met.
Sector submission checks	New for the 2018 submission, sector submissions are subject to thorough review against data and chapter standards and are required to resolve any issues promptly. This enables the remainder of the inventory compilation to proceed smoothly because quality is assured.

Figure A6.1.1 shows how these QA/QC processes align with the overall preparation of the inventory.

Figure A6.1.1   How the quality assurance and quality control processes and products align with the preparation of the inventory

Planned improvements

Start with an idea, such as from a list of possible improvements (the 'QA file' could inform ideas).

Include all planned improvements in **QC 1 planned recalculations and improvements for the reporting governance group**.

Get improvements peer reviewed and complete **QC 2 peer-review change form** if it affects: emission factor, parameter, methodology or activity data source.

Plus unplanned improvements

Unplanned improvements, including recommendations from the expert review team, and resolution of any other issues as required.

Fill out **QC 5 recalculation form** if it is a change to:
- emissions >500 kilotonnes
- methodology
- an emission factor
- emissions that result in the trend reversing.

Sectoral compilation

Prepare common reporting format data and report sections, and improvements if applicable.

Quality control checks
- **QC 3 Tier 1 checklist** for common reporting format data.
- **QC 4 chapter checklist** for peer review of chapter.
- **QC 6 common reporting format automated checks** using web reporter.
- **QC 10 data quality.**

Deliver to the National Inventory Compiler:
- **QC 7 approval of chapter from reporting governance group manager.**
- **QC 10 approval of data quality.**
- The latest flow diagrams for report:
  - **QC 8 data flow diagram**
  - **QC 9 data improvement process diagram** for Land Use, Land-Use Change and Forestry and Agriculture sectors.
- Include **QC 2** and **QC 5** forms as applicable.

A6.2 General assessment of completeness

A6.2.1 Emissions reported as 'NE' (not estimated)

According to the United Nations Framework Convention on Climate Change (UNFCCC) reporting guidelines (UNFCCC, 2013), the notation key 'NE' signifies that emissions and/or removals occur but have not been estimated or reported. It can be applied for the following reasons:

- if emissions are insignificant, that is, they should not exceed 0.05 per cent of the national total greenhouse gas (GHG) emissions, and do not exceed 500 kilotonnes carbon dioxide equivalent (kt CO_2-e) (paragraph 37(b) of the UNFCCC reporting guidelines)

- the total national aggregate of estimated emissions for all gases and categories considered insignificant shall remain below 0.1 per cent of the national total GHG emissions (paragraph 37(b) of the UNFCCC reporting guidelines)

- when an activity occurs in the Party but the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006) do not provide methodologies to estimate emissions and removals (footnote 6 of the UNFCCC reporting guidelines (UNFCCC, 2013)). If this is the case, the category is considered to be non-mandatory, providing the emissions from the category have not been previously reported.

The UNFCCC reporting guidelines also state that, once emissions from a specific category have been reported in a previous submission, emissions from this specific category shall be reported in subsequent GHG inventory submissions (UNFCCC, 2013).

New Zealand's gross emissions are 78,726.9 kt CO_2-e in 2016. The threshold of 0.1 per cent for New Zealand's 2018 submission is 78.7 kt CO_2-e and the threshold of 0.05 per cent is 39.4 kt CO_2-e. Both values are below 500 kt CO_2-e.

Table A6.2.1 summarises New Zealand's direct greenhouse gas emissions reported as 'NE' (not estimated) in the 2018 submission.

Table A6.2.1   Summary of NE (not estimated) entries in 2018 submission

CRF category code	Category	Gas	Explanation
Energy			
1.B.1.a.1.iii	Abandoned underground mines	CH_4	Methane (CH_4) emissions from this category do not occur in the North Island of New Zealand and are not estimated for the South Island. New Zealand does not have any reliable information on activities related to CH_4 emissions from abandoned mines to reliably report on it. There is a project under way that evaluates abundant mines, which has been completed for the North Island but not for the South Island. Judging from the results for the North Island, emissions from the South Island can be also 'NO' (not occurring), so it is the only information we can use here.
1.B.2.a.5	Distribution of oil products	CO_2, CH_4	This category is not mandatory: the 2006 IPCC Guidelines do not provide the default Intergovernmental Panel on Climate Change (IPCC) emission factor for calculating Tier 1 estimates of CH_4 emissions from the distribution of refined oil products. New Zealand did not report an emissions estimate from this category prior to the 2018 submission.

CRF category code	Category	Gas	Explanation
Agriculture			
3.A.4	Poultry	CH_4	This category is not mandatory: the 2006 IPCC Guidelines state (page 10.27, vol 4-2) that the Tier 1 method for estimating CH_4 emissions from Enteric fermentation for poultry is not developed. Also, table 10-10 (page 10.28, vol 4-2) indicates that there is insufficient data to establish a CH_4 emission factor for poultry for either developed or developing countries.
3.B.2.5	Indirect N_2O emissions	N_2O	The 2006 IPCC Guidelines for determining indirect nitrous oxide (N_2O) emissions do not provide a methodology for estimating emissions from leaching and run-off. In addition, indirect N_2O emissions from leaching and run-off are insignificant in New Zealand, because almost all livestock are kept outdoors all year round on pasture. These emissions have not been reported prior to the 2017 submission.
3.B.2.5	N_2O emissions per MMS	N_2O	Direct N_2O emissions from anaerobic lagoons (dairy and swine) and daily spread (swine) are reported under Agricultural soils (see table 6.2.2). The 2006 IPCC Guidelines assume that negligible direct N_2O emissions occur in anaerobic lagoons and daily spread, and only occur once the stored effluent is spread onto agricultural soil. For more information, see chapter 5, section 5.3.2 (Direct nitrous oxide emissions from manure management) and section 5.5.2 (Urine and dung deposited by grazing animals) of this national inventory report.
3.D.1.2.c	Other organic fertilisers applied to soils	N_2O	Emissions from 'Other organic fertilisers applied to soils' are not estimated due to their insignificance. Emissions are roughly estimated to be 20 kt CO_2-e (van der Weerden et al., 2014). Emissions are below the threshold of 0.05 per cent of the national total greenhouse gas emissions and do not exceed 500 kt CO_2-e.
3.I	Other carbon-containing fertilisers	CO_2	The 2006 IPCC Guidelines do not provide guidance for reporting on other carbon-containing fertilisers. Other carbon-containing synthetic fertilisers besides limestone, dolomite and urea are not applied to agricultural land in New Zealand.
Land Use, Land-Use Change and Forestry			
4.A – D	Forest land and wetlands: Drainage and rewetting and other management of organic and mineral soils	CO_2	New Zealand has no activity data on rewetting of organic soils. Organic soils make up less than 1 per cent of New Zealand's land use area.
4.A – D	Forest land, cropland, grassland and wetlands: Drainage and rewetting and other management of organic and mineral soils	CH_4, N_2O	No methodology is provided in the 2006 IPCC Guidelines for estimating emissions from this source category.
4.B.1	Cropland remaining cropland/4(V) Biomass burning/ Wildfires/Cropland remaining cropland	N_2O	New Zealand does not have sufficient information on biomass burning activities to reliably report on it.
4.B.2	Land converted to cropland/4(V) Biomass burning/ Wildfires/Land converted to cropland	CH_4, N_2O	New Zealand does not have sufficient information on biomass burning activities to reliably report on it.

CRF category code	Category	Gas	Explanation
4.D	Wetlands	CH$_4$	No IPCC guidance is provided for calculating Tier 1 estimates of carbon stock changes in organic soils for this land use category. New Zealand does not have sufficient information on biomass burning activities to reliably report on it.
4.E	Settlements	CH$_4$	No IPCC guidance is provided for calculating Tier 1 estimates of carbon stock changes in organic soils for this land use category. New Zealand does not have sufficient information on biomass burning activities to reliably report on it.
4.F	Other land	CH$_4$	No IPCC guidance is provided for calculating Tier 1 estimates of carbon stock changes in organic soils for this land use category. New Zealand does not have sufficient information on biomass burning activities to reliably report on it.
Waste			
5.B.1	Composting/Municipal solid waste	CH$_4$, N$_2$O	New Zealand does not have any reliable activity data to provide an accurate emission estimate from this category. Assuming that if 1 per cent of all New Zealand household waste is composted (most conservative estimate), these emissions would be CH$_4$ 3.4 + N$_2$O 2.4 = 5.8 kt CO$_2$-e, which is less than 0.05 per cent of the national gross emissions and less than 500 kt CO$_2$-e..
5.D.1 and 5.D.2	Domestic wastewater and Industrial wastewater	Amount of CH$_4$ flared	NE (not estimated) is used for activity data, because New Zealand does not have any information regarding the CH$_4$ flaring in this source category. The amount of CH$_4$ flared does not contribute to New Zealand's total emissions, but the implied emission factor only (as per the 2006 IPCC Tier 1 methodology provided in table 5D of the common reporting format tables).

The estimate of emissions for all of New Zealand's source categories marked as 'NE' (not estimated) results in 25.8 kt CO$_2$-e, which is below the 0.1 per cent of the total emissions threshold (78.7 kt CO$_2$-e).

A6.2.2   Emissions reported as 'IE' (included elsewhere)

According to the UNFCCC reporting guidelines (UNFCCC, 2013), the notation key 'IE' signifies that emissions and/or removals for this activity or category are estimated and included in the inventory but not presented separately for this category.

Table A6.2.2 details where the notation key 'IE' (included elsewhere) has been used in this submission of the inventory.

Table A6.2.2   Emissions reported using the 'IE' (included elsewhere) notation key

CRF category code	Category	Reported under the following source category:	Notation key explanation
1.A.2.a	Iron and steel – liquid fuels	1.A.2.g.viii – Other – Liquid fuels	Disaggregated data do not exist.
1.A.2.a	Iron and steel – solid fuels	2.C.1 – Iron and steel production	All emissions from the use of coal in this category are included in the Industrial Processes and Product Use sector because the primary purpose of the coal is to produce iron.
1.A.2.f	Non-metallic minerals – biomass	1.A.2.g.viii – Other – Biomass	Disaggregated data do not exist.
1.A.2.g.v	Construction – all fuels	1.A.2.g.iii – Mining	Disaggregated data do not exist.

CRF category code	Category	Reported under the following source category:	Notation key explanation
1.A.3.b.ii–iv	Road transportation (other than 'Cars') – all fuels	1.A.3.b.i – Cars	Disaggregated data do not exist. Disaggregation of carbon dioxide (CO_2) emissions is included in the plan, but the implementation has not yet been completed.
1.A.4.c.ii–iii	Agriculture/forestry/fishing – Off-road vehicles and other machinery	1.A.4.c.i – Agriculture/ forestry/fishing – Stationary	Agriculture/forestry/fishing has not been disaggregated into stationary, mobile and fishing: data are not available.
1.B.2.b.1	Natural gas/exploration	1.B.2.a.1 – Oil exploration	In New Zealand, exploration is not specifically aimed at obtaining oil or gas, that is, oil exploration is not separated from gas exploration by planning, processes, equipment or resources. Thus the exploratory wells are drilled without distinction of their purpose, that is, whether the expected outcome is oil, gas, both or none and there is no reliable way to predict which it would be to estimate proportions of mostly oil and mostly gas wells. In that sense, disaggregated data for oil and gas exploration do not exist. Considering that available emission factors for well drilling and testing also do not distinguish between oil and gas, all emissions from oil and gas exploration are placed in the same category.
1.B.2.b.3	Natural gas/processing	CO_2, CH_4	Fugitive emissions of CO_2 and methane (CH_4) have not been formally estimated, though a rough estimate of the likely level of emissions indicates that they are not significant: CO_2: 625 Mm^3 (Kapuni field production) * 7.9e-6 = 0.005 kt CH_4: 625 Mm^3 (Kapuni field production) * 9.7e-5 * 25 = 1.5 kt CO_2-e. These would still keep the national total aggregate of estimated emissions for all gases and categories considered insignificant below 0.1 per cent of the national total greenhouse gas emissions.
1.B.2.c.1.i–ii	Venting/oil and Venting/gas	1.B.2.c.1.iii – Venting/combined	The fields produce both oil and gas and, therefore, are reported as combined. Disaggregated data do not exist.
1.B.2.c.1.i–ii	Flaring/oil and Flaring/gas	1.B.2.c.1.iii – Flaring/ combined	The fields produce both oil and gas and, therefore, are reported as combined. Disaggregated data do not exist.
2.A.3	Glass production	2.A.4.b – Other process uses of carbonates/Other uses of soda ash	Carbon dioxide emissions are reported in 2.A.4.b because this aggregates emissions from glass production with other uses of carbonates, due to confidentiality concerns for both glass and aluminium production. A very small number of firms in New Zealand are involved in either of these activities and use carbonates.

CRF category code	Category	Reported under the following source category:	Notation key explanation
3.A.4	Enteric fermentation/other/ buffalo	3.A.1.A – Dairy cattle	A small herd of around 200 buffalo was brought into New Zealand around 2007 for specialised cheese and dairy production. These buffalo are reported within the dairy herd so the notation key 'IE' is used from 2007 onwards.
3.B.1.4 & 3.B.2.4	Manure management/other/ buffalo	3.B.1.A – Dairy cattle 3.B.2.A – Dairy cattle	For both nitrous oxide (N_2O) and CH_4 emissions, the notation key 'NO' (not occurring) is used up to 2006 because there were no buffalo recorded in New Zealand before 2007. A small herd of around 200 buffalo was brought into New Zealand around 2007 for specialised cheese and dairy production. These buffalo are reported within the dairy herd so the notation key 'IE' is used from 2007 onwards. For more information, see chapter 5, section 5.1.4 (Minor livestock categories) of this national inventory report (NIR).
3.B.2.5	N_2O Emissions per MMS[56]	3.D – Agricultural soils	Direct N_2O emissions from anaerobic lagoons (dairy and swine) and daily spread (swine), are reported under Agricultural soils.
3.D.1.2.b	Sewage sludge applied to soils	Included under the Waste sector 5.A.1.a	Direct N_2O emissions from sewage sludge are reported under 5.A.1.a in the Waste sector. Sewage sludge activity data are obtained from water treatment industry surveys and do not disaggregate the amount of sludge used for different purposes. Due to the small amount of emissions coming from sewage sludge, further disaggregation of the activity data is considered resource prohibitive. Sewage sludge is a very small source of nitrogen, contributing 84 tonnes of nitrogen annually (van der Weerden et al., 2014). Emissions of N_2O are less than 0.002 kilotonnes.
3.E	Prescribed burning of savannas	Biomass burning (table 4(V) of LULUCF), category C. Grassland	Prescribed burning of savanna is reported under the Land Use, Land-Use Change and Forestry (LULUCF) sector. See chapter 6, section 6.11.5 of this NIR (Biomass burning (table 4(V) of LULUCF), category C. Grassland).

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56   MMS stands for a manure management system (see chapter 5).

CRF category code	Category	Reported under the following source category:	Notation key explanation
4.A.1/4(V)	Controlled burning/Forest land remaining forest land	Carbon dioxide emissions are captured by the general carbon stock change calculation if the fire-damaged area is harvested and replanted. If the stand is allowed to grow on but with a reduced stocking, the CO_2 emissions are accounted for at the eventual time of harvest.	Carbon dioxide emissions are captured by the general carbon stock change calculation if the fire-damaged area is harvested and replanted. If the stand is allowed to grow on but with a reduced stocking, the CO_2 emissions are accounted for at the eventual time of harvest.
4.A.2/4(V)	Controlled burning/Land converted to forest land Wildfires/Land converted to forest land	Carbon dioxide emissions are captured by the general carbon stock change calculation if the fire-damaged area is harvested and replanted. If the stand is allowed to grow on but with a reduced stocking, the CO_2 emissions are accounted for at the eventual time of harvest.	Carbon dioxide emissions are captured by the general carbon stock change calculation if the fire-damaged area is harvested and replanted. If the stand is allowed to grow on but with a reduced stocking, the CO_2 emissions are accounted for at the eventual time of harvest.
4.B.1/4(V)	Controlled burning/Cropland remaining cropland	Included under the Agriculture sector	Carbon dioxide and CH_4 emissions from burning of crop stubble are reported in the Agriculture sector.
4.B.1/4(V)	Wildfires/Cropland remaining cropland	Any CO_2 emissions from wildfires on non-forest land are likely to be offset by the subsequent carbon gain from the regrowth of biomass, which is also not accounted for. Alternatively, if the wildfire resulted in land-use change, then any CO_2 emissions would be captured by the general carbon stock change calculation that is performed when land is converted to a new land use.	Any CO_2 emissions from wildfires on non-forest land are likely to be offset by the subsequent carbon gain from the regrowth of biomass, which is also not accounted for. Alternatively, if the wildfire resulted in land-use change, then any CO_2 emissions would be captured by the general carbon stock change calculation that is performed when land is converted to a new land use.
4.B.2/4(V); **4.C.1/4(V);** **4.C.2/4(V);** **4.D.2/4(V)**	Wildfires/Land converted to cropland; Wildfires/Grassland remaining grassland Wildfires/Land converted to grassland Wildfires/Land converted to wetlands	Any CO_2 emissions from wildfires on non-forest land are likely to be offset by the subsequent carbon gain from the regrowth of biomass, which is also not accounted for. Alternatively, if the wildfire resulted in land-use change, then any CO_2 emissions would be captured by the general carbon stock change calculation that is performed when land is converted to a new land use.	Any CO_2 emissions from wildfires on non-forest land are likely to be offset by the subsequent carbon gain from the regrowth of biomass, which is also not accounted for. Alternatively, if the wildfire resulted in land-use change, then any CO_2 emissions would be captured by the general carbon stock change calculation that is performed when land is converted to a new land use.
4.A.1/4(I); **4.D.1/4(I)** **4.D.2/4(I)**	Direct N_2O emissions from N inputs to managed soils/Inorganic N fertilisers and Direct N_2O emissions from N inputs to managed soils/Organic N fertilisers from the following categories: Forest Land Remaining Forest Land Wetlands Remaining Wetlands Land Converted to Wetlands Settlements Remaining Settlements Land Converted to Settlements	Included under the Agriculture sector	New Zealand does not disaggregate data on nitrogen fertiliser by land use, therefore, all N_2O emissions from organic and inorganic fertilisers are reported in the Agriculture sector.

CRF category code	Category	Reported under the following source category:	Notation key explanation
4.E.1/4(I)	Settlements Remaining Settlements		
4.E.2/4(I)	Land Converted to Settlements		
4.B.1/4(V)	Controlled burning/Cropland remaining cropland	Included under the Agriculture sector	All emissions from burning of crop stubble are reported in the Agriculture sector.
4.C.1/4(V); 4.D.1/4(V)	Controlled Burning/Grassland remaining grassland Controlled Burning/Wetland remaining wetland Wildfires/Wetland remaining wetland	If due to temperate climate and rainfall any CO_2 emissions from burning on non-forest land are likely to be off-set by the subsequent carbon gain from the re-growth of biomass, which is also not accounted for. Alternatively, if the fire resulted in land-use change, then any CO_2 emissions would be captured by the general carbon stock change calculation that is performed when land is converted to a new land use.	This is not a significant activity in New Zealand due to its temperate climate and rainfall distribution, and any CO_2 emissions from burning on non-forest land are likely to be off-set by the subsequent carbon gain from the re-growth of biomass, which is also not accounted for. Alternatively, if the fire resulted in land-use change, then any CO_2 emissions would be captured by the general carbon stock change calculation that is performed when land is converted to a new land use.
4.C.2/4(V); 4.D.2/4(V) 4.E/4(V)	Controlled Burning/Land converted to grassland Controlled Burning/Land converted to wetlands Biomass burning/Land converted to settlements	Carbon dioxide emissions from the controlled burning of land converted to this category are captured by the general carbon stock change calculation that is performed when land is converted to a new land use.	Carbon dioxide emissions from the controlled burning of land converted to this category are captured by the general carbon stock change calculation that is performed when land is converted to a new land use.
5.D.1	Domestic wastewater	5.A Solid waste	Activity data - sludge amounts are included in solid waste disposal
5.D.2	Industrial wastewater	5.A Solid waste	Activity data - sludge amounts are included in solid waste disposal

Note: Due to a bug in the CRF Reporter, it was impossible to open the IE and NE comment windows in the CRF Reporter for category 3.B.2.5. The relevant explanations have been entered into the general cell comments window, which was available at the time of inventory compilation. For this reason, category 3.B.2.5 does not appear in the CRF table 9. New Zealand sent the relevant bug report to the CRF developers. As this was not a problem for other categories, the explanations for IE and NE were entered in the appropriate windows and thus appeared in the CRF table 9.

Annex 6: References

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Van der Weerden A, de Klein C, Kelliher F, Rollo M. 2014. *Reporting to 2006 IPCC Guidelines for N$_2$O Emissions from Additional Sources of Organic N: Final Report*. MPI Technical Report. Wellington: Ministry for Primary Industries.

Annex 7: Overview of Tokelau

A7.1 Geography

Tokelau consists of three small coral atolls that lie between latitudes 8 and 10 degrees south and 171 and 173 degrees west. Atafu, the most northern atoll, has a surface area of 3.5 square kilometres; Nukunonu, the central atoll, is 4.7 square kilometres and Fakaofo, the southern atoll, is 4 square kilometres (figure 7.1.1).

Figure A7.1.1   Map of Tokelau
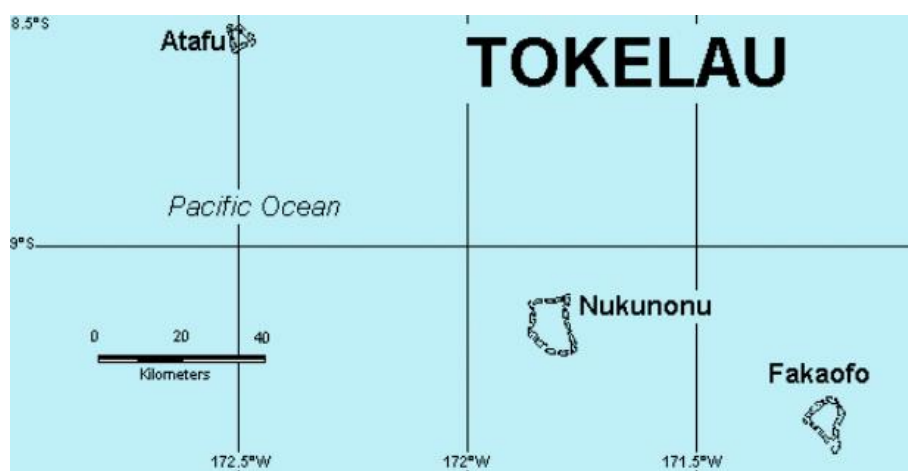
From Atafu in the north to Fakaofo in the south, Tokelau extends for less than 200 kilometres. The atolls are approximately 3–5 metres above sea level.

Tokelau's total Exclusive Economic Zone is about 300,000 square kilometres.

A7.2 Population

Tokelau's population is 1,499 (2016 Tokelau census).

All Tokelauans have New Zealand citizenship. According to the 2013 New Zealand census, 7,173 people indicating full or partial Tokelauan descent live in New Zealand.

A7.3 Economy and industry overview

Tokelau's economy is dominated by economic assistance from New Zealand and fisheries revenue (US$13.5 million in the 2016 fishing year). New Zealand provides general budget support to help the delivery of essential services, consistent with its constitutional and United Nations Charter obligations.

Energy and transport

Electricity and heat production

In 2012, Tokelau switched from diesel-generated electricity to nearly 100 per cent renewable energy generation (solar power). Solar energy generation was put in place in all three atolls with battery storage for 24 hour, seven days per week operations and distribution to all residences and facilities. However, since the installation of solar panels in 2012, the use of electricity has gone up. When a back-up is required, the balance comes from diesel generators.

Gas cooking using imported natural gas is the preferred method used by 72.0 per cent of households, replacing kerosene stoves. For the past decade, the use of kerosene stoves dropped from 56.6 per cent of households in 2006 to 23.6 per cent in 2016 (2016 Tokelau census).

Energy consumption

There is no significant industry in Tokelau. All energy is used by domestic and fishing activities and community–government activities (e.g., meeting halls and offices, village freezers, building projects, stevedoring).

According to the 2016 Tokelau census, every household has a fridge and a freezer, and some households now have air conditioning. The United Nations Development Programme has recently funded a programme of replacing old inefficient fridges and freezers with new ones, under the Tokelau Energy Sector Support Project.

Most households (over 60 per cent) also own a washing machine, a computer and a television. Over 50 per cent of households own aluminium boats and outboard motors. Some items, such as freezers, televisions and washing machines are owned at similar rates across the three atolls. Ownership rates of other items, such as sewing machines, stereos and computers, vary significantly across the three atolls.

Tokelau transport data

Tokelau currently has no air transportation, so the only means of transport to and from Tokelau is by sea. All travel and supplies originate and terminate in Samoa, Tokelau's closest neighbour. The trip from the nearest port, Apia, usually takes between 24 hours and 30 hours.

Until recently, the main forms of transport on the atolls were trucks, pick-ups, motorbikes and a range of golf carts. Currently, on-island transportation on Fakaofo atoll is primarily by electric car (including the local ambulance) fuelled by solar energy, with solar-powered streetlights ensuring safety on the roadways. The private importation of other vehicles has increased recently.

According to its 2016 census, Tokelau has 176 aluminium boats with 160 outboard motors, which use most of the imported petrol. Most of the diesel use is by the ferries travelling to and from Samoa. A new search and rescue vessel that will also provide general inter-atoll transport is to be delivered to Tokelau in late 2018, and this is expected to increase the use of diesel.

A7.4 Agriculture

Land-based and agricultural resources

Fish are an important food source in Tokelau, because low fertility of the coral soil means few crops are supported. Food needs not met by locally grown produce are supplemented by imports.

Cultivated food crops are generally limited to breadfruit (*Artocarpus altilis*), giant swamp taro 'pulaka' (*Cyrtosperma chamissonis*); taro palagi (*Xanthosoma sagittifolium*); giant taro (*Alocasia macrorrhizos*); banana (*Mus* sp. [2 varieties]); papaya (*Carica papaya*); pandanus 'fala' (*Pandanus odoratissimus*); pumpkin (*Cucurbita* sp.); and coconut (*Cocos nucifera*).

Little agriculture is taking place in Tokelau. Coconuts are used for human and livestock consumption. Fakaofo grows small amounts of swamp taro. The villages have breadfruit trees and some banana patches; the women's committees run community gardens and grow pandanus for traditional crafts (mats, hats, fans). A recent United Nations-sponsored project is the establishment of keyhole gardens by Tokelau youth.[57]

Farm animals

The only domestic farm animals kept are pigs (in community pens) and chickens (free-ranging) (table A7.4.1). There is the potential of generating energy from the piggery waste and reducing the effluent pollution of the lagoon.

Table A7.4.1   **Number of livestock in Tokelau (2016)**

Atoll	Residents	Households	Pigs	Chickens
Atafu	413	88	742	270
Fakaofo	399	85	419	50
Nukunonu	385	83	536	305
Tokelau	**1,197**	**256**	**1,697**	**625**

Source: 2016 Tokelau census

Note: For comparison, the number of residents and households in different atolls has been added to the table.

A7.5   Land use

Tokelau's total land area is 10–12 square kilometres. Most (75 per cent) of that is covered in coconut trees and other native vegetation. According to the 2012 conservation survey of Tokelau (Pierce et al., 2012), the vegetation of the three islands comprises varying areas of indigenous trees, including *Pisonia*, *Pandanus*, *Morinda* and *Tournefortia*, and coconut plantations.

The motu[58] are separated by channels with gaps of typically 30–100 metres at low tide, sometimes more. Roads and distinct trails occupy very little of the land area of Tokelau and exist almost entirely on the four inhabited motu.

Village lands under active management for trails, roads, village greens, gardens and plantations comprise ruderal vegetation.[59] Traditional Polynesian village green areas are not very evident in Tokelau because of the sandy soil and low rainfall.

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[57]   A keyhole garden is a small (approximately 2 metre wide) circular raised garden with a keyhole-shaped indentation on one side. A keyhole garden holds moisture and nutrients due to an active compost pile placed in the centre of a round bed.

[58]   Each atoll consists of a number of islets (motu).

[59]   Plant species that first colonise disturbed lands.

A7.6 Waste collection

According to the 2016 Tokelau census, most household rubbish is collected by village workers. Figure A7.6.1 shows Fakaofo had the highest proportion of households where all rubbish was collected (72.9 per cent). Of all private occupied dwellings, 98.8 per cent had at least some of their household rubbish collected. Collected rubbish is mostly either burned on the reef or buried in centralised areas of the islands. Exceptions are organic waste, which is fed daily to pigs, large beer bottles that are exported for recycling to Apia (Samoa) and metal waste that is collected and sold as scrap in Samoa under a memorandum of understanding with a Samoan company.[60]

Figure A7.6.1   Household rubbish collected by village workers, by atoll (2016)
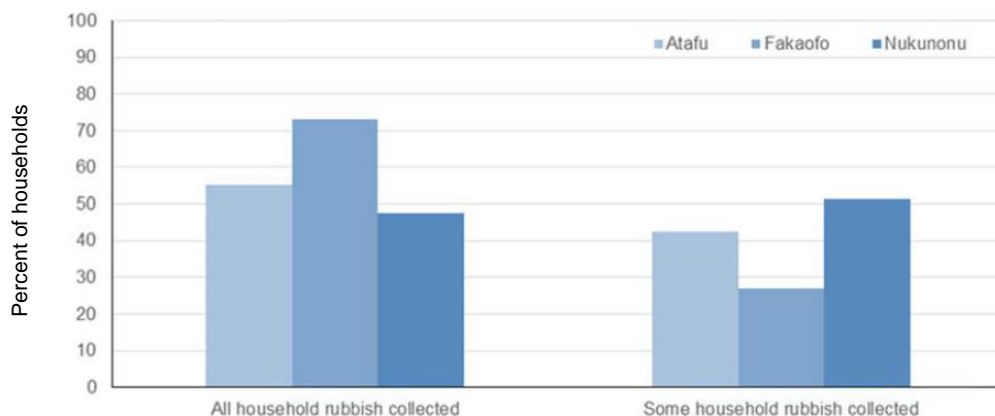
Source: 2016 Tokelau Census of Population and Dwellings

Where village workers do not collect household rubbish, households use alternative methods for disposal. The most common methods are burning, burial and disposing of in the garden.

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[60] See Government of Tokelau. 2017. *Solid Waste Management: MOU Signed between Tokelau EDNRE and Pacific Recycle Co. Ltd*. Retrieved from www.tokelau.org.nz/Bulletin/December+2017/Solid+Waste+Management+MOU+Signed+between+Tokelau+EDNRE+and+Pacific++Recycle+Co.+Ltd.html (9 March 2018).

Annex 7: References

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