New Zealand's Greenhouse Gas Inventory

1990–2018

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

Volume 1, Chapters 1–15

New Zealand Government

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Abbreviations

AAP	average animal population
AAU	assigned amount unit
AD	activity data
AIC	Akaike information criterion
ANZSIC	Australian and New Zealand Standard Industrial Classification
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
CF_4	perfluoromethane
C_2F_6	perfluoroethane
C_3F_8	perfluoropropane
CaO	calcium oxide
$Ca(OH)_2$	calcium hydroxide
CCF_i	carbon content factor
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 reductions
CFC	chlorofluorocarbon
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
COP	Conference of the Parties
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
CRA	Calculation and Reporting Application
CRF	common reporting format
DAP	diammonium phosphate
DCD	dicyandiamide

DEF	default emissions factor
DEF	diesel exhaust fluid
DM	dry matter
DMD	dry-matter digestibility
DMI	dry-matter intake
DOC	degradable organic carbon
DPFI	Delivery of Petroleum Fuels by Industry
EEZ	Exclusive Economic Zone
EF	emission factor
EF_3	emission factor for N_2O emissions from urine and dung nitrogen
$EF_{3,PRP}$	emission factor for N_2O emissions from urine and dung nitrogen deposited on pasture, range and paddock by grazing animals
EPA	Environmental Protection Authority
ERT	expert review team
ERU	emission reduction unit
ETS	Emissions Trading Scheme
FAME	fatty acid methyl ester
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
FENZ	Fire and Emergency New Zealand
FMRL	forest management reference level
$FMRL_{corr}$	Technically corrected 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
G20	Group of Twenty
ha	hectare(s)
HCFC	hydrochlorofluorocarbon
HFC	hydrofluorocarbon
IAE	International Energy Agency
IE	included elsewhere

IEF	implied emission factor
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Processes and Product Use
IRENA	International Renewable Energy Agency
k_m	energy efficiency for maintenance or the efficiency of utilisation of metabolisable energy for maintenance activities
KP	Kyoto Protocol
KP-LULUCF	Land Use, Land-use Change and Forestry activities under the Kyoto Protocol
kt	kilotonne(s)
LCDB	land cover database
lCER	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
LUM	land use map
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
MiCORE	Ministry for Climate, Oceans and Resilience (Tokelau)
MJ	megajoule
MOS	Monthly Oil Supply
MPI	Ministry for Primary Industries
Mt	megatonne(s)
MW	megawatt(s)
N	nitrogen
N_2O	nitrous oxide
NA	not applicable
NE	not estimated
NEFD	National Exotic Forest Description
N_{ex}	nitrogen excretion rates
NF_3	nitrogen trifluoride

NH_3	ammonia
NIR	national inventory report
NMVOC	non-methane volatile organic compound
NO	not occurring
NO_3	nitrate
NOx	nitrogen oxides (other than nitrous oxide)
NRFA	New Zealand Rural Fire Authority
NSD	National Soils Database
NZAGRC	New Zealand Agricultural Greenhouse Gas Research Centre
NZAS	New Zealand Aluminium Smelters Limited
NZ ETS	New Zealand Emissions Trading Scheme
NZLRI	New Zealand Land Resource Inventory
NZU	New Zealand Unit
ODS	ozone-depleting substances
OECD	Organisation for Economic Co-operation and Development
PFC	perfluorocarbon
PGGRC	Pastoral Greenhouse Gas Research Consortium
PJ	petajoule(s)
PSP	permanent sample plot
QA	quality assurance
QC	quality control
RGG	Reporting Governance Group
RMU	removal unit
SEforALL	Sustainable Energy for All
SEF	standard electronic format
SF_6	sulphur hexafluoride
SO_2	sulphur dioxide
SOC	soil organic carbon
Stats NZ	Statistics New Zealand
TACCC	transparency, accuracy, completeness, consistency and comparability
tCER	temporary certified emission reduction unit
TJ	terajoule
TOW	total organic product in wastewater
UEF	unique emissions factor
UNFCCC	United Nations Framework Convention on Climate Change
WTO	World Trade Organisation

Executive summary

Key points

In 2018

- New Zealand's gross greenhouse gas emissions were 78,862 kilotonnes carbon dioxide equivalent (kt CO_2-e), comprising 44 per cent carbon dioxide, 43 per cent methane, 10 per cent nitrous oxide and 2 per cent fluorinated gases.
- The Agriculture and Energy sectors were the two largest contributors to gross emissions, at 48 per cent and 41 per cent respectively.
- The Land Use, Land-Use Change and Forestry (LULUCF) sector offset 30 per cent of New Zealand's gross emissions.
- New Zealand's net emissions were 55,468 kt CO_2-e in 2018.

Since 1990

- New Zealand's gross emissions have increased by 24 per cent (15,271 kt CO_2-e). The five emission sources that contributed the most to this increase were:
  - enteric fermentation from dairy cattle (methane)
  - fuel use in road transport (carbon dioxide)
  - agricultural soils, from increased fertiliser use (nitrous oxide)
  - industrial and household refrigeration and air-conditioning systems from increased use of hydrofluorocarbon-based refrigerants that replaced ozone depleting substances (fluorinated gases)
  - fuel use in *Manufacturing industries and construction* from increased production due to economic growth (carbon dioxide).
- New Zealand's net emissions increased by 57 per cent (20,174 kt CO_2-e) due to the underlying increase in gross emissions and the increased volume of timber that was harvested from New Zealand's plantation forest estate in 2018 compared with 1990.

Between 2017 and 2018

- Gross emissions decreased by 1 per cent, which was largely attributed to a decrease in emissions from the Energy sector (by 3 per cent or 1,058 kt CO_2-e) driven mainly by:
  - a decrease in emissions from *Manufacturing industries and construction* largely due to outages at the Pohokura natural gas field
  - a decrease in emissions from the *Public electricity and heat production* category primarily due to a reduced need for natural gas-fired electricity generation in response to higher levels of hydro generation.
- Emissions from the Agriculture, Industrial processes and product use, and Waste sectors did not show significant changes overall beyond small annual variations below 1 per cent.
- Net emissions decreased by 3 per cent (1,463 kt CO2-e), due to the underlying decrease in gross emissions and increased removals from LULUCF.
- Between 2017 and 2018, net emissions from the LULUCF sector decreased by 3 per cent (684 kt CO_2-e), largely due to a reduced rate of deforestation and an increase in the production of harvested wood products.

Improvements

- Emissions estimates for the entire time series are recalculated due to improvements to the inventory. The largest changes to this inventory are:
  - new nitrous oxide emission factors in the Agriculture sector for livestock excreta, to more accurately reflect emissions resulting from different kinds of livestock grazed on flat land and sloped land
  - updated carbon stocks and stock change for pre-1990 natural forest following a re-analysis, with a number of method improvements to increase accuracy.

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 (GHGs) 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 basis for measuring New Zealand's progress towards its international emissions reduction targets.

The inventory submission consists of the common reporting format (CRF) database containing inventory data for 1990–2018 from all emissions and removals in New Zealand together with this publication, the national inventory report, which is a narrative that presents major emission trends and methodologies for estimating emissions and removals. It also includes sections on the inventory uncertainties, recalculations and improvements. In addition, the standard electronic format tables that contain data on emission units and emission reduction units in the emissions register and their transfers between the registers of different countries are included in this submission.

Inventory reporting under the Convention covers seven direct GHGs: 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] Indirect GHGs[2] are also included; however, only emissions and removals of the direct GHGs are included in estimates of total national emissions under the Convention and accounted for under the Kyoto Protocol.

The gases are reported under six sectors: Energy; Industrial Processes and Product Use (IPPU); Agriculture; Land Use, Land-Use Change and Forestry (LULUCF); Waste and New Zealand's 'Other' sector (Tokelau).

New Zealand ratified the Convention on 16 September 1993 and the Paris Agreement on 4 October 2016. The extension (as of 13 November 2017) of New Zealand's ratification of the Convention and the Paris Agreement to include Tokelau means, *inter alia*, that New Zealand's national inventory shall include GHG emissions and removals estimates from Tokelau. Starting from 2019, emissions from Tokelau are included in New Zealand's greenhouse inventory.

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).

1990–2018

In 1990, New Zealand's gross GHG emissions were 63,590.9 kilotonnes carbon dioxide equivalent (kt CO_2-e). Between 1990 and 2018, GHG emissions increased by 15,271.4 kt CO_2-e

[1] Nitrogen trifluoride emissions do not occur in New Zealand and, therefore, 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).

(24.0 per cent) to 78,862.3 kt CO_2-e in 2018 (figure ES 2.1). From 1990 to 2018, 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*, *Product uses as substitutes for ODS*[4] and *Manufacturing industries and construction* (especially the categories *Chemicals* and *Food processing, beverages and tobacco*).

2017–2018

Between 2017 and 2018, New Zealand's gross emissions decreased by 778.6 kt CO_2-e (1.0 per cent), which was mainly driven by a decrease of emissions from the Energy sector (1,058.4 kt CO_2-e or 3.2 per cent). This was mainly attributed to decreases in CO_2 emissions from the *Manufacturing industries and construction* category and the *Public electricity and heat production* category. The decrease in emissions from *Manufacturing industries and construction* was largely due to outages at the Pohokura natural gas field, which saw a 34 per cent production drop between 2017 and 2018 levels.[5] The decrease in emissions from the *Public electricity and heat production* category was primarily due to a decrease in natural gas-fired generation in response to higher levels of hydro generation.

Emissions from the Agriculture, IPPU and Waste sectors did not show significant changes beyond small annual variations below 1 per cent.

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 35,293.9 kt CO_2-e. Between 1990 and 2018, net GHG emissions increased by 20,174.3 kt CO_2-e (57.2 per cent) to 55,468.2 kt CO_2-e (figure ES 2.1).

The four categories that contributed the most to the increase in net emissions between 1990 and 2018 were *Enteric fermentation from dairy cattle*, *Road transportation*, *Land remaining forest land* and *Land converted to forest land*.

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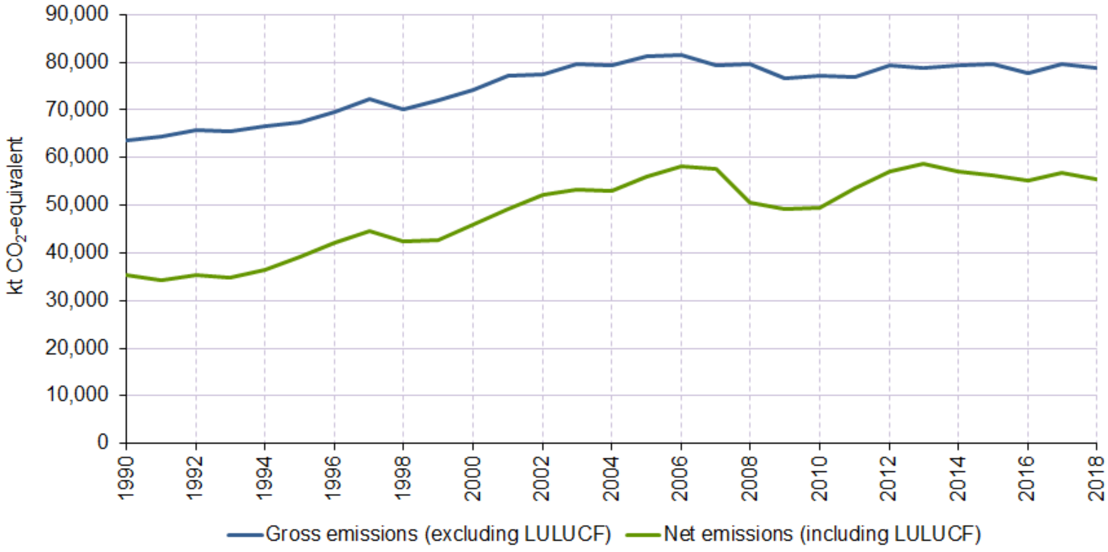
3 Methane emissions produced from the digestive process in ruminant livestock.

4 'ODS' stands for ozone depleting substances.

5 See *Energy in New Zealand* (Ministry of Business, Innovation and Employment, 2019) page 54 for further information.

Figure ES 2.1 **New Zealand's gross and net emissions (under the Convention) from 1990 to 2018**



Accounting for New Zealand's 2020 target

For the period 2013 to 2020, New Zealand has taken a target under the Convention. This target is to reduce emissions to 5 per cent 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.[6] This is 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).

New Zealand tracks progress towards its 2020 target by regularly publishing a net position. This report can be found on New Zealand's Ministry for the Environment website.[7]

ES.3 Greenhouse gas trends

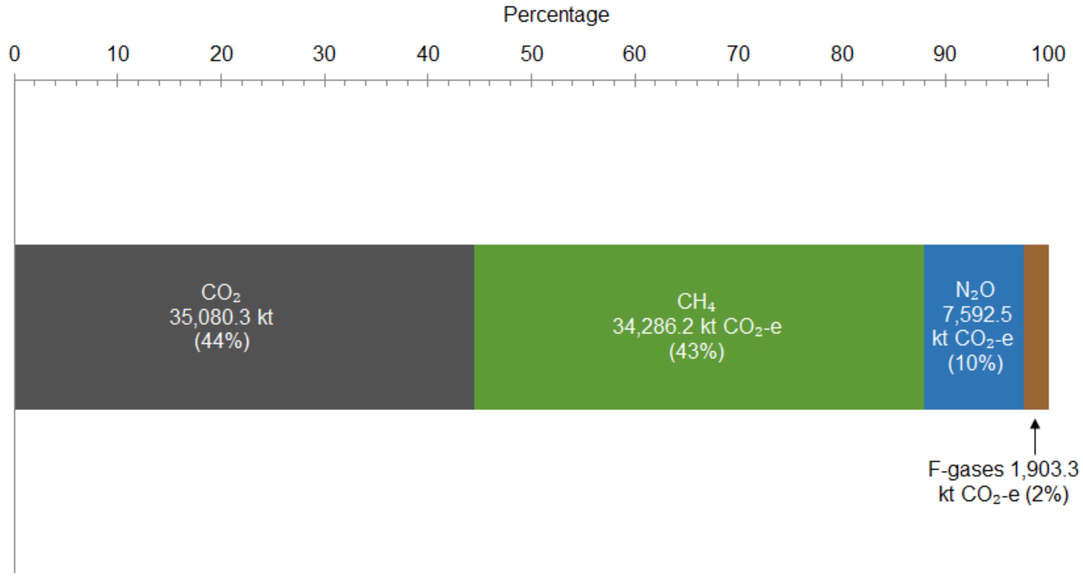
Inventory reporting under the Convention covers the following direct GHGs: CO_2, CH_4, N_2O, SF_6, PFCs, HFCs and NF_3. Because NF_3 emissions do not occur in New Zealand, no NF_3 data are included in this report. Figure ES 3.1 presents New Zealand's 2018 emissions by gas.

Table ES 3.1 provides a summary of emissions for each gas in 1990 and 2018 and the changes since 1990. This is also illustrated in figure ES 3.2.

6 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).

7 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 ES 3.1 New Zealand's gross emissions by gas in 2018



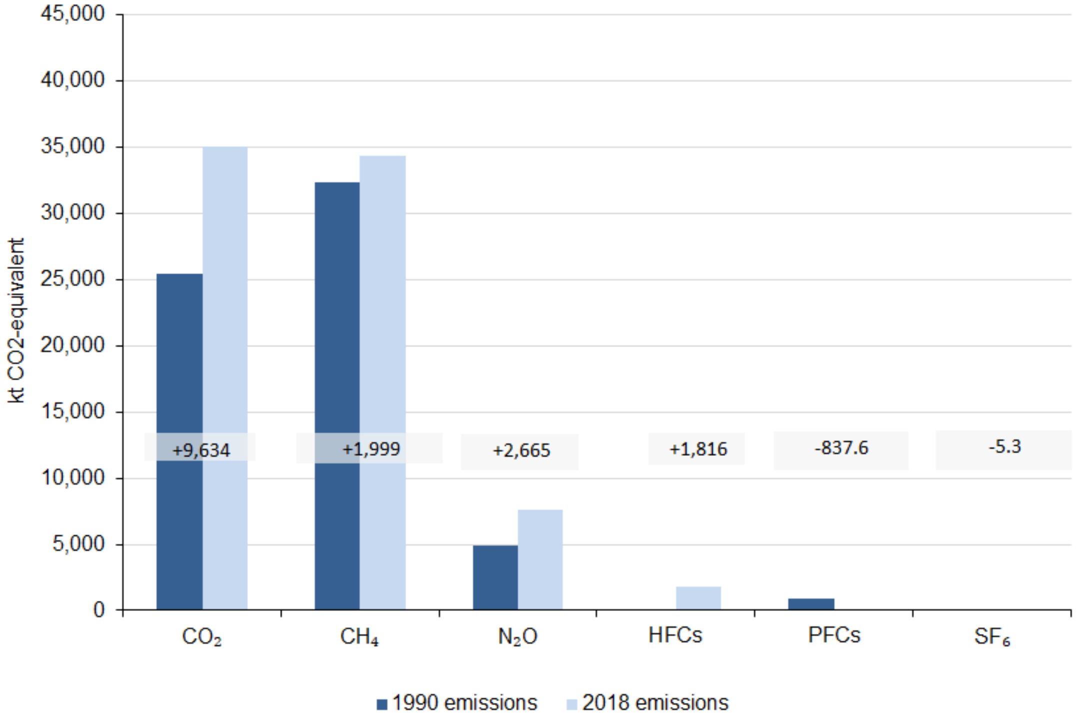
Note: The percentages may not add up to 100 per cent due to rounding.

Table ES 3.1 New Zealand's gross emissions by gas in 1990 and 2018

Direct greenhouse gas emissions	kt CO_2-equivalent 1990	kt CO_2-equivalent 2018	Change from 1990 (kt CO_2-equivalent)	Change from 1990 (%)
CO_2	25,446.3	35,080.3	9,634.1	37.9
CH_4	32,287.6	34,286.2	1,998.6	6.2
N_2O	4,927.1	7,592.5	2,665.3	54.1
HFCs	0.0	1,816.1	1,816.1	NA
PFCs	909.9	72.4	–837.6	–92.0
SF_6	20.0	14.7	–5.3	–26.3
Gross, all gases	**63,590.9**	**78,862.3**	**15,271.4**	**24.0**

Note: Gross emissions exclude net removals from the LULUCF sector. The per cent change for HFCs is not applicable (NA) because no emissions 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 2018



In 1990, CH_4 made up the largest proportion of gross emissions, while in 2018, 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 in the inventory has decreased over the time series, because CO_2 emissions have increased by a greater amount.

This trend reflects the increase in CO_2 emissions from the Energy sector as the biggest contributor of CO_2 to New Zealand's gross emissions (ranging between 87.0 per cent and 89.1 per cent of gross CO_2 emissions across the entire time series).

In 2018, 23,568.6 kt CO_2 was sequestered by the LULUCF sector,[8] bringing the net emissions from the sector down to –23,394.1 kt CO_2-e. This offset 29.7 per cent of New Zealand's gross emissions.

Between 1990 and 2018, the amount of CO_2 removed from the atmosphere by the LULUCF sector decreased by 5,038.2 kt (17.6 per cent) from the 1990 level of 28,606.8 kt. The decrease reflects the age structure of the forest and is the result of increased harvesting and deforestation since 1990.

Indirect gases

Indirect GHGs 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 GHG emissions in 1990 and 2018 as well as the change between these years.

8 Reporting rules under the Convention.

Table ES 3.2 New Zealand's indirect greenhouse gas emissions (excluding LULUCF) in 1990 and 2018

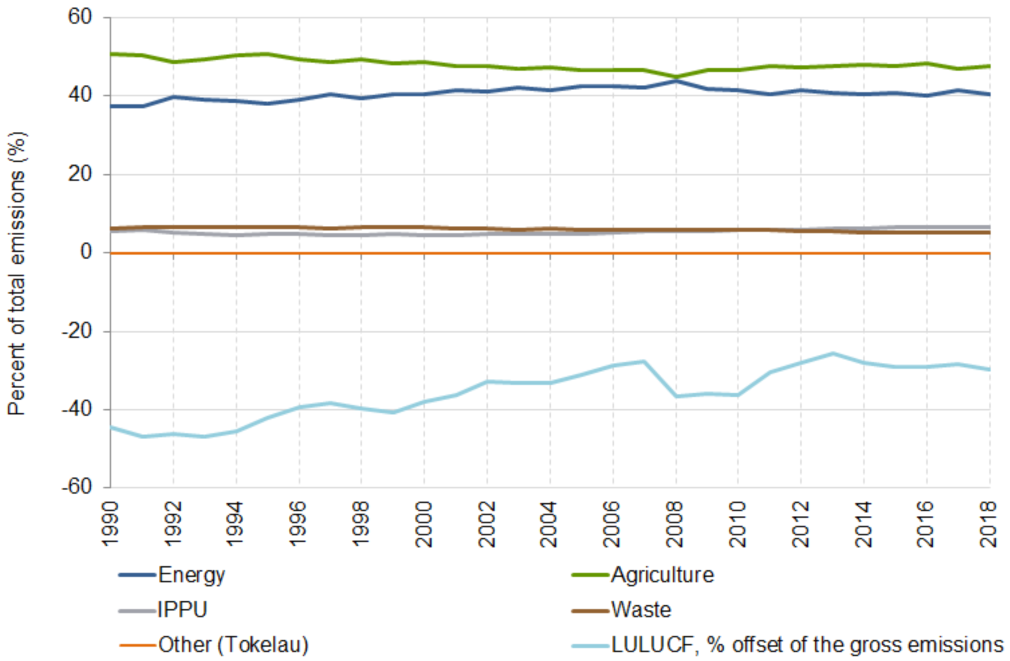
Indirect greenhouse gas emissions	kt 1990	kt 2018	Change from 1990 (kt)	Change from 1990 (%)
CO	602.8	739.8	137.0	22.7
NMVOCs	145.0	191.3	46.3	32.0
NO_x	101.7	168.3	66.6	65.5
SO_2	57.1	71.3	14.3	25.0

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. Together, these sectors produced almost 90 per cent of New Zealand's gross GHG emissions. The IPPU and Waste sectors produce relatively small amounts of GHGs, contributing between 4 per cent and 7 per cent to the gross emissions 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 GHG sink between 1990 and 2018.

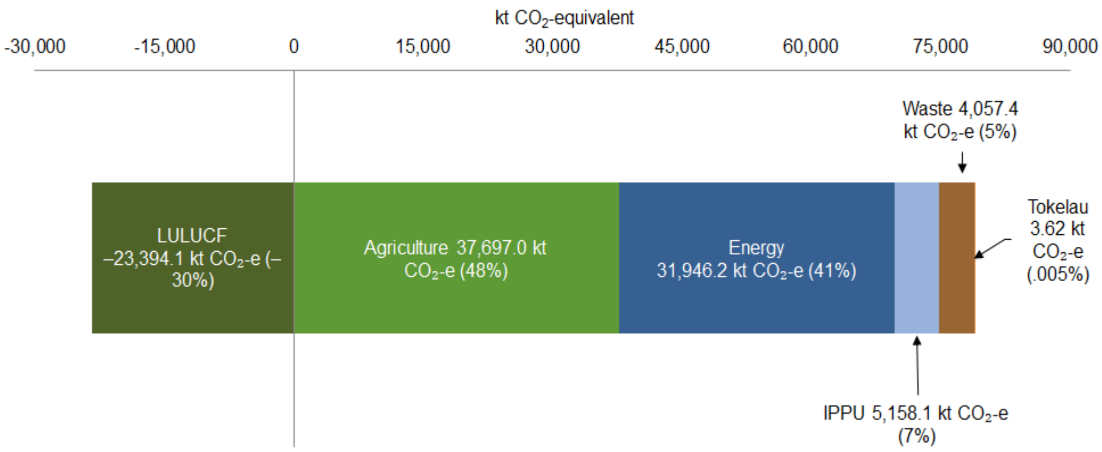
Figure ES 4.1 Changes in New Zealand's gross emissions profile by sector from 1990 to 2018



Note: Net removals from the LULUCF sector are as reported under the Convention (chapter 6).

Figure ES 4.2 shows emissions by sector in 2018. Agriculture was New Zealand's largest sector (47.8 per cent of the gross emissions). New Zealand's Energy sector contributed 40.5 per cent to the gross emissions, while the IPPU and Waste sectors contributed 6.5 per cent and 5.1 per cent to the gross emissions respectively.

Figure ES 4.2 New Zealand's emissions by sector in 2018



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.

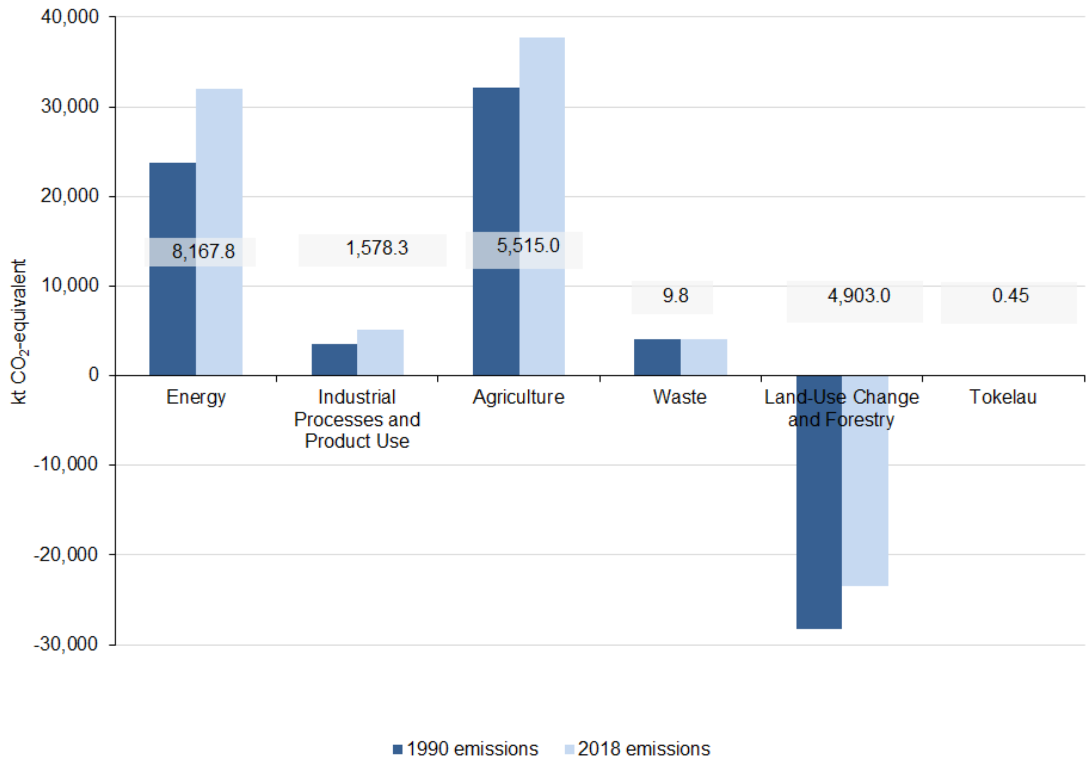
Table ES 4.1 and figure ES 4.3 summarise emissions by sector in 1990 and 2018 as well as the change between those years. A more detailed description of the emission trends for each sector is presented in chapter 2, section 2.2.

Table ES 4.1 New Zealand's gross emissions by sector in 1990 and 2018

Sector	kt CO_2-equivalent 1990	kt CO_2-equivalent 2018	Change from 1990 (kt CO_2-equivalent)	Change from 1990 (%)
Energy	23,778.3	31,946.2	8,167.8	34.3
Industrial Processes and Product Use	3,579.9	5,158.1	1,578.3	44.1
Agriculture	32,182.0	37,697.0	5,515.0	17.1
Waste	4,047.6	4,057.4	9.8	0.2
Other (Tokelau)	3.17	3.62	0.45	14.2
Gross (excluding LULUCF)	**63,590.9**	**78,862.3**	**15,271.4**	**24.0**
LULUCF	–28,297.0	–23,394.1	4,903.0	17.3
Net (including LULUCF)	**35,293.9**	**55,468.2**	**20,174.3**	**57.2**

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. For Tokelau contributions, see chapter 2, table 2.1.1.

Figure ES 4.3 Change in New Zealand's emissions by sector, comparing 1990 and 2018



Sector-specific trends

Energy (chapter 3)

2018

In 2018, emissions from the Energy sector contributed 31,946.2 kt CO_2-e or 40.5 per cent of New Zealand's gross GHG emissions (see figure ES 4.2). The largest sources of emissions in the Energy sector were the *Road transportation* category, contributing 15,070.9 kt CO_2-e (47.2 per cent), and the *Public electricity and heat production* category, contributing 3,310.8 kt CO_2-e (10.4 per cent) to energy emissions.

1990–2018

In 2018, emissions from the Energy sector were 34.3 per cent higher (8,167.8 kt) than the 1990 level of 23,778.3 kt CO_2-e. This growth in emissions is primarily from *Road transportation*, which increased by 7,595.6 kt CO_2-e (101.6 per cent), *Chemicals*, which increased by 708.6 kt CO_2-e (129.0 per cent), and *Food processing, beverages and tobacco*, which increased by 1,249.7 kt CO_2-e (75.4 per cent).

The main drivers for emission increases in the *Road transportation* and *Food processing, beverages and tobacco* categories are New Zealand's population growth since 1990 (by 42 per cent) and continuing economic growth associated with the increasing demand for transporting people and goods as well as food production for domestic use and export.

One of the main drivers for increasing emissions in the *Chemicals* category is a significant increase in the production of methanol in New Zealand. This is due to the fast-growing export market for methanol because of its increasing use as a clean transport fuel by New Zealand's trading partners. The other driver is an increased production of ammonia and urea due to the growing demand for fertilisers in New Zealand's agriculture sector.

In 2018, emissions from 1.A.1.c *Manufacture of solid fuels and other energy industries* were much lower than the 1990 level, by 1,464.1 kt CO_2-e (85.0 per cent). This decrease is primarily due to the cessation of synthetic gasoline production in 1997. Figure ES 4.1 shows the energy emissions time series from 1990 to 2018. 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 2007–08 global economic recession, earthquakes in 2011, 2013 and 2016, and the changes in rainfall levels from year to year, which affect the amount of hydroelectricity produced (see section 2.2 in chapter 2 for further details).

2017–2018

Between 2017 and 2018, emissions from the Energy sector decreased by 1,058.4 kt CO_2-e (3.2 per cent). This is primarily due to a 472.6 kt CO_2-e (27.3 per cent) decrease in emissions from category 1.A.2.c *Chemicals*. The decrease was partially offset by an increase from category 1.A.3.b *Road transport*, which increased by 295.2 kt CO_2-e (2.0 per cent).

There was also a 305.4 kt CO_2-e (8.4 per cent) decrease in emissions for category 1.A.1.a *Public electricity and heat production*. This was primarily due to a decrease in natural gas-fired generation in response to higher levels of hydro generation.

IPPU (chapter 4)

2018

In 2018, emissions from the IPPU sector contributed 5,158.1 kt CO_2-e or 6.5 per cent of New Zealand's gross GHG emissions (see figure ES 4.2).

The largest source of emissions is the *Metal industry* category, where substantial CO_2 emissions come 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 *Product uses as substitutes for ODS*. 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 in the category *Manufacturing industries and construction*.

1990–2018

IPPU sector emissions in 2018 were 1,578.3 kt CO_2-e (44.1 per cent) higher than emissions in 1990 (3,579.9 kt CO_2-e). This was mainly driven by an increase in 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 increased use of household and commercial air conditioning. Carbon dioxide emissions have also increased, due to the growth in 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*.

2017–2018

IPPU sector emissions in 2018 were 36.8 kt CO_2-e (0.7 per cent) higher than emissions in 2017. This change was the net result of an increase in emissions from the *Product uses as substitutes for ODS* category (157.5 kt CO_2-e or 9.5 per cent) offset by small decreases in all other significant categories driven by varying production rates.

Agriculture (chapter 5)

2018

In 2018, the Agriculture sector contributed 37,696.96 kt CO_2-e (47.8 per cent) of New Zealand's gross emissions (see figure ES 4.2).

The largest source of emissions within the Agriculture sector in 2018 was CH_4 emissions from *Enteric fermentation*, a process that produces CH_4 from livestock digestive systems. The remainder of the emissions from the Agriculture sector are N_2O emissions from *Agricultural soils* (which come from adding nitrogen to the soil, e.g., through livestock manure and nitrogen fertiliser), CH_4 and N_2O emissions from *Manure management*, and smaller amounts of CO_2 from the use of urea and lime. *Enteric fermentation* is responsible for 74.1 per cent of the total emissions from the sector, *Agricultural soils* 18.6 per cent, and the remaining 7.3 per cent of emissions come from *Manure management*, *Field burning of agricultural residues*, *Liming* and *Urea application*.

1990–2018

In 2018, New Zealand's Agriculture sector emissions were 17.1 per cent (5,515.0 kt CO_2-e) above the 1990 level (32,181.96 kt CO_2-e). This increase is primarily due to a 56.7 per cent (2,542.5 kt CO_2-e) increase in N_2O emissions from the *Agricultural soils* category and a 5.2 per cent (1,390.0 kt CO_2-e) increase in CH_4 emissions from the *Enteric fermentation* category.

The main drivers for these changes were a 672.5 per cent increase in synthetic nitrogen fertiliser applied since 1990 and an 85.6 per cent increase in the size of the national dairy herd over the same time period.[9] Falls of 52.9 per cent in the sheep population and 19.1 per cent in the non-dairy cattle population have partially offset these increases.

2017–2018

Total agricultural emissions in 2018 were 0.7 per cent (278.2 kt CO_2-e) higher than in 2017. This increase was due to an increase in emissions from non-dairy (beef) cattle, dairy cattle, sheep, and nitrogen fertiliser use.

Non-dairy cattle emissions increased 1.3 per cent (82.0 kt CO_2-e) as the national non-dairy herd increased. Dairy cattle emissions increased 0.3 per cent (49.3 kt CO_2-e), because a small fall in the national dairy herd was offset by a small increase in total milk production (LIC and DairyNZ, 2019). Sheep emissions increased 0.4 per cent (41.7 kt CO_2-e), because a small decrease in the sheep population was offset by an increase in average slaughter weights. The change between 2017 and 2018 is due to strong commodity prices (for dairy and meat products) as well as favourable climatic conditions supporting pasture growth. The rate of decline in sheep populations has slowed in recent years due to strong lamb prices.

Emissions increased from synthetic nitrogen fertiliser, urea application and liming. These increased 3.3 per cent (54.0 kt CO_2-e), 3.4 per cent (19.9 kt CO_2-e) and 7.7 per cent (35.3 kt CO_2-e) respectively.

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.

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[9] The national dairy herd increased by 3.2 million animals in the period 1990–2018.

2018

The LULUCF sector under the Convention was a sink of –23,394.1 kt CO_2-e net emissions. This offset 29.7 per cent of New Zealand's gross emissions in 2018. 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.

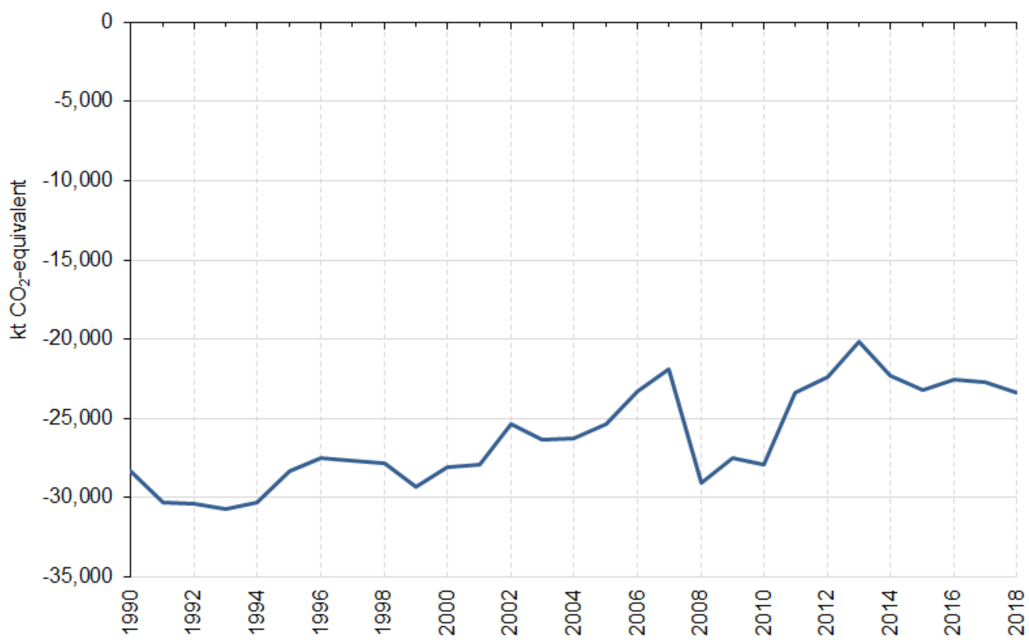
1990–2018

For the entire period 1990–2018, the LULUCF sector represented a net sink, that is, each year the total removals from the sector were greater than its total emissions.

From 1990 to 2018, net emissions from LULUCF increased by 4,903.0 kt CO_2-e (17.3 per cent) from the 1990 level of –28,297.0 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 emissions 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 deforestation of planted forests that occurred leading up to 2008, before the introduction of the New Zealand Emissions Trading Scheme (NZ ETS).[10] Emissions from deforestation were much lower in 2008. The level of harvesting has generally been increasing since 2008.

Figure ES 4.4 New Zealand's LULUCF sector net emissions from 1990 to 2018



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

2017–2018

Between 2017 and 2018, net CO_2 emissions from the LULUCF sector decreased by 684.0 kt CO_2-e (3.0 per cent). The largest change occurred in the *Harvested wood products* category, with a decrease in net emissions of 2,366.8 kt CO_2-e. The increase in the production of harvested wood products was driven by an increase in the rate of harvesting of planted forests between 2017 and 2018. This increase in harvesting contributed to an increase in emissions from *Forest land* by 2,150.9 kt CO_2-e over this period, the second-largest change in emissions for the LULUCF sector.

Waste (chapter 7)

2018

In 2018, emissions from the Waste sector contributed 4,057.4 kt CO_2-e or 5.1 per cent of New Zealand's gross GHG emissions. The largest source category is the *Solid waste disposal* category.

1990–2018

Total Waste sector emissions in 2018 were 9.8 kt CO_2-e (0.2 per cent) above 1990 emissions of 4,047.6 kt CO_2-e. Annual emissions increased between 1990 and 2002, peaking at 4,838.2 kt CO_2-e in 2002, and have generally 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 entire 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 in chapter 2 and figures 7.1.1 and 7.1.2 in chapter 7.

2017–2018

Total Waste sector emissions in 2018 were 35.2 kt CO_2-e (0.9 per cent) lower than in 2017. This decrease is largely the result of decreases in CH_4 emissions in the *Solid waste disposal* category, due to an increase in CH_4 recovery and a slight reduction in farm waste.

Other sector (Tokelau – chapter 8)

2018

The total amount of emissions of GHGs from all sources in Tokelau in 2018 were 3.62 kt CO_2-e, contributing approximately 0.005 per cent to New Zealand's gross emissions. The largest source category was the *Domestic navigation* category contributing 1.50 kt CO_2-e (81.2 per cent of all energy emissions and 41.6 per cent of gross emissions from Tokelau).

1990–2018

In 1990, gross emissions from Tokelau were 3.17 kt CO_2-e. Between 1990 and 2018, gross emissions from Tokelau increased by 14.2 per cent (0.45 kt CO_2-e) to 3.62 kt CO_2-e in 2018.

The emission categories that contributed the most to this change were *Domestic navigation* and *Refrigeration and air conditioning*. The changes in *Domestic navigation* are a result of Tokelau gaining ownership and use of the ferry *Mataliki* in 2016 and cargo vessel *Kalopaga* in 2018 leading to an increasing number of sea voyages between the atolls, which increased transport emissions. Emissions from Tokelau's IPPU sector have also increased slightly as fridges and freezers have become more commonly used. Further changes in Tokelau's Energy sector emissions are a significant rise then drop (by approximately 400 per cent and 82.5 per cent respectively) in consumption of imported petroleum products used for electricity production in Tokelau. Emissions from Tokelau's Agriculture sector have decreased slightly as a result of a reduced population of pigs (figure 2.2.12). The trends are shown in chapter 2, figure 2.2.12, and in chapter 8.

2017–2018

Total Tokelau emissions in 2018 were 0.10 kt CO_2-e (2.8 per cent) higher than emissions in 2017. This increase is largely the result of increases in CO_2 emissions in the *Domestic navigation* category, due to increasing shipping within Tokelau.

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

Under the Kyoto Protocol, reporting of *Afforestation and reforestation* and *Deforestation* activities since 1990, and *Forest management* is mandatory during the second commitment period. 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 2018 was 698,497 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 2018 is 9,443 hectares.

Deforestation

The area deforested between 1 January 1990 and 31 December 2018 was 201,206 hectares. The area subject to *Deforestation* in 2018 was 3,740 hectares.

Forest management

The net area reported under *Forest management* as at the end of 2018 was 9,208,933 hectares (table ES 5.1(a)). This represents 34.3 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	2017[P]	2018[P]
Afforestation and reforestation						
Net cumulative area since 1990	677,229	679,128	680,963	683,921	689,747	698,497
Area in calendar year	4,530	3,447	3,502	4,281	6,461	9,443
Deforestation						
Net cumulative area since 1990	176,101	184,637	190,560	193,974	197,466	201,206
Area in calendar year	14,232	8,536	5,923	3,414	3,493	3,740
Forest management						
Area included	9,224,080	9,217,093	9,212,837	9,211,357	9,210,186	9,208,933
Total area included	**10,077,410**	**10,080,857**	**10,084,359**	**10,089,252**	**10,097,399**	**10,108,636**

Note: Afforestation and reforestation refers to new forest established since 31 December 1989 but excluding 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 (all figures for 2017 and 2018 in this table are provisional).

Emissions and removals in 2018

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

- net removals of 17,593.2 kt CO_2-e for *Afforestation and reforestation*
- net emissions of 2,146.2 kt CO_2-e for *Deforestation*
- net removals of 13,898.9 kt CO_2-e for *Forest management*.

Emissions and removals from 2013 to 2018

Estimates of emissions and removals for activities under Article 3.3 and Article 3.4 of the Kyoto Protocol for the period 2013 to 2018 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.

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

	kt CO_2-equivalent					
Activity	2013	2014	2015	2016	2017[P]	2018[P]
Afforestation and reforestation	–17,542.2	–17,824.5	–18,066.9	–17,790.2	–-17,790.2	–17,593.2
Deforestation	9,525.6	5,667.4	3,640.3	1,821.5	1,977.1	2,146.2
Forest management	–18,487.6	–16,962.0	–15,470.4	–13,119.5	–13,136.0	–13,898.9
Net emissions	**–26,504.2**	**–29,119.1**	**–29,897.0**	**–29,088.2**	**–28,949.2**	**–29,346.0**
Accounting quantity	**–8,016.6**	**–12,157.1**	**–14,426.6**	**–15,968.7**	**–15,813.2**	**–15,447.0**

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. P = provisional figure (all figures for 2017 and 2018 in this table are provisional).

ES.6 Improvements introduced

The inventory follows a process of continuous improvement as per the Convention principles. A range of improvements have been made to the inventory since the last submission. Improvements are made from year to year, to follow recommendations from international expert review teams, correct errors and implement additional changes planned 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 and/or removals in a given year may differ from emissions and/or removals reported in the previous inventory submission.

The main improvements by sector are outlined below. Chapter 10 provides information on all recalculations made to the estimates.

Energy (chapter 3)

No significant improvements have been introduced that would affect emissions estimates. Projects to implement improvements for the reference approach and sectoral approach are ongoing, and results will be reported in our next submission.

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

IPPU (chapter 4)

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 this submission, emissions from refrigeration and air conditioning for 2013 to 2017 have been recalculated to better account for fluctuations in import volumes and refrigerant stockpiled by importers.

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

Agriculture (chapter 5)

The improvements in the 2020 inventory submission included revisions to emission factors, methodologies and activity data as follows:

- use of new N_2O emission factors for animal excreta ($EF_{3,PRP}$). These emission factors are now split by livestock type and hill slope and are applied using a new model that calculates the amount of livestock excreta deposited onto different slopes (low,[11] medium[12] and steep[13]). This improvement affected emissions from dairy cattle, beef cattle, sheep and deer in the *Agricultural soils* category. This improvement also affects the Agriculture emissions profile. The Agricultural Advisory Panel recommended this improvement as a result of extensive research conducted over the past decade.

[11] Land with a gradient between 0 degrees and 12 degrees.

[12] Gradient greater than 12 degrees and 24 degrees.

[13] Gradient greater than 24 degrees.

- use of revised activity data for the proportion of dairy goats in the overall farmed goat population. This change affected emissions from goats in the *Enteric fermentation*, *Manure management* and *Agricultural soils* categories. The Agricultural Advisory Panel recommended the inclusion of the new activity data, while further improvements will be considered for future inventory submissions.
- minor improvements to the equations used to estimate energy efficiency for maintenance (k_m) for beef cattle, sheep and deer, which is used to help calculate energy requirements, intake, and nitrogen excretion. This change included the specification of a constant to more significant figures and reverting to the IPCC default value for the gross energy content of feed of 18.45 megajoules per kilogram of dry matter (MJ/kg DM). This change had a small effect on estimated emissions in the *Enteric fermentation*, *Manure management* and *Agricultural soils* categories.

LULUCF (chapter 6)

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

- undertaking a revised analysis of the pre-1990 natural forest plot data (Paul et al., unpublished). This resulted in a 55.4 per cent reduction in the estimate for carbon stock change in the regenerating component of pre-1990 natural forest, compared with the previous submission
- revising the post-1989 planted forest yield table for the 2020 submission, which affected the estimates of carbon stock per hectare.

Waste (chapter 7)

Minor 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.

The most significant changes to emissions have been made to the *Unmanaged waste disposal sites* source category and have resulted in the largest recalculation for the Waste sector as a result of the corrections made.

Other sector (Tokelau – chapter 8)

Significant changes and improvements have been made in the Tokelau emission estimates since the 2019 submission. Overall, improvements and recalculations made for the Tokelau sector have resulted in a 13.0 per cent (0.5 kt CO_2-e) decrease in emissions in 1990 and a 22.9 per cent (0.7 kt CO_2-e) increase in emissions in 2017.

KP-LULUCF (chapter 11)

Improvements have been introduced to the 2020 submission resulting in recalculations for all three activities. These improvements are listed in chapter 2 and chapter 6 (LULUCF).

Improvements to national inventory system

No changes have been made in the legal or institutional arrangements in the national inventory system since the last inventory submission (2019).

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 reviewing that involved secretariat staff from the United Nations Framework Convention on Climate Change took place during the period leading up to go-live of the new Register.

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 for the first commitment period (CP1).

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

At the beginning of the calendar year 2019, 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. No second commitment period (CP2) units were held by New Zealand in 2019.

New Zealand's national registry did not hold any temporary certified emission reduction units or long-term certified emissions reduction units during 2019.

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 United Nations Framework Convention on Climate Change along with this inventory submission.

Executive summary: References

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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 (GHGs). The report also suggests that, since the beginning of the industrial revolution (about 1750 AD), the atmospheric concentrations of the GHGs carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) have all increased due to human activity. Continued emissions of GHGs 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 GHG emissions. The annual inventory of GHG 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[14] to the Convention commit to providing technology transfer, capacity building and financial assistance to non-Annex I[15] Parties (developing country parties).

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[14] 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.

[15] 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'.

Annex I Parties also agreed to aim to return GHG 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 GHG levels would be stabilised at a safe 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.

To accelerate and intensify the actions and investments needed for a sustainable low carbon future, parties to the convention reached a landmark agreement in Paris, France, on 12 December 2015. The Paris Agreement was ratified by New Zealand on 4 October 2016. The extension (as of 13 November 2017) of New Zealand's ratification of the Convention and the Paris Agreement to include Tokelau means, *inter alia*, that New Zealand's national inventory shall include GHG emissions and removals estimates from Tokelau. From 2019, emissions from Tokelau are included in New Zealand's greenhouse inventory.

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, noting that GHG targets in the Kyoto Protocol only apply to Annex I Parties. The original objective of the Kyoto Protocol was to reduce the aggregate emissions of six GHGs from Annex I Parties 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 CP1 was to return emissions to 1990 levels[16] 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 new targets in 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 its target for the 2013–20 period.

When reporting emissions and removals from the Land Use, Land-Use Change and Forestry (LULUCF) sector, New Zealand uses the land-based approach, set out in 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*.

[16] 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.

1.1.3 The inventory

The Convention covers emissions and removals of all anthropogenic GHGs 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 described in 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 inventory.

A complete inventory submission contains two main 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 UNFCCC secretariat. The results of these reviews are available (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).[17] The indirect GHGs,[18] 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 GHGs (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 six sectors: Energy, Industrial Processes and Product Use (IPPU), Agriculture, LULUCF, Waste and New Zealand's 'Other' sector (Tokelau).

From 2019, greenhouse gas emissions from Tokelau, New Zealand's overseas dependent territory,[19] were included in New Zealand's 'Other' sector.

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.

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

18 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 (for example, where CO is converted to CO_2) or when chemical reactions in the atmosphere involving these gases change the concentrations of direct greenhouse gases.

19 In the United Nations Charter (UN, 1945), a non-self-governing territory is defined as a territory "whose people have not yet attained a full measure of self-government". Tokelau has been on the United Nations list of non-self-governing territories since 1946, following the declaration of the intention by New Zealand to transmit information on the Tokelau Islands under Article 73e of the United Nations Charter.

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 the 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 developing country 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 enabled New Zealand to meet its international obligations under the Convention and Kyoto Protocol. A Prime Ministerial directive for the administration of the 2002 Act named 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.

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 Articles 4 and 12 of the Convention and 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 this Part (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 GHGs.

On 13 November 2017, New Zealand also extended its ratification of the Convention and the Paris Agreement to include Tokelau. This means, *inter alia*, that New Zealand's national GHG inventory shall include the GHG estimates from Tokelau. Further details are included in chapter 8, section 8.1.3.

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: inventory management, inventory planning and preparation, quality assurance/quality control (QA/QC) processes, communication and error management. This is a living document that is updated as required.

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 CRF tables and writing sectoral inventory chapters, is carried out by a number of designated government agencies.

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.

Inventory governance within each sector, as well as sector-level 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 GHG emissions and removals. The RGG is chaired by MfE, and its membership includes representation from the Ministry for Primary Industries (MPI), the Ministry of Business, Innovation and Employment (MBIE) and the Environmental Protection Authority (EPA). 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 the 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 agencies that impact on the delivery of the work programme
- 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, if required.

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.

MfE coordinates with the Tokelau Ministry for Climate, Oceans and Resilience (MiCORE; formerly known as the Climate Change Agency) on Tokelau's inventory data and information and provides guidance on the inventory data collection, processing and delivery under the Memorandum of Understanding (MoU) between New Zealand and Tokelau.

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 and livestock statistics data for estimating emissions from the Agriculture and Waste sectors.

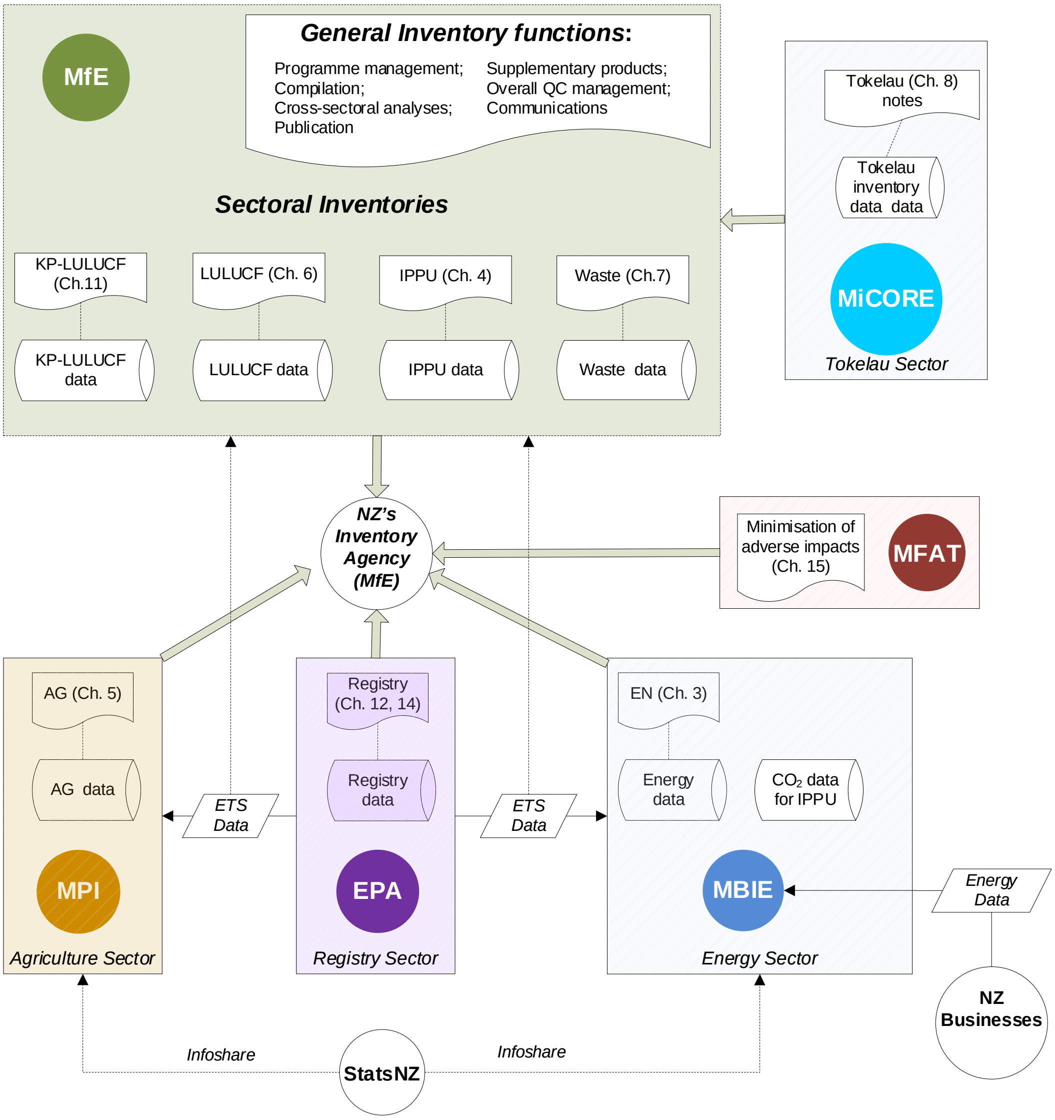
The Ministry of Foreign Affairs and Trade (MFAT) provides information on the minimisation of adverse impacts under Article 13.4 of the Kyoto Protocol, as reported in chapter 15.

MiCORE and the Tokelau National Statistics Office coordinate efforts in activity data collection and data processing for estimating emissions from Tokelau for all inventory sectors.

The Climate Change Response Act 2002 establishes the requirement for a registry and a registrar. The EPA is the designated agency responsible for the implementation and operation of New Zealand's national registry under the Kyoto Protocol, the New Zealand Emissions Trading Register. The registry is electronic and accessible via the internet (www.emissionsregister.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.

The above arrangements are presented in figure 1.2.1, which 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

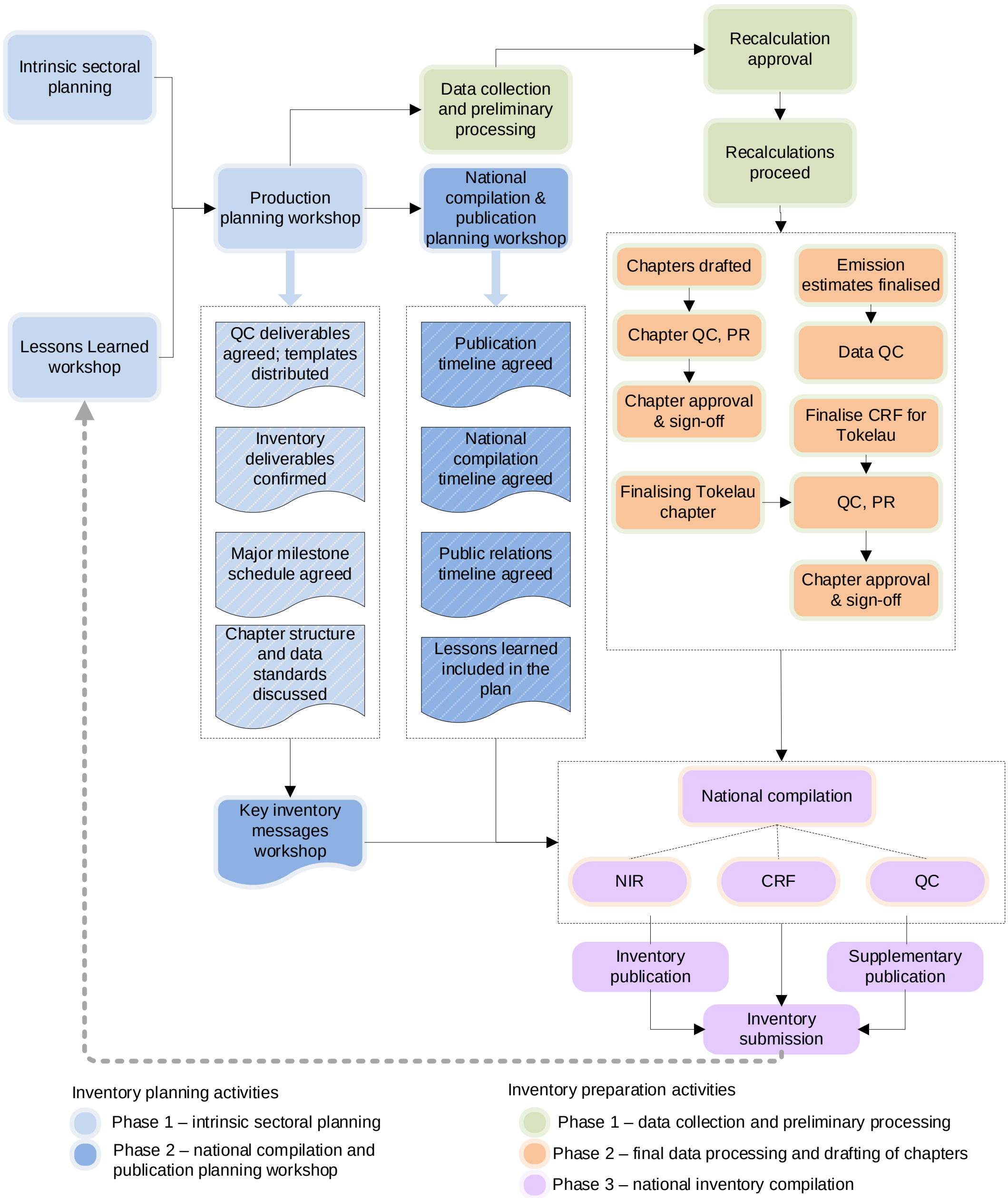


Note: AG = Agriculture; EN = Energy; EPA = Environmental Protection Authority; ETS = Emissions Trading Scheme; IPPU = Industrial Processes and Product Use; KP-LULUCF = Kyoto Protocol Land Use, Land-use Change and Forestry; LULUCF = Land Use, Land-use Change and Forestry; MBIE = Ministry of Business, Innovation and Employment; MFAT = Ministry of Foreign Affairs and Trade; MfE = Ministry for the Environment; MiCORE = Tokelau Ministry for Climate, Oceans and resilience; 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 the 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 developing the plan.

The second phase of the inventory planning also includes a workshop dedicated to key messages for the inventory, which is an integral part of the cross-sectoral compilation. The workshop's output is the set of key inventory messages agreed between the sector leads, national inventory compiler and primary peer reviewers. The key messages are used for both the National Inventory Report and the inventory Snapshot, which presents a brief description of the inventory findings.

The inventory planning process for Tokelau is governed by the MoU between New Zealand and Tokelau. Further information is provided in chapter 8.

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 analysing 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 are 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.

Tokelau follows the same inventory preparation cycle. The inventory data from Tokelau are finalised in November and generally undergo the same processes as the rest of the inventory.

During the inventory planning and preparation cycles, 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. This plan has been updated as the automatic QC tools have been developed and the approach to the final CRF data approvals has been modified. Details of the QA/QC activities performed during the compilation of the 2019 submission are discussed in the relevant sections below. Examples of QC checks are provided in the Excel spreadsheets accompanying this submission.

Quality control

The focus of New Zealand's QC plan is to meet the transparency, accuracy, completeness, consistency, and 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
- applying automated inventory tools, where available, 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
- performing CRF data integrity checks and adhering to the reporting guidelines once data compilation in each sector is complete
- ensuring the chapters in the inventory and their structure 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 in line with the 2006 IPCC Guidelines (IPCC, 2006b). Wherever possible, manual checking has been replaced by, or supplemented with, automated checks.

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 CRF tables were also checked for anomalies, errors and omissions.

After the CRF data were compiled in each inventory sector, MfE personnel reviewed the CRF data for each sector and category for data integrity and time-series consistency prior to sector finalisation. This is to ensure that the CRF does not contain blank entries in the reported categories, and all instances of using the 'IE' (included elsewhere) and 'NE' (not estimated) notation keys for GHG emissions, as well as large variations in the implied emission factors, have been explained. The results of these checks were provided to the sector leads to make any corrections and to include the relevant references and explanations, if required, in order to finalise the CRF data for each inventory sector. The finalised sector-level data were entered into the web-based CRF database by sector compilers by 7 February 2020.

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.

Tokelau's inventory data undergo QC processes at the Tokelau National Statistics Office, in consultation with the relevant sector leads, national QC Manager and the National Inventory Compiler in New Zealand. The Tokelau sector in the CRF undergoes the same CRF data integrity checks as other inventory sectors.

Annex 6 contains details of the QA/QC processes applied during the 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 under the UNFCCC as an important element of quality assurance. Regular meetings to discuss the 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 Energy sector leads had a discussion of sectoral issues with the Danish inventory team during bilateral meetings in 2017 dedicated to different aspects of the Energy sectoral inventory, specifically data sources, data collection, verification processes; using the New Zealand Emissions Trading Scheme (NZ ETS) data for higher tier methods in the Energy sector; applying higher tier methods for road transport; disaggregation of non-road liquid fuel use; and fugitive emissions from fuels.

The Agriculture sector completed a major QA review of its calculation models with an external party in 2013. Since then, there has also been other QA activities for agriculture, including a bilateral review with Australia in 2014, and an external review of equations used to determine metabolisable energy requirements in 2016. In 2019, an external consultant was contracted to review and develop a QA plan for the Energy sector. The recommendations from that project are currently being implemented. For more information, see chapter 5, section 5.1.6, of the 2020 inventory 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 significance of the Agriculture sector to New Zealand's emissions, government 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 documented and archived for future reference.

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 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 result in identifying 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 preparing 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 the confidentiality of businesses that contribute data to the inventory (as appropriate), two approaches are used:

- where emissions can be reported without compromising confidentiality, the corresponding activity data are not reported and are marked as confidential in the CRF tables
- 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 (2019) inventory submission.

Changes in New Zealand's inventory system in the last (2019) submission were associated with including GHG emissions from Tokelau in New Zealand's GHG inventory (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 file recovery for the inventory in the event of a disaster, a distributive strategy for storage is in place. This includes storing 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 inventory 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), and the Kyoto Protocol decisions pertaining to reporting and review (UNFCCC, 2005 a–k, 2012, 2013c, 2016a, 2016b).

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 inventory category and the 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 1990–2018 (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 2019* (MBIE, 2019). 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 category 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*[20] category, updated activity data have been obtained through a detailed annual survey covering the electrical, refrigeration and other industry participants (CRL Energy Ltd., 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.

For the small amounts of indirect GHG 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 GHGs.

Agriculture

New Zealand has developed a Tier 2 methodology with country-specific emission factors. This methodology uses detailed data on livestock population and production to calculate livestock energy requirements for four major livestock categories (*Dairy cattle*, *Non-dairy (beef) cattle*,

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[20] 'ODS' stands for ozone depleting substances.

Sheep and *Deer*). Other livestock are classified as 'minor' due to their small total contribution to agricultural emissions and are outlined below. Animal population data are collected by Statistics New Zealand. Productivity data are available from the Livestock Improvement Corporation (LIC) 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 MPI and are used to derive live weights.

Other livestock species combined (*Swine*, *Goats*, *Horses*, *Llamas and alpacas*, *Mules and asses*, and *Poultry*) account for only 0.5 per cent of New Zealand's agriculture emissions. Emissions from these minor livestock species are estimated using Tier 1 methods. Where information is available, New Zealand has used country-specific emission methodology and factors. Rabbits are considered an agricultural pest in New Zealand, and, based on expert opinion, only a very small number of rabbits are farmed in the country (R. Sanson, pers. comm., 2019). Because of this, emissions from farmed rabbits are not estimated (NE) because their emissions are insignificant. There is no known farming of other fur-bearing animals in New Zealand.

For estimating emissions from the *Agricultural soils* category, New Zealand uses methodologies based on the IPCC Guidelines (IPCC, 2006a), 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 the *Agricultural soils* category. 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, A3.1.6 and A3.1.7). Table 5.5.5 in chapter 5 contains the parameters used to estimate emissions where specific mitigation technologies are used.

Activity data for the *Liming* category are obtained from Statistics New Zealand, and activity data on the use of synthetic fertiliser containing nitrogen are provided by the Fertiliser Association of New Zealand. A Tier 2 (model) approach is used to calculate emissions from the *Burning of agricultural residues* category. 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 applied to estimate biomass carbon in the pools with the most living biomass at maturity: *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. Furthermore, a Tier 2 approach has been used to estimate carbon stock changes in the *Harvested wood products* category.

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:

- use of field plot measurements for natural and planted forests
- use of allometric models and a forest carbon modelling system to estimate carbon stock and carbon stock change in natural and planted forests respectively (Beets et al., 2014; Paul et al., unpublished(a), unpublished(b); Paul and Kimberley, unpublished)

- wall-to-wall land use mapping for 1990, 2008, 2012 and 2016 using satellite and aircraft remotely sensed imagery, with additional information on post-1989 forest afforestation and deforestation of planted forest used for estimating the 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, are used for the years for which they are available (2010 onwards). Activity data for all other sources were based on specific surveys or estimates. 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 most 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.

Other sector (Tokelau)

The Tokelau National Statistics Office collects and processes activity data from Tokelau for inventory preparation. Table 1.4.1 contains the key sources of activity data from Tokelau used in the GHG inventory.

Table 1.4.1 Key sources for activity data in Tokelau

Item	Name/abbreviation	Explanation	Used where
1	Census	Tokelau Census of Population and Dwellings 2006, 2011, 2016 www.tinyurl.com/TokelauCensus	Census data; interpolations for populations of people and livestock; solid and water waste disposal (flush toilets), number of private aluminium boats/outboard motors, home appliances
2	Archives NZ	Archives New Zealand, Wellington	Historic Census records going back to 1951, at five-year intervals (TNSO collation and analysis)
3	HIES	Tokelau Household Income and Expenditure Survey 2015/16 www.tinyurl.com/TokelauHIES	Population and dwellings data supplementary to Census, in partnership with Pacific Community (SPC)
4	SNZ, StatsNZ	Statistics New Zealand, Wellington www.stats.govt.nz	Major partner in collection, analysis and publication of Tokelau Census data
5	TNSO	Tokelau National Statistics Office, Apia www.tokelau.org.nz/Stats.html	Joint collection, analysis and publication of Tokelau Census data
6	DoE	Tokelau Department of Energy	Estimate of diesel use for 24/7 power generation in 2004, plus before and after installation of solar in July–September 2012 (personal communication Mr Robin Pene, DoE director)
7	PPS	Petroleum Product Supplies Ltd Apia	Fuel prices and volumes supplied for shipping and on-atoll use of diesel, petrol, kerosene and lubricant oil
8	DoF	Tokelau Department of Finance	Paid invoices and payment records to PPS, Origin, and on-atoll stores
9	2018 vehicle survey	Photo survey of Tokelau motorised vehicles on-atoll, August–December 2018	Personal communication JA Jasperse, TNSO

Item	Name/abbreviation	Explanation	Used where
10	Origin	Origin Energy Samoa Ltd, Apia	Prices and volumes supplied for on-atoll use of propane for cooking
11	PCTrade-Green	Excel version of PCTrade package developed by StatsNZ, Christchurch	Used for analysing cargo shipping manifests, providing number of return voyages Apia–Tokelau over time, imports of goods, and exports of recyclables to date (2014–June 2019 data available)
12	DoH	Tokelau Department of Health	Anecdotal information on inhalers, laser gas, fire extinguishers
13	TSS	Tokelau Department of Transport and Support Services, Apia	Cargo shipping manifests for analysis of imports of all goods, and export of recyclables
14	2014 Imports study	Jasperse, JA. 2016. *Analysis of 2014 imports into Tokelau from Samoa, Part 2: Stores' invoices reconciled with cargo manifests, and quality of life implications*. Tokelau National Statistics Office	Various Energy and Waste sector data, for example, calculation of per capita protein consumption www.tokelau.org.nz/Bulletin/September+2016/2014+imports+final.html
15	EDNRE	Tokelau Department of Economic Development, Natural Resources and Environment	Anecdotal information on waste disposal and export
16	PCRAFI	Koroisamanunu, Iva; Joy Papao; Mereoni Ketewai; and Arieta Sokota: *Mission Preliminary Report (Fieldwork undertaken from 8 August – 2 September 2013). SOPAC technical note (PR193)*, May 2014. Water and Sanitation Programme and Disaster Reduction Programme. Applied Geoscience and Technology Division (SOPAC), Suva, Fiji Islands	Information on drinking water, wastewater and sanitation
17	MiCORE	Tokelau Ministry of Climate, Oceans and Resilience	Partner to Memorandum of Understanding (MOU) with New Zealand Ministry for the Environment (MfE) leading to the present inventory

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 2018, or the trend of emissions. The key categories identified in the 2018 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 2018 are:

- CO_2 emissions from *Land converted to forest land* (14.1 per cent)
- CO_2 emissions from *Road transportation – Liquid fuels* (13.5 per cent)
- CH_4 emissions from *Dairy cattle – Enteric fermentation* (12.3 per cent)
- CO_2 emissions from *Forest land – Harvested wood products* (9.7 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 2018, are:

- CH_4 emissions from *Sheep – Enteric fermentation* (19.5 per cent as a decrease)
- CO_2 emissions from *Forest land – Harvested wood products* (13.8 per cent as an increase)
- CO_2 emissions from *Forest land – Land Converted to Forest Land* (10.1 per cent as a decrease)
- CH_4 emissions from *Dairy cattle – Enteric fermentation* (6.0 per cent as an increase).

For gross emissions, table 1.5.2(b) identifies that the major contributions to the level analysis for 2018 are:

- CO_2 emissions from *Road transportation – Liquid fuels* (19.0 per cent)
- CH_4 emissions from *Dairy cattle – Enteric fermentation* (17.3 per cent)
- CH_4 emissions from *Sheep – Enteric fermentation* (10.6 per cent)
- CH_4 emissions from *Non-dairy cattle – Enteric fermentation* (6.9 per cent).

As detailed in table 1.5.3(b), the key categories that were identified as having the largest relative influence on the trend, when compared with the average change in gross emissions from 1990 to 2018, are:

- CH_4 emissions from *Sheep – Enteric fermentation* (21.8 per cent as a decrease)
- CH_4 emissions from *Dairy cattle – Enteric fermentation* (14.8 per cent as an increase)
- CO_2 emissions from *Road transportation – Liquid fuels* (14.4 per cent as an increase)
- CO_2 emissions from *Energy industries – Manufacture of solid fuels* and *Other energy industries – Gaseous fuels* (4.5 per cent as a decrease).

Table 1.5.1 Summary of New Zealand's key categories for the 2018 level assessment and the trend assessment for 1990 to 2018 (including and excluding LULUCF activities)

Quantitative method used: IPCC Tier 1			
CRF category code	**IPCC category**	**Gas**	**Criteria for identification**[21]
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	L1, 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, T1
1.A.2.d	Manufacturing Industries and Construction – Pulp, Paper and Print Solid Fuels	CO_2	T1
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.a	Other Sectors – Commercial/Institutional Solid Fuels	CO_2	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.A.4.c	Other Sectors – Agriculture/Forestry/Fishing Solid Fuels	CO_2	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	T1
1.B.2.c.1.ii	Venting – Gas	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

21 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**[21]
IPPU			
2.A.1	Mineral Industry – Cement Production	CO_2	L1, T1
2.C.1	Metal Industry – Iron and Steel Production	CO_2	L1, T1
2.C.3	Metal Industry – Aluminium Production	CO_2	L1, T1
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	CH4	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, T1
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 Fertilizers	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, T1
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
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.A.2	Forest Land – Land Converted to Forest Land	N_2O	T1
4.B.1	Cropland – Cropland Remaining Cropland	CO_2	L1, T1
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) 2018 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): 2018					
CRF category code	**IPCC category**	**Gas**	**2018 estimate (kt CO_2-e)**	**Level assessment (%)**	**Cumulative total (%)**
4.A.2	Forest Land – Land Converted to Forest Land	CO_2	–15,594.2	14.1	14.1
1.A.3.b	Transport – Road Transportation Liquid Fuels	CO_2	14,956.5	13.5	27.5
3.A.1	Option A – Dairy Cattle	CH_4	13,611.6	12.3	39.8
4.G	Land Use, Land-Use Change and Forestry – Harvested Wood Products	CO_2	–10,746.7	9.7	49.5
3.A.2	Other (please specify) – Sheep	CH_4	8,390.1	7.6	57.1
3.A.1	Option A – Non-dairy Cattle	CH_4	5,402.2	4.9	61.9
3.D.1.3	Direct N_2O Emissions from Managed Soils – Urine and Dung Deposited by Grazing Animals	N_2O	3,824.2	3.4	65.4
5.A	Waste – Solid Waste Disposal	CH_4	3,651.8	3.3	68.7
4.C.2	Grassland – Land Converted to Grassland	CO_2	2,434.9	2.2	70.9
1.A.1.a	Energy Industries – Public Electricity and Heat Production Gaseous Fuels	CO_2	2,366.6	2.1	73.0
2.F.1	Product Uses as Substitutes for ODS – Refrigeration and Air Conditioning	HFCs	1,711.9	1.5	74.5
2.C.1	Metal Industry – Iron and Steel Production	CO_2	1,694.4	1.5	76.1
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Solid Fuels	CO_2	1,626.7	1.5	77.5
3.D.1.1	Direct N_2O Emissions From Managed Soils – Inorganic N Fertilizers	N_2O	1,411.3	1.3	78.8
4.A.1	Forest Land – Forest Land Remaining Forest Land	CO_2	–1,385.7	1.2	80.1
3.B.1.1	Option A – Dairy Cattle	CH_4	1,263.2	1.1	81.2
1.A.2.c	Manufacturing Industries and Construction – Chemicals Gaseous Fuels	CO_2	1,241.0	1.1	82.3
4.C.1	Grassland – Grassland Remaining Grassland	CO_2	1,175.2	1.1	83.4
1.A.3.a	Domestic Aviation – Jet Kerosene	CO_2	1,079.9	1.0	84.3
1.A.4.c	Other Sectors – Agriculture/Forestry/Fishing Liquid Fuels	CO_2	1,041.3	0.9	85.3
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Gaseous Fuels	CO_2	1,010.7	0.9	86.2
1.A.1.a	Energy Industries – Public Electricity and Heat Production Solid Fuels	CO_2	928.9	0.8	87.0
3.D.2.1	Indirect N_2O Emissions From Managed Soils – Atmospheric Deposition	N_2O	919.6	0.8	87.9
1.A.2.g.iii	Other (please specify) – Mining (excluding fuels) and Quarrying Liquid Fuels	CO_2	664.3	0.6	88.5
3.H	Agriculture – Urea Application	CO_2	608.2	0.5	89.0
1.B.2.d	Other (please specify) – Geothermal	CO_2	583.4	0.5	89.5
1.A.1.b	Energy Industries – Petroleum Refining Liquid Fuels	CO_2	579.7	0.5	90.1
2.C.3	Metal Industry – Aluminium Production	CO_2	554.9	0.5	90.6
3.D.2.2	Indirect N_2O Emissions from Managed Soils – Nitrogen Leaching and Run-off	N_2O	508.7	0.5	91.0
3.G	Agriculture – Liming	CO_2	494.9	0.4	91.5

(a) IPCC Tier 1 category level assessment – including LULUCF (net emissions): 2018					
CRF category code	**IPCC category**	**Gas**	**2018 estimate (kt CO_2-e)**	**Level assessment (%)**	**Cumulative total (%)**
3.A.4	Other Livestock – Deer	CH_4	488.0	0.4	91.9
1.A.4.a	Other Sectors – Commercial/Institutional Gaseous Fuels	CO_2	458.1	0.4	92.3
2.A.1	Mineral Industry – Cement Production	CO_2	418.0	0.4	92.7
1.A.2.d	Manufacturing Industries and Construction – Pulp, Paper and Print Gaseous Fuels	CO_2	376.7	0.3	93.0
1.A.4.b	Other Sectors – Residential Gaseous Fuels	CO_2	362.7	0.3	93.4
4.B.1	Cropland – Cropland Remaining Cropland	CO_2	333.6	0.3	93.7
1.B.2.c.1.ii	Venting – Gas	CO_2	287.0	0.3	93.9
1.A.2.f	Manufacturing Industries and Construction – Non-metallic Minerals Solid Fuels	CO_2	265.4	0.2	94.2
1.A.3.d	Domestic Navigation – Residual Fuel Oil	CO_2	265.0	0.2	94.4
1.A.4.a	Other Sectors – Commercial/Institutional Liquid Fuels	CO_2	260.9	0.2	94.6
1.A.1.c	Energy Industries – Manufacture of Solid Fuels and Other Energy Industries Gaseous Fuels	CO_2	257.3	0.2	94.9
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Liquid Fuels	CO_2	256.2	0.2	95.1

(b) IPCC Tier 1 category level assessment – excluding LULUCF (gross emissions): 2018					
CRF category code	**IPCC category**	**Gas**	**2018 estimate (kt CO_2-e)**	**Level assessment (%)**	**Cumulative total (%)**
1.A.3.b	Transport – Road Transportation Liquid Fuels	CO_2	14,956.5	19.0	19.0
3.A.1	Option A – Dairy Cattle	CH_4	13,611.6	17.3	36.2
3.A.2	Other (please specify) – Sheep	CH_4	8,390.1	10.6	46.9
3.A.1	Option A – Non-dairy Cattle	CH_4	5,402.2	6.9	53.7
3.D.1.3	Direct N_2O Emissions From Managed Soils – Urine and Dung Deposited by Grazing Animals	N_2O	3,824.2	4.8	58.6
5.A	Waste – Solid Waste Disposal	CH_4	3,651.8	4.6	63.2
1.A.1.a	Energy Industries – Public Electricity and Heat Production Gaseous Fuels	CO_2	2,366.6	3.0	66.2
2.F.1	Product Uses as Substitutes for ODS – Refrigeration and Air Conditioning	HFCs	1,711.9	2.2	68.4
2.C.1	Metal Industry – Iron and Steel Production	CO_2	1,694.4	2.1	70.5
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Solid Fuels	CO_2	1,626.7	2.1	72.6
3.D.1.1	Direct N_2O Emissions From Managed Soils – Inorganic N Fertilizers	N_2O	1,411.3	1.8	74.4
3.B.1.1	Option A – Dairy Cattle	CH_4	1,263.2	1.6	76.0
1.A.2.c	Manufacturing Industries and Construction – Chemicals Gaseous Fuels	CO_2	1,241.0	1.6	77.5
1.A.3.a	Domestic Aviation – Jet Kerosene	CO_2	1,079.9	1.4	78.9
1.A.4.c	Other Sectors – Agriculture/Forestry/Fishing Liquid Fuels	CO_2	1,041.3	1.3	80.2
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Gaseous Fuels	CO_2	1,010.7	1.3	81.5
1.A.1.a	Energy Industries – Public Electricity and Heat Production Solid Fuels	CO_2	928.9	1.2	82.7

(b) IPCC Tier 1 category level assessment – excluding LULUCF (gross emissions): 2018					
CRF category code	IPCC category	Gas	2018 estimate (kt CO_2-e)	Level assessment (%)	Cumulative total (%)
3.D.2.1	Indirect N_2O Emissions From Managed Soils – Atmospheric Deposition	N_2O	919.6	1.2	83.9
1.A.2.g.iii	Other (please specify) – Mining (excluding fuels) and Quarrying Liquid Fuels	CO_2	664.3	0.8	84.7
3.H	Agriculture – Urea Application	CO_2	608.2	0.8	85.5
1.B.2.d	Other (please specify) – Geothermal	CO_2	583.4	0.7	86.2
1.A.1.b	Energy Industries – Petroleum Refining Liquid Fuels	CO_2	579.7	0.7	86.9
2.C.3	Metal Industry – Aluminium Production	CO_2	554.9	0.7	87.6
3.D.2.2	Indirect N_2O Emissions from Managed Soils – Nitrogen Leaching and Run-off	N_2O	508.7	0.6	88.3
3.G	Agriculture – Liming	CO_2	494.9	0.6	88.9
3.A.4	Other Livestock – Deer	CH_4	488.0	0.6	89.5
1.A.4.a	Other Sectors – Commercial/Institutional Gaseous Fuels	CO_2	458.1	0.6	90.1
2.A.1	Mineral Industry – Cement Production	CO_2	418.0	0.5	90.7
1.A.2.d	Manufacturing Industries and Construction – Pulp, Paper and Print Gaseous Fuels	CO_2	376.7	0.5	91.1
1.A.4.b	Other Sectors – Residential Gaseous Fuels	CO_2	362.7	0.5	91.6
1.B.2.c.1.ii	Venting – Gas	CO_2	287.0	0.4	92.0
1.A.2.f	Manufacturing Industries and Construction – Non-metallic Minerals Solid Fuels	CO_2	265.4	0.3	92.3
1.A.3.d	Domestic Navigation – Residual Fuel Oil	CO_2	265.0	0.3	92.6
1.A.4.a	Other Sectors – Commercial/Institutional Liquid Fuels	CO_2	260.9	0.3	93.0
1.A.1.c	Energy Industries – Manufacture of Solid Fuels and Other Energy Industries Gaseous Fuels	CO_2	257.3	0.3	93.3
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Liquid Fuels	CO_2	256.2	0.3	93.6
3.D.1.4	Direct N_2O Emissions From Managed Soils – Crop Residues	N_2O	253.2	0.3	93.9
5.D	Waste – Wastewater Treatment and Discharge	CH_4	246.4	0.3	94.2
1.A.4.b	Other Sectors – Residential Liquid Fuels	CO_2	218.1	0.3	94.5
1.A.2.g.viii	Other (please specify) – Other (please specify) Liquid Fuels	CO_2	208.4	0.3	94.8
1.A.1.b	Energy Industries – Petroleum Refining Gaseous Fuels	CO_2	206.5	0.3	95.0

Table 1.5.3(a & b) 1990–2018 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)	2018 estimate (kt CO_2-e)	Trend assessment	Absolute contribution to trend (%)	Absolute cumulative total (%)
3.A.2	Other (please specify) – Sheep	CH_4	14,172.1	8,390.1	0.147	19.5	19.5
4.G	Land Use, Land-Use Change and Forestry – Harvested Wood Products	CO_2	–2,072.9	–10,746.7	0.105	13.8	33.3
4.A.2	Forest Land – Land Converted to Forest Land	CO_2	–19,598.9	–15,594.2	0.076	10.1	43.4
3.A.1	Option A – Dairy Cattle	CH_4	5,940.0	13,611.6	0.045	6.0	49.4
1.A.3.b	Transport – Road Transportation Liquid Fuels	CO_2	7,164.6	14,956.5	0.039	5.2	54.6

(a) IPCC Tier 1 category trend assessment – including LULUCF (net emissions)							
CRF category code	**IPCC category**	**Gas**	**1990 estimate (kt CO_2-e)**	**2018 estimate (kt CO_2-e)**	**Trend assessment**	**Absolute contribution to trend (%)**	**Absolute cumulative total (%)**
3.A.1	Option A – Non-dairy Cattle	CH_4	5,754.7	5,402.2	0.039	5.1	59.7
1.A.1.c	Energy Industries – Manufacture of Solid Fuels and Other Energy Industries Gaseous Fuels	CO_2	1,720.1	257.3	0.026	3.4	63.1
1.A.1.a	Energy Industries – Public Electricity and Heat Production Gaseous Fuels	CO_2	3,011.8	2,366.6	0.025	3.3	66.4
5.A	Waste – Solid Waste Disposal	CH_4	3,711.1	3,651.8	0.023	3.1	69.5
4.C.2	Grassland – Land Converted to Grassland	CO_2	253.4	2,434.9	0.022	2.9	72.3
4.A.1	Forest Land – Forest Land Remaining Forest Land	CO_2	−7,515.6	−1,385.7	0.019	2.6	74.9
2.C.3	Metal Industry – Aluminium Production	PFCs	909.9	72.4	0.014	1.9	76.8
4.C.1	Grassland – Grassland Remaining Grassland	CO_2	−216.1	1,175.2	0.013	1.8	78.6
1.A.2.g.viii	Other (please specify) – Other (please specify) Solid Fuels	CO_2	731.1	51.4	0.012	1.5	80.1
3.D.1.1	Direct N_2O Emissions From Managed Soils – Inorganic N Fertilizers	N_2O	230.3	1,411.3	0.011	1.5	81.6
3.D.1.3	Direct N_2O Emissions From Managed Soils – Urine and Dung Deposited by Grazing Animals	N_2O	2,926.9	3,824.2	0.008	1.1	82.7
3.B.1.1	Option A – Dairy Cattle	CH_4	376.8	1,263.2	0.007	0.9	83.6
1.A.1.b	Energy Industries – Petroleum Refining Liquid Fuels	CO_2	778.9	579.7	0.007	0.9	84.5
1.A.4.c	Other Sectors – Agriculture/ Forestry/Fishing Liquid Fuels	CO_2	1,072.3	1,041.3	0.007	0.9	85.4
3.H	Agriculture – Urea Application	CO_2	39.2	608.2	0.006	0.8	86.2
1.A.4.a	Other Sectors – Commercial/ Institutional Liquid Fuels	CO_2	500.6	260.9	0.006	0.7	86.9
1.A.4.b	Other Sectors – Residential Solid Fuels	CO_2	344.9	27.0	0.005	0.7	87.7
1.A.2.c	Manufacturing Industries and Construction – Chemicals Gaseous Fuels	CO_2	528.7	1,241.0	0.004	0.6	88.2
1.B.1.a.1	Coal Mining and Handling – Underground Mines	CH_4	289.6	59.7	0.004	0.6	88.8
2.C.1	Metal Industry – Iron and Steel Production	CO_2	1,306.7	1,694.4	0.004	0.5	89.3
1.A.2.f	Manufacturing Industries and Construction – Non-metallic Minerals Solid Fuels	CO_2	382.9	265.4	0.004	0.5	89.8
1.A.3.a	Domestic Aviation – Jet Kerosene	CO_2	892.6	1,079.9	0.003	0.5	90.2
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Gaseous Fuels	CO_2	445.1	1,010.7	0.003	0.4	90.6
3.A.4	Other Livestock – Goats	CH_4	196.6	19.9	0.003	0.4	91.1
2.A.1	Mineral Industry – Cement Production	CO_2	448.7	418.0	0.003	0.4	91.5
1.B.2.b.5	Natural Gas – Distribution	CH_4	277.5	203.0	0.002	0.3	91.8

(a) IPCC Tier 1 category trend assessment – including LULUCF (net emissions)							
CRF category code	IPCC category	Gas	1990 estimate (kt CO_2-e)	2018 estimate (kt CO_2-e)	Trend assessment	Absolute contribution to trend (%)	Absolute cumulative total (%)
4.B.1	Cropland – Cropland Remaining Cropland	CO_2	357.8	333.6	0.002	0.3	92.1
1.B.2.d	Other (please specify) – Geothermal	CO_2	228.6	583.4	0.002	0.3	92.4
1.A.3.b	Transport – Road Transportation Gaseous Fuels	CO_2	140.8	0.0	0.002	0.3	92.7
3.A.4	Other Livestock – Deer	CH_4	432.7	488.0	0.002	0.3	93.0
3.D.2.1	Indirect N_2O Emissions From Managed Soils – Atmospheric Deposition	N_2O	704.9	919.6	0.002	0.3	93.3
1.A.1.a	Energy Industries – Public Electricity and Heat Production Solid Fuels	CO_2	474.8	928.9	0.002	0.3	93.5
1.A.2.d	Manufacturing Industries and Construction – Pulp, Paper and Print Gaseous Fuels	CO_2	348.9	376.7	0.002	0.2	93.8
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Liquid Fuels	CO_2	265.1	256.2	0.002	0.2	94.0
1.A.4.a	Other Sectors – Commercial/ Institutional Solid Fuels	CO_2	142.2	68.7	0.002	0.2	94.2
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Solid Fuels	CO_2	938.6	1,626.7	0.002	0.2	94.4
2.C.3	Metal Industry – Aluminium Production	CO_2	449.0	554.9	0.002	0.2	94.6
1.A.2.g.iii	Other (please specify) – Mining (excluding fuels) and Quarrying Liquid Fuels	CO_2	331.5	664.3	0.002	0.2	94.8
4.A.2	Forest Land – Land Converted to Forest Land	N_2O	124.6	53.1	0.002	0.2	95.0

(b) IPCC Tier 1 category trend assessment – excluding LULUCF (gross emissions)							
CRF category code	IPCC category	Gas	1990 estimate (kt CO_2-e)	2018 estimate (kt CO_2-e)	Trend assessment	Absolute contributio n to trend (%)	Absolute cumulative total (%)
3.A.2	Other (please specify) – Sheep	CH_4	14,172.1	8,390.1	0.094	21.8	21.8
3.A.1	Option A – Dairy Cattle	CH_4	5,940.0	13,611.6	0.064	14.8	36.6
1.A.3.b	Transport – Road Transportation Liquid Fuels	CO_2	7,164.6	14,956.5	0.062	14.4	51.0
1.A.1.c	Energy Industries – Manufacture of Solid Fuels and Other Energy Industries Gaseous Fuels	CO_2	1,720.1	257.3	0.019	4.5	55.5
3.A.1	Option A – Non-dairy Cattle	CH_4	5,754.7	5,402.2	0.018	4.1	59.6
2.F.1	Product Uses as Substitutes for ODS – Refrigeration and Air Conditioning	HFCs	0.0	1,711.9	0.018	4.1	63.6
1.A.1.a	Energy Industries – Public Electricity and Heat Production Gaseous Fuels	CO_2	3,011.8	2,366.6	0.014	3.2	66.9
3.D.1.1	Direct N_2O Emissions From Managed Soils – Inorganic N Fertilizers	N_2O	230.3	1,411.3	0.012	2.7	69.6

(b) IPCC Tier 1 category trend assessment – excluding LULUCF (gross emissions)							
CRF category code	IPCC category	Gas	1990 estimate (kt CO_2-e)	2018 estimate (kt CO_2-e)	Trend assessment	Absolute contribution to trend (%)	Absolute cumulative total (%)
2.C.3	Metal Industry – Aluminium Production	PFCs	909.9	72.4	0.011	2.5	72.1
5.A	Waste – Solid Waste Disposal	CH_4	3,711.1	3,651.8	0.010	2.3	74.3
1.A.2.g.viii	Other (please specify) – Other (please specify) Solid Fuels	CO_2	731.1	51.4	0.009	2.0	76.4
3.B.1.1	Option A – Dairy Cattle	CH_4	376.8	1,263.2	0.008	1.9	78.2
1.A.2.c	Manufacturing Industries and Construction – Chemicals Gaseous Fuels	CO_2	528.7	1,241.0	0.006	1.4	79.6
3.H	Agriculture – Urea Application	CO_2	39.2	608.2	0.006	1.3	81.0
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Solid Fuels	CO_2	938.6	1,626.7	0.005	1.1	82.1
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Gaseous Fuels	CO_2	445.1	1,010.7	0.005	1.1	83.1
1.A.4.b	Other Sectors – Residential Solid Fuels	CO_2	344.9	27.0	0.004	1.0	84.1
1.A.1.b	Energy Industries – Petroleum Refining Liquid Fuels	CO_2	778.9	579.7	0.004	0.9	85.0
1.A.4.a	Other Sectors – Commercial/Institutional Liquid Fuels	CO_2	500.6	260.9	0.004	0.9	85.9
1.A.1.a	Energy Industries – Public Electricity and Heat Production Solid Fuels	CO_2	474.8	928.9	0.003	0.8	86.7
1.B.2.d	Other (please specify) – Geothermal	CO_2	228.6	583.4	0.003	0.7	87.4
1.B.1.a.1	Coal Mining and Handling – Underground Mines	CH_4	289.6	59.7	0.003	0.7	88.1
1.A.4.c	Other Sectors – Agriculture/Forestry/Fishing Liquid Fuels	CO_2	1,072.3	1,041.3	0.003	0.7	88.8
1.A.2.g.iii	Other (please specify) – Mining (excluding fuels) and Quarrying Liquid Fuels	CO_2	331.5	664.3	0.003	0.6	89.4
3.A.4	Other livestock – Goats	CH_4	196.6	19.9	0.002	0.5	89.9
1.A.2.f	Manufacturing Industries and Construction – Non-metallic Minerals Solid Fuels	CO_2	382.9	265.4	0.002	0.5	90.4
1.A.1.b	Energy Industries – Petroleum Refining Gaseous Fuels	CO_2	0.0	206.5	0.002	0.5	90.9
3.D.1.3	Direct N_2O Emissions From Managed Soils – Urine and Dung Deposited by Grazing Animals	N_2O	2,926.9	3,824.2	0.002	0.5	91.4
1.A.3.b	Transport – Road Transportation Gaseous Fuels	CO_2	140.8	0.0	0.002	0.4	91.8
1.A.4.a	Other Sectors – Commercial/Institutional Gaseous Fuels	CO_2	236.1	458.1	0.002	0.4	92.2
1.B.2.c.1.ii	Venting – Gas	CO_2	109.3	287.0	0.002	0.4	92.5

(b) IPCC Tier 1 category trend assessment – excluding LULUCF (gross emissions)							
CRF category code	**IPCC category**	**Gas**	**1990 estimate (kt CO_2-e)**	**2018 estimate (kt CO_2-e)**	**Trend assessment**	**Absolute contribution to trend (%)**	**Absolute cumulative total (%)**
1.A.2.g.viii	Other (please specify) – Other (please specify) Liquid Fuels	CO_2	51.5	208.4	0.001	0.3	92.9
1.B.2.b.5	Natural Gas – Distribution	CH_4	277.5	203.0	0.001	0.3	93.2
1.A.4.c	Other Sectors – Agriculture/ Forestry/Fishing Solid Fuels	CO_2	35.1	182.2	0.001	0.3	93.5
2.A.1	Mineral Industry – Cement Production	CO_2	448.7	418.0	0.001	0.3	93.9
1.A.4.b	Other Sectors – Residential Gaseous Fuels	CO_2	185.6	362.7	0.001	0.3	94.2
1.A.4.a	Other Sectors – Commercial/ Institutional Solid Fuels	CO_2	142.2	68.7	0.001	0.3	94.4
1.A.2.d	Manufacturing Industries and Construction – Pulp, Paper and Print Solid Fuels	CO_2	109.5	38.4	0.001	0.2	94.7
2.F.4	Product Uses as Substitutes for ODS – Aerosols	HFCs	0.0	95.6	0.001	0.2	94.9
1.B.2.d	Other (please specify) – Geothermal	CH_4	54.8	153.4	0.001	0.2	95.1

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 2018, *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). Uncertainties for the source categories were originally determined at the lowest level where information and data were available. The uncertainty estimates within each sector were made by the personnel at the agencies responsible for the sector, which is a part of New Zealand's national system arrangements.

The low level uncertainties have then been aggregated by the sector compiling agencies up to the second level category for each of CO_2, CH_4, N_2O and SF_6 separately, and HFCs and PFCs as groups. These aggregated category level data have been submitted to the National Inventory Compiler for performing overall uncertainty calculations for level and trend uncertainties for gross and net emissions (excluding and including LULUCF).

In most cases, to aggregate uncertainties from subcategories, sectoral compilers used the approach 1 recommended in the 2006 IPCC Guidelines (equation 3.2, page 3.28).

In the IPPU sector (for the ODS category only), the emissions are estimated using a mass balance approach as indicated in chapter 4. This approach uses the data on imports of each gas as the total for all applications for an input. In this calculation, it would not be appropriate to combine the uncertainties for subcategories using the propagation method because they are not independent variables and, therefore, an expert judgement on the bulk value of HFCs was used.

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.

In the LULUCF sector, uncertainties were combined and aggregated using the error propagation procedure outlined in approach 1 for the 2006 IPCC Guidelines (equation 3.1 and equation 3.2, page 3.28). These uncertainties take into account natural variability, measurement error, and model prediction error. 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 chapter 6. Further detailed analysis of LULUCF uncertainties is presented in annex 3.2.3.

Gross emissions

Uncertainty in 2018

The uncertainty in gross emissions (excluding emissions and removals from the LULUCF sector) is ±9.0 per cent. This is a decrease of 0.3 percentage points from 2017. Emissions of CH_4 from *Enteric fermentation* (±16.0 per cent), N_2O from *Agricultural soils* (± 56.4 per cent) and CH_4 from *Solid waste disposal* (±100.3 per cent) categories had the highest levels of emissions uncertainty, contributing 5.7 per cent, 5.0 per cent and 4.6 per cent to the overall uncertainty of gross emissions in 2018. The uncertainty in these categories reflects the inherent variability when estimating emissions from natural systems.

Uncertainty in 1990

In 1990, the uncertainty in gross emissions was 9.8 per cent. Emissions of CH_4 from *Enteric fermentation* and *Solid waste disposal*, and N_2O from *Agricultural soils* contributed with 6.7 per cent, 5.9 per cent and 4.0 per cent respectively to the overall uncertainty of gross emissions in 1990.

Uncertainty in the trend

The trend uncertainty in gross emissions (excluding emissions and removals from the LULUCF sector) from 1990 to 2018 is ±8.5 per cent. This is an increase of 0.3 percentage points from 2017. The increase in trend uncertainty is a result of a net increase in activity data uncertainties for the Energy sector.

Net emissions

Uncertainty in 2018

The uncertainty for New Zealand's inventory, including emissions and removals from the LULUCF sector, in 2018 is ±12.1 per cent, an increase of 1.5 percentage points from 2017. This increase is mainly due to the correction of an error in the uncertainties for *Forest land*. Emissions of CO_2 from *Forest land* (±50.8 per cent), CO_2 from *Harvested wood products* (±69.0 per cent) and CH_4 from *Enteric fermentation* (±16.0 per cent) categories had the highest levels of net uncertainty for 2018, at 7.8 per cent, 6.7 per cent and 4.0 per cent of the overall uncertainty in the net emissions.

Uncertainty in 1990

In 1990, the uncertainty in net emissions was 16.2 per cent. Emissions of CO_2 from *Forest Land* and CH_4 from *Enteric Fermentation* and *Solid waste disposal* contributed with 14.7 per cent, 4.5 per cent and 4.0 per cent respectively to the overall uncertainty of net emissions in 1990.

Uncertainty in the trend

When emissions and removals from the LULUCF sector are included, the overall uncertainty in the trend from 1990 to 2018 is ±12.0 per cent. This is an increase of 3.7 percentage points from 2017. Updated uncertainty estimates for activity data in the Energy and LULUCF sectors and emission factors in the LULUCF sector 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 2018 is ±15.2 per cent. The uncertainty for net emissions from the *Deforestation* category in 2018 is ±2.3 per cent. The uncertainty for net emissions from the *Forest management* category in 2018 is ±53.9 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 ±56.0 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 2018 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 paragraph 37(b) of the UNFCCC reporting guidelines (UNFCCC, 2013b) is presented in annex 6.2.

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 (the 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 for CP1 (covering the five-year period 2008 to 2012).

The commitment period reserve for CP1 of 278,608,260 metric tonnes CO_2-e is 90 per cent of the assigned amount. The value of the commitment reserve for CP1 was fixed after the initial review in 2007. The number of units held in the national registry during CP1 could not fall below this amount.

At the end of the CP1 of the Kyoto Protocol, New Zealand retired Kyoto Protocol 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. As such, New Zealand has no assigned amount for CP2; however, New Zealand has chosen to maintain a registry connected to the International Transaction Log. This is required because the Register continues to hold Kyoto Protocol units, and these are required to be able to be reconciled via the International Transaction Log. New Zealand has also committed to apply the Kyoto Protocol accounting approach for the period 2013 to 2020 (the period covered by CP2).

Although most international unit transfers of Kyoto Protocol 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 New Zealand's national inventory reporting. Also, changes to international trading may occur after CP2 ends and new arrangements for international trading under the Paris Agreement come into effect.

New Zealand replaced its registry system in August 2016. The new Register was tested and reviewed by the UNFCCC secretariat prior to it going live.

At the beginning of the 2019 calendar year, 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 2019 were the same as at the beginning of 2019, 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 2019.

New Zealand's national registry did not hold any temporary certified emission reduction units or long-term certified emission reduction units during 2019.

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

1.9 New Zealand's Emissions Trading Scheme

The NZ ETS is the Government's main tool for reducing greenhouse gas emissions. The following sections explain the background of the NZ ETS and how the data collected for the NZ ETS have been used to verify CO_2 emissions in the Energy and IPPU sectors.

1.9.1 New Zealand Units

The NZ ETS is based on trading units that represent 1 tonne of CO_2-e, called a New Zealand Unit (NZU), which is created and distributed by the New Zealand Government. The scheme was established through the Climate Change Response Act 2002 and came into effect progressively from 2008, with coverage since 2010 of all emissions except agricultural methane and nitrous oxide. Sectors under the scheme are required to report on their emissions and surrender units to the Government to cover their emissions. The Government supplies units for emissions removals through forestry and exports of emitting products from New Zealand. The emissions price is then determined by the market, based on supply and demand of units, and this price creates a financial incentive for businesses that emit greenhouse gases to invest in technologies and practices that reduce emissions.

1.9.2 Verification

NZ ETS participants are required to record and report the GHG 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
- methodologies
- 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 year 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.

Energy

No significant improvements have been introduced for the 2020 inventory submission. Projects to implement improvements for the reference approach and sectoral approach are ongoing, and results will be reported in the 2021 submission.

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 this submission, emissions from refrigeration and air conditioning for 2013 to 2017 have been recalculated to better account for fluctuations in import volumes and refrigerant stockpiled by importers.

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

Agriculture

New Zealand has improved Agriculture sector emissions information in this submission through:

- use of new N_2O emission factors from animal excreta ($EF_{3,PRP}$), which are now split by livestock type and hill slope, and are applied using a new model that calculates the amount of livestock excreta deposited onto different slopes (low, medium and steep). This improvement to emission calculation affected emissions from dairy cattle, non-dairy cattle, sheep and deer in the *Agricultural soils* category. The MPI Agricultural Advisory Panel has recommended this improvement as a result of extensive research conducted over the past decade. Further detail on this improvement can be found in chapter 5, section 5.5.5, chapter 10, section 10.1.3 and annex 3.
- use of revised activity data for the proportion of dairy goats in the overall farmed goat population, to reflect recent research. This improvement affected emissions from goats in the *Enteric Fermentation* and *Agricultural soils* categories. Further detail on this improvement can be found in chapter 5, section 5.1.5 and chapter 10, section 10.1.3.
- minor improvements to the equations used to estimate energy efficiency for maintenance (k_m) for beef cattle, sheep and deer, which is used to help calculate energy requirements, intake, and nitrogen excretion. These minor improvements included the specification of a constant to more significant figures and reverting to the IPCC default value for the gross energy content of feed of 18.45 megajoules per kilogram of dry matter (MJ/kg DM). The combined improvements had only a small effect on estimated emissions in the *Enteric fermentation*, *Manure management* and *Agricultural soils* categories because of the insignificance of the change from the previous values of 18.40 MJ/kg DM for cattle and deer and 18.50 MJ/kg DM for sheep. Further detail on this improvement can be found in chapter 5, sections 5.1.5 and 5.3.5 and chapter 10, section 10.1.3.

The MPI Agriculture Inventory Advisory Panel met on 29 October 2019 and recommended that these proposed improvements be incorporated in the 2020 inventory submission. The Deputy Director-General, Policy and Trade at MPI approved these improvements for inclusion in the inventory.

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):

- a revised analysis of the pre-1990 natural forest plot data, which was undertaken for the 2020 submission (Paul and Kimberley, unpublished). This resulted in a significant reduction in the estimate for carbon stock change in the regenerating component of pre-1990 natural forest, compared with the previous submission. Details of the revised analysis and the drivers of this reduction can be found in chapter 6, section 6.4.5, under Forest land
- revision of the post-1989 planted forest yield table for the 2020 submission. The revised yield table uses data from the annual national forest inventories of 2016, 2017 and 2018 and previous periodic national forest inventories between 2007 and 2015. The analysis of the data collected has provided a plot-based estimate of carbon stock and mean carbon density within this forest type, which leads to more accurate estimates.

Chapter 6, 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

Minor 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 responses to issues found during reviews of previous submissions. Due to these changes, emissions in the Waste sector have increased by 5.8 kt CO_2-e (0.1 per cent) in 1990 and decreased by 32.1 kt CO_2-e (0.8 per cent) in 2017.

The most significant changes to emissions have been made to the *Unmanaged waste disposal sites* category and have resulted in the largest recalculation for the waste sector. This has decreased emissions from this category by 0.3 kt CO_2-e (0.0 per cent) in 1990 and decreased emissions by 25.2 kt CO_2-e (1.1 per cent) in 2017. This change is the result of corrections made to the calculations.

In addition, several other minor improvements and corrections have been made to this and other categories in the Waste sector. Further details can be found in chapter 7 (waste) and also in chapter 10 (improvements and recalculations) section 10.1.5.

Other sector (Tokelau)

Significant changes and improvements have been made in the Tokelau emission estimates since the 2019 submission. These improvements are a combination of refinements as a result of historic information coming to hand (for electricity in 2004 and for transport 1990–2014); improved fuel calculations (based on a full year rather than 9 months; estimated number of roundtrips Apia–Tokelau during 1990–2014; average fuel use per trip), and the correction of errors including to the number of pigs. Improvements and recalculations made for the Tokelau sector have resulted in a 13 per cent (0.5 kt CO_2-e) decrease in emissions in 1990 and a 22.9 per cent (0.7 kt CO_2-e) increase in emissions in 2017.

The previously reported decrease of on-island diesel use of 80 per cent in 2012 negated an increase of 400 per cent in 2004, when Tokelau households and public sector got access to electric power for 24 hours a day, 7 days a week. Until then, electricity had been available to households only between 6 pm and 10 pm, a major quality of life aspect.

Several other improvements and minor corrections have been made to all categories, in the process of automating the calculation of Tokelau's emissions using a model developed in an Excel spreadsheet, based on the IPPC reporting framework. It requires annual updates of input data such as fuel purchases, number of voyages (roundtrips Apia–Tokelau, inter-island trips) and five yearly Census data to be input into a single worksheet.

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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). Gross emissions include emissions from Tokelau.

1990–2018

In 1990, New Zealand's gross GHG emissions were 63,590.9 kilotonnes of carbon dioxide equivalent (kt CO_2-e). Between 1990 and 2018, gross GHG emissions increased by 15,271.4 kt CO_2-e (24.0 per cent) to 78,862.3 kt CO_2-e in 2018 (figure 2.1.1). From 1990 to 2018, 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*[22] *from dairy cattle*, *Road transportation*, *Agricultural soils*, *Product uses as substitutes for ODS*[23] and *Manufacturing industries and construction* (especially the categories *Chemicals* and *Food processing, beverages and tobacco*).

2017–2018

New Zealand's gross emissions between 2017 and 2018 decreased by 778.6 kt CO_2-e (1.0 per cent), which was mainly driven by a decrease in emissions from the Energy sector (1,058.4 kt CO_2-e or 3.2 per cent). This was mainly attributed to decreases in CO_2 emissions from the *Manufacturing industries and construction* category and the *Public electricity and heat production* category. The decrease in emissions from *Manufacturing industries and construction* was largely due to outages at the Pohokura natural gas field, which saw a 34 per cent production drop between 2017 and 2018 levels.[24] The decrease in emissions from the *Public electricity and heat production* category was primarily due to a decrease in natural gas-fired generation in response to higher levels of hydro generation.

Emissions from the Agriculture, IPPU and Waste sectors did not show significant changes beyond small annual variations below 1 per cent.

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

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22 Methane emissions produced from the digestive process in ruminant livestock.

23 'ODS' stands for ozone depleting substances.

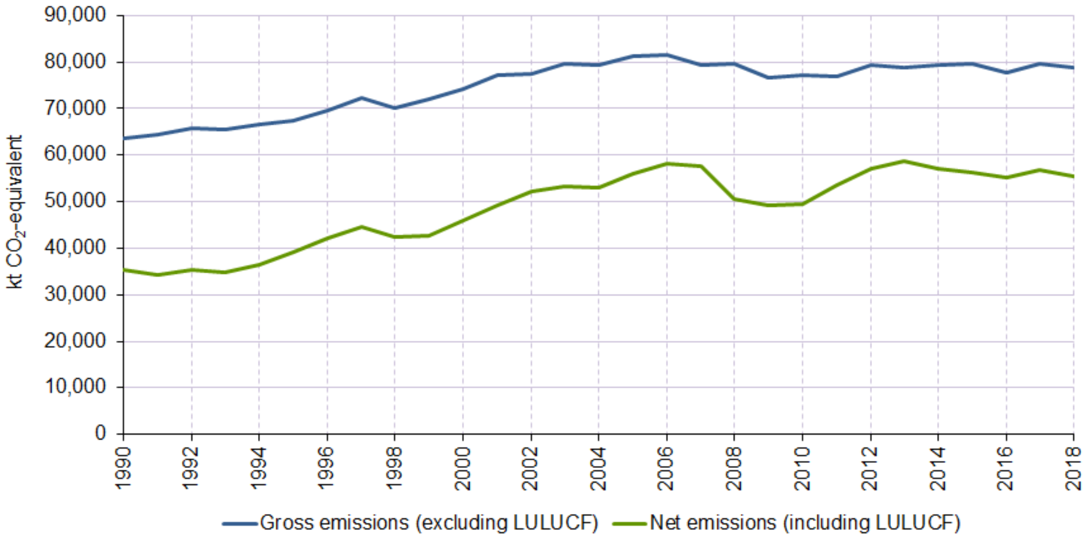
24 See *Energy in New Zealand* (Ministry of Business, Innovation and Employment, 2019) page 54, for further information.

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 35,293.9 kt CO_2-e. Between 1990 and 2018, net GHG emissions increased by 20,174.3 kt CO_2-e (57.2 per cent) to 55,468.2 kt CO_2-e (figure 2.1.1). The four categories that contributed the most to the increase in net emissions between 1990 and 2018 were *Enteric fermentation from dairy cattle*, *Road transportation*, *Land remaining forest land* and *Land converted to forest land*.

Figure 2.1.1 New Zealand's gross and net emissions (under the Convention) from 1990 to 2018



Accounting for New Zealand's 2020 target

For the period 2013 to 2020, New Zealand has taken a quantified economy-wide emissions reduction target under the Convention to reduce emissions to 5 per cent below 1990 levels by 2020.[25]

New Zealand's emissions budget for the period 2013 to 2020 is 509,774,982 tonnes CO_2-e.[26] This is 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 calculated as the emissions New Zealand would have on a straight-line track from a 1990 level in 2010 (equal to gross emissions in 1990 from the Initial Report) to the target (i.e., the same amount multiplied by 0.95).

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.

25 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 to its target, to ensure New Zealand's actions are transparent and have integrity.

26 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).

For the period so far (2013 to 2018), New Zealand's gross emissions sum to 473,874.9 kt CO_2-e. The contribution towards New Zealand's target from LULUCF activities under the Kyoto Protocol is a net removal of 81,829.3 kt CO_2-e. This comprises net removals of 107,090.2 kt CO_2-e from *Afforestation and reforestation* less emissions of 24,607.0 kt CO_2-e from *Deforestation* (see section 2.3 for further detail).

The accounting rules for the LULUCF activities 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.[27]

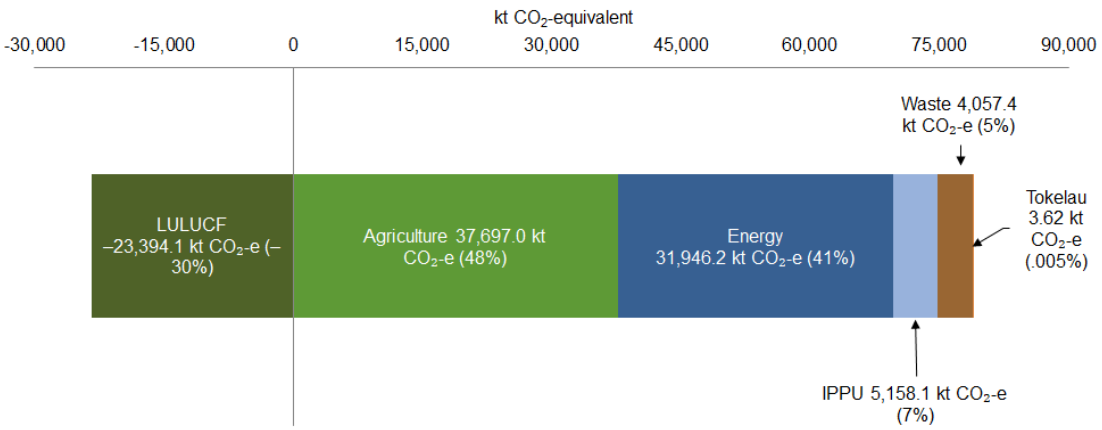
2.2 Emission trends by sector

As per the UNFCCC reporting guidelines, New Zealand reports emissions and removals for the following sectors: Energy, IPPU, Agriculture, LULUCF, and Waste. To this, New Zealand adds emissions from Tokelau, reported as New Zealand's 'Other' sector.

2.2.1 New Zealand's emissions by sector and by gas in 2018

New Zealand's emissions by sector reflect the composition of the national economy. The Agriculture sector was the source of 47.8 per cent of New Zealand's gross emissions in 2018. New Zealand's Energy sector contributed 40.5 per cent to the national gross emissions, while the IPPU and Waste sectors contributed 6.5 per cent and 5.1 per cent respectively (figure 2.2.1). The Other sector (Tokelau) contributed 0.005 per cent to the national gross emissions. The LULUCF sector currently represents a sink with a net removals value of –23,394.1 kt CO_2-e. This offsets 29.7 per cent of New Zealand's gross emissions.

Figure 2.2.1 New Zealand's emissions by sector in 2018

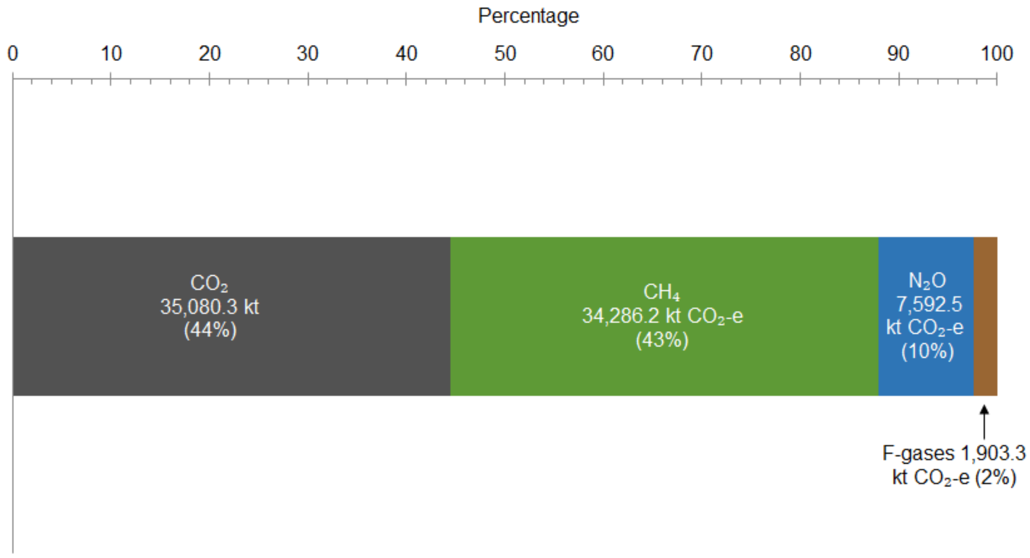


Note: The percentages may not add up to 100 per cent due to rounding.

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

[27] 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 2.2.2 New Zealand's gross emissions by gas in 2018



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 44.5 per cent to New Zealand's gross emissions (35,080.3 kt CO_2) (figure 2.2.2). The Energy sector produces the largest amount of CO_2, at 30,890.6 kt (88.1 per cent of New Zealand's CO_2 emissions in 2018). The categories contributing most to CO_2 emissions in the Energy sector are *Transport* (16,484.0 kt CO_2, 47.0 per cent of New Zealand's CO_2 emissions) and *Manufacturing industries and construction* (6,280.0 kt CO_2, 17.9 per cent of New Zealand's CO_2 emissions). In 2018, the LULUCF sector was a CO_2 sink, sequestering 23,568.6 kt CO_2 (67.2 per cent) of CO_2 emissions. This resulted in net CO_2 emissions of 11,511.7 kt in 2018.

The amount of methane (CH_4) emitted in New Zealand in 2018 (measured as CO_2-e) is 43.5 per cent of gross emissions (34,286.2 kt CO_2-e). Nitrous oxide (N_2O), at 9.6 per cent (7,592.5 kt CO_2-e), is the third-largest component of New Zealand's gross emissions. The Agriculture sector produces the largest amounts of both CH_4 and N_2O. In 2018, the contributions of the Agriculture sector to national emissions of CH_4 and N_2O were 85.9 per cent and 94.2 per cent respectively. The major source of CH_4 in the Agriculture sector is *Enteric fermentation* (27,939.0 kt CO_2-e, 81.5 per cent of New Zealand's gross CH_4 emissions). Emissions from the *Agricultural soils* category (from adding nitrogen to soil, for example, manure or fertiliser) are the largest source of gross N_2O emissions (7,026.3 kt CO_2-e, 92.5 per cent of national N_2O emissions).

Methane is also the largest component of the Waste sector emissions, contributing 3,921.6 kt CO_2-e, or 11.4 per cent, of gross CH_4 emissions.

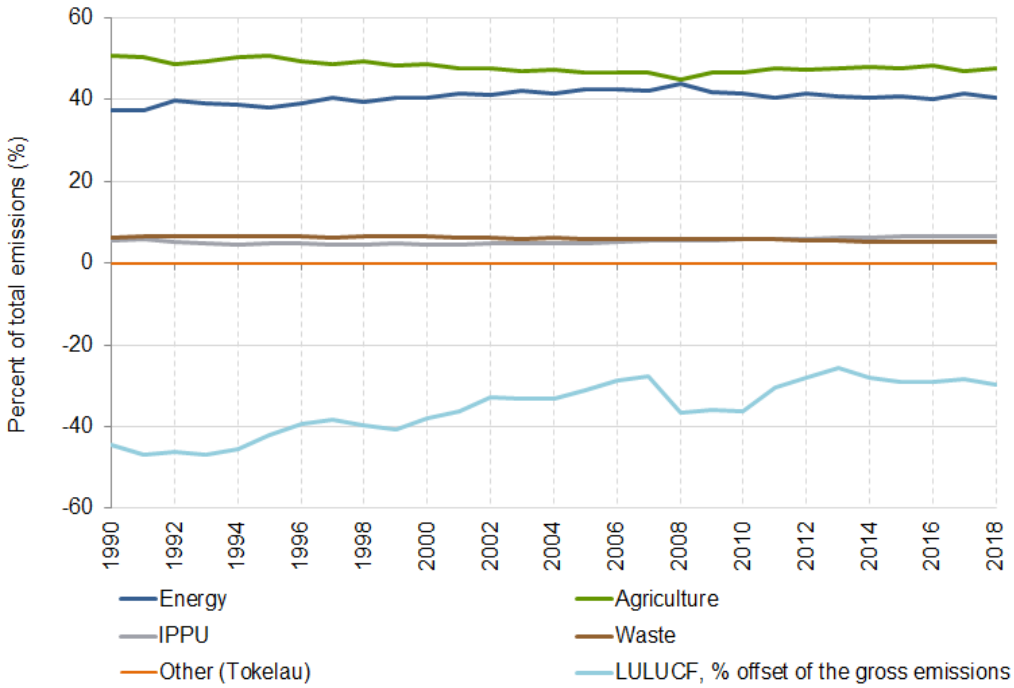
Fluorinated gases (hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6))[28] collectively contribute 2.4 per cent to New Zealand's gross emissions. The IPPU sector is the only source of fluorinated gases in New Zealand. Taken together, the emissions of HFCs, PFCs and SF_6 were 1,903.3 kt CO_2-e in 2018. No manufacture of any of the fluorinated greenhouse gases occurs in New Zealand; they are all imported. Emissions of fluorinated gases are dominated by HFCs (95.4 per cent of all fluorinated gases). The PFCs and SF_6 contribute 3.8 per cent and 0.8 per cent to total emissions of fluorinated gases respectively. Almost all PFCs (99.99 per cent) are released during aluminium production.

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

2.2.2 Emission trends by sector from 1990 to 2018

Throughout the time series 1990 to 2018, the Agriculture and Energy sectors dominate New Zealand's gross emissions, together producing almost 90 per cent of New Zealand's gross GHG emissions from 1990 to 2018. The IPPU and Waste sectors show relatively small contributions of GHGs to total gross emissions from 1990 to 2018. The total amount of annual emissions from each of these sectors ranged between 4 per cent and 7 per cent 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 to 2018 period. Table 2.2.1 and figure 2.2.4 summarise the contribution of each sector to New Zealand's emissions in 1990 and 2018 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 2018



Note: Net removals from the LULUCF sector are as reported under the Convention (chapter 6).

Table 2.2.1 New Zealand's emissions by sector between 1990 and 2018

Sector	kt CO_2-equivalent 1990	kt CO_2-equivalent 2018	Change from 1990 (kt CO_2-equivalent)	Change from 1990 (%)
Energy	23,778.3	31,946.2	8,167.8	34.3
Industrial processes and product use	3,579.9	5,158.1	1,578.3	44.1
Agriculture	32,182.0	37,697.0	5,515.0	17.1
Waste	4,047.6	4,057.4	9.8	0.2
Other (Tokelau)	3.17	3.62	0.45	14.2
Gross (excluding LULUCF)	**63,590.9**	**78,862.3**	**15,271.4**	**24.0**
LULUCF	–28,297.0	–23,394.1	4,903.0	17.3
Net (including LULUCF)	**35,293.9**	**55,468.2**	**20,174.3**	**57.2**

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 comparing 1990 and 2018

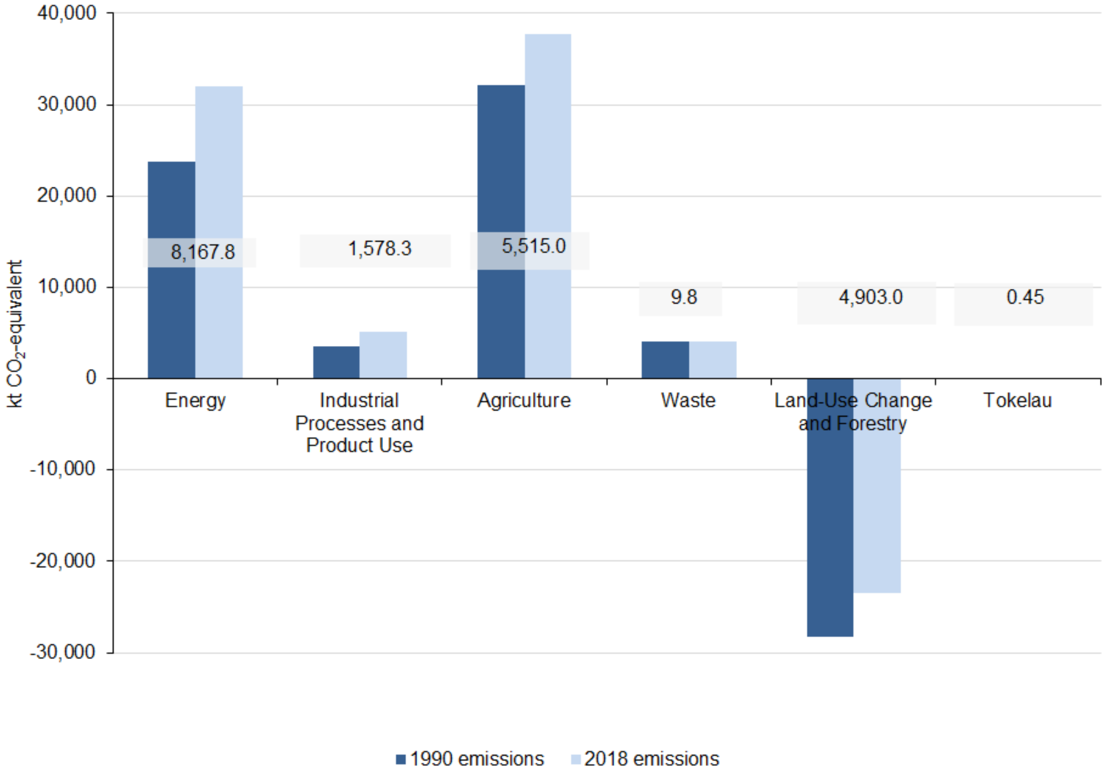
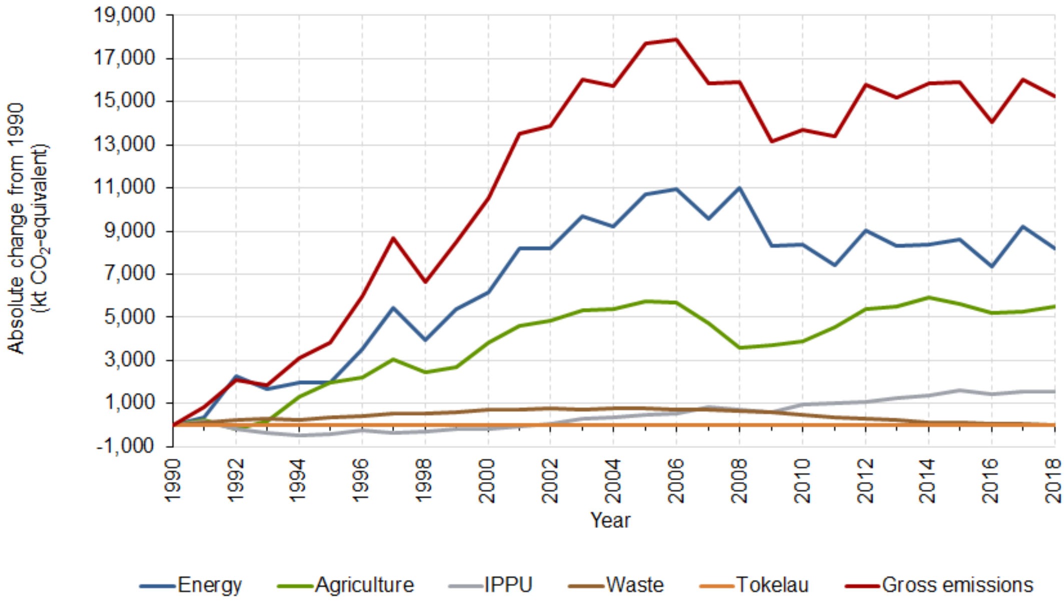


Figure 2.2.5 presents the absolute change in gross emissions for each sector (LULUCF is excluded from the estimate of gross emissions). The figure shows that the absolute changes in New Zealand's gross emissions were mostly influenced by changes in the Agriculture and Energy sectors. This is to be expected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

The figure also shows an increase in emissions from Tokelau, which is mainly due to ongoing increases in emissions from *Domestic navigation*.

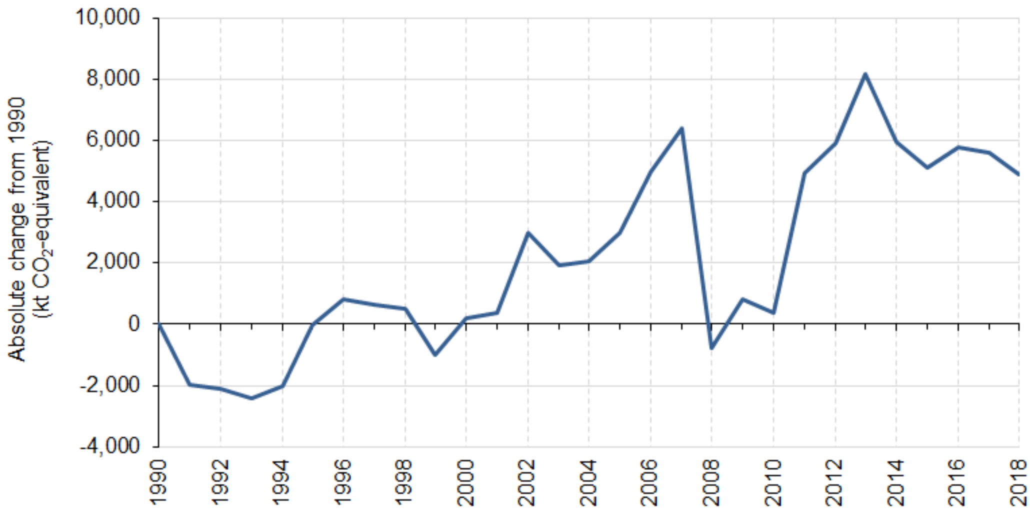
Figure 2.2.5 **Absolute change in New Zealand's gross emissions by sector from 1990 to 2018**



Note: Gross emissions exclude emissions from LULUCF.

Net removals from the LULUCF sector fluctuate significantly over the time series. The fluctuations in net removals 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 2018**



Energy sector

Emissions from the Energy sector are dominated by CO_2 (96.7 per cent of all emissions from the sector) and smaller amounts of CH_4 and N_2O (2.6 per cent and 0.7 per cent 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. A large proportion of New Zealand's stationary energy needs are met by renewables, mainly hydro power and wind.[29]

[29] Electricity generated from renewable energy sources was 84.0 per cent in 2018.

2018

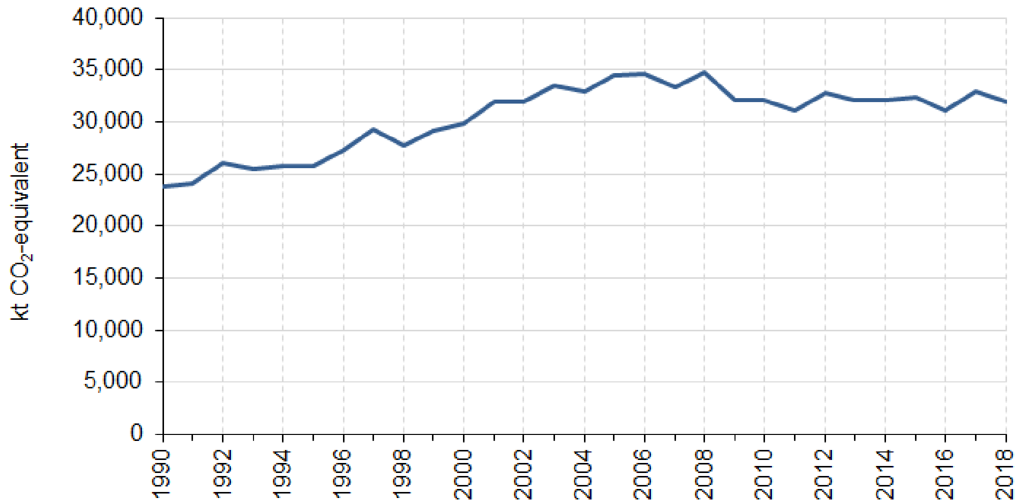
In 2018, the Energy sector produced 31,946.2 kt CO_2-e, representing 40.5 per cent of New Zealand's gross GHG emissions. The largest sources of emissions in the Energy sector were *Road transportation*, contributing 15,070.9 kt CO_2-e (47.2 per cent), and *Public electricity and heat production*, contributing 3,310.8 kt CO_2-e (10.4 per cent) to energy emissions.

1990–2018

In 2018, emissions from the Energy sector were 34.3 per cent higher (8,167.8 kt) than the 1990 level of 23,778.3 kt CO_2-e. This growth in emissions is primarily from *Road transportation*, which increased by 7,595.6 kt CO_2-e (101.6 per cent), *Chemicals*, which increased by 708.6 kt CO_2-e (129.0 per cent), and *Food processing, beverages and tobacco*, which increased by 1,249.7 kt CO_2-e (75.4 per cent). In 2018, emissions from 1.A.1.c *Manufacture of solid fuels and other energy industries* were much lower than the 1990 level, by 1,464.1 kt CO_2-e (85.0 per cent). This decrease is primarily due to the cessation of synthetic gasoline production in 1997.

Figure 2.2.7 shows the Energy sector emissions time series from 1990 to 2018. 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 2018



2017–2018

Between 2017 and 2018, emissions from the Energy sector decreased by 1,058.4 kt CO_2-e (3.2 per cent). This is primarily due to emissions from category 1.A.2.c *Chemicals*, which decreased by 472.6 kt CO_2-e (27.3 per cent). The decrease was partially offset by an increase from category 1.A.3.b *Road transport*, which increased by 295.2 kt CO_2-e (2.0 per cent).

There was also a 305.4 kt CO_2-e (8.4 per cent) decrease in emissions for category 1.A.1.a *Public electricity and heat production*. This was primarily due to a decrease in natural gas-fired generation in response to higher levels of hydro generation.

IPPU sector

The IPPU sector in New Zealand produces CO_2 (59.7 per cent of IPPU sectoral emissions), fluorinated gases (36.9 per cent of the sector) and smaller amounts of CH_4 and N_2O (1.8 per cent and 1.6 per cent respectively). The major source categories in the IPPU sector are *Iron and steel production*, *Refrigeration and air conditioning*, *Aluminium production* and *Cement production*.

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

2018

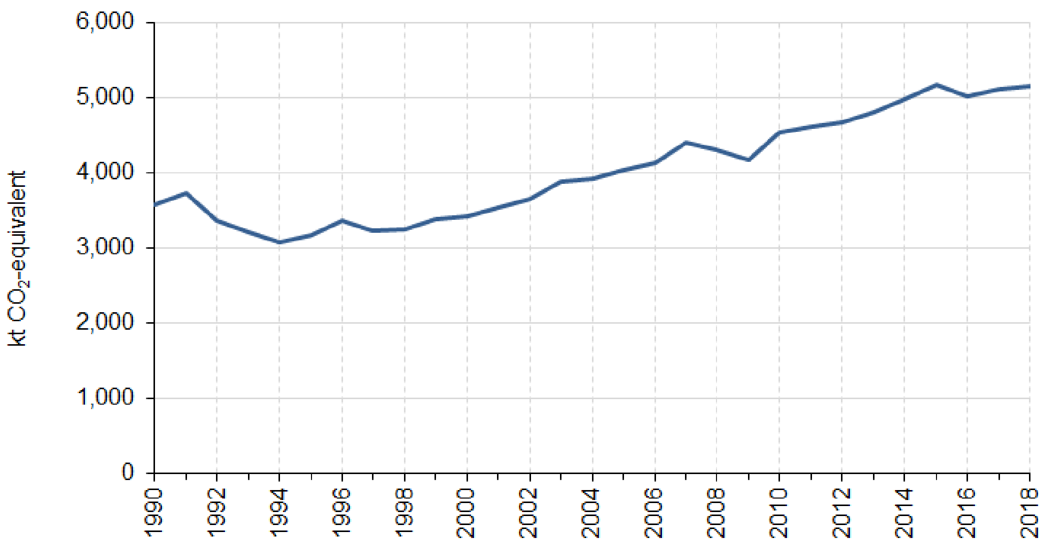
In 2018, emissions from the IPPU sector contributed 5,158.1 kt CO_2-e or 6.5 per cent of New Zealand's gross GHG emissions.

The largest category in the IPPU sector is the *Metal industry*, with substantial CO_2 emissions from *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 (HFCs and PFCs) come from the *Product uses as substitutes for ODS* category. The IPPU sector also produces smaller amounts of CH_4 from methanol production and N_2O used for medical applications in the *Other product manufacture and use* category.

1990–2018

IPPU sector emissions in 2018 were 1,578.3 kt CO_2-e (44.1 per cent) higher than emissions in 1990 (3,579.9 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 growth in 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 for the IPPU sector are shown in figure 2.2.8.

Figure 2.2.8 **New Zealand's IPPU sector emissions from 1990 to 2018**



2017–2018

IPPU sector emissions in 2018 were 36.8 kt CO_2-e (0.7 per cent) higher than emissions in 2017. This change was the net result of an increase in emissions from the *Product uses as substitutes for ODS* category (157.5 kt CO_2-e or 9.5 per cent) offset by small decreases in all other significant categories driven by varying production rates.

Agriculture sector

The Agriculture sector in New Zealand produces three main greenhouse gases, CH_4, N_2O and CO_2, which comprise 78.1 per cent, 19.0 per cent and 2.9 per cent of all Agriculture sector emissions respectively. Trends in Agriculture sector emissions are largely driven by the population of ruminant livestock categories (Dairy cattle, Non-dairy cattle, Sheep, and Deer).

The largest contributing categories in the Agriculture sector are *Enteric fermentation* and *Agricultural soils*. Emissions from the Agriculture sector reflect total livestock population, the type of livestock and farming systems, and the level of production.

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

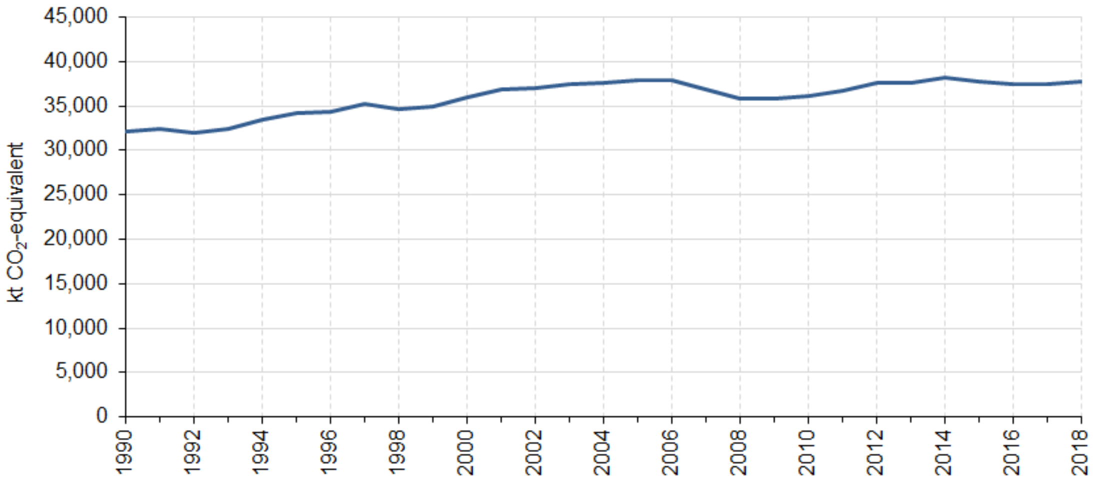
- changes over time to the population of the main livestock types farmed in New Zealand. Since 1990, the dairy cattle population has increased, while sheep and beef cattle populations have decreased as the profitability of dairy products has risen relative to sheep and beef products (see figures 5.1.3a and 5.1.3b in chapter 5)
- significant increases to livestock productivity (for both milk and meat yield per head of livestock, and lambing percentage) that have been achieved by New Zealand farmers since 1990. This has resulted in increased feed intake per animal to meet higher production energy demands. Increased feed intake results in increased CH_4 (from increased enteric fermentation) and N_2O emissions (from increased excreta deposited on pasture) per animal
- the incidence of severe droughts, which forced many farmers to reduce their livestock populations, which in turn reduced livestock-related emissions. Noteworthy droughts that have affected the emission trend negatively, when compared with previous years, occurred in the summers of 2008, 2013, 2015 and 2016. The Ministry for Primary Industries produces quarterly reports that summarise the effects of these events at a sector level and provide short-term forecasts (for more information, see www.mpi.govt.nz/news-and-resources/economic-intelligence-unit/situation-and-outlook-for-primary-industries/)
- commodity price fluctuations that drive farmer investment decisions in livestock numbers and species as well as production inputs. The Ministry for Primary Industries produces quarterly reports that summarise these decisions at a sector level and provide short-term forecasts (for more information, see www.mpi.govt.nz/news-and-resources/economic-intelligence-unit/situation-and-outlook-for-primary-industries/)
- shifting land use across different types of livestock farming and other agriculture. The Agriculture sector uses 45 per cent of New Zealand's land area, mostly for grazing. Between 1990 and 2017, the area used for sheep, beef and deer grazing has decreased by 34.2 per cent (Beef + Lamb New Zealand Ltd, 2019), while the area used for dairy grazing has increased by 70.4 per cent (LIC and DairyNZ, 2019)
- use of synthetic (not organic) nitrogen (N) fertiliser. The amount of synthetic N fertiliser applied to agricultural land has increased by 672.5 per cent since 1990.

2018

In 2018, the Agriculture sector was responsible for 37,696.96 kt CO_2-e (47.8 per cent of New Zealand's gross emissions) (figure 2.2.9).

The largest source of emissions from the Agriculture sector in 2018 was CH_4 emissions from *Enteric fermentation* (74.1 per cent of the total sector emissions) and N_2O emissions from *Agricultural soils* (18.6 per cent of total sector emissions).

Figure 2.2.9 New Zealand's Agriculture sector emissions from 1990 to 2018



1990–2018

In 2018, New Zealand's Agriculture sector emissions were 17.1 per cent (5,515.0 kt CO_2-e) above the 1990 level (32,181.96 kt CO_2-e). This increase is primarily due to a 56.7 per cent (2,542.5 kt CO_2-e) increase in N_2O emissions in the *Agricultural soils* category and a 5.2 per cent (1,390.0 kt CO_2-e) increase in CH_4 emissions in the *Enteric fermentation* category. Emissions in 2018 were 1.1 per cent below their peak in 2014.

The main drivers for these changes were a 672.5 per cent increase in synthetic N fertiliser application and an 85.6 per cent increase in the size of the national dairy herd since 1990.[30] A reduction of 52.9 per cent in the sheep population and 19.1 per cent in the non-dairy cattle population has partially offset these increases.

2017–2018

Total agricultural emissions in 2018 were 0.7 per cent (278.2 kt CO_2-e) higher than in 2017. This increase was due to an increase in emissions from non-dairy (beef) cattle, dairy cattle, sheep, and fertiliser use.

In 2018, non-dairy cattle emissions increased 1.3 per cent (82.0 kt CO_2-e) as the population increased. Dairy cattle emissions increased 0.3 per cent (49.3 kt CO_2-e), due to a reduction in the dairy population, which was partly offset by an increase in total milk production (LIC and DairyNZ, 2019). Sheep emissions increased 0.4 per cent (41.7 kt CO_2-e), due to a small decrease in the sheep population, partially offset by an increase in average slaughter weights. The change between 2017 and 2018 is due to strong commodity prices (for dairy and meat products) as well as favourable climatic conditions supporting pasture growth.

In 2018, emissions increased from synthetic N fertiliser, urea application and liming. These increased 3.3 per cent (54.0 kt CO_2-e) 3.4 per cent (19.9 kt CO_2-e) and 7.7 per cent (35.3 kt CO_2-e) 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.

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30 The national dairy herd increased by 3.2 million animals in the period 1990–2018.

2018

In 2018, the LULUCF sector under the Convention was a sink with a net emissions value of –23,394.1 kt CO_2-e. This offset 29.7 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.

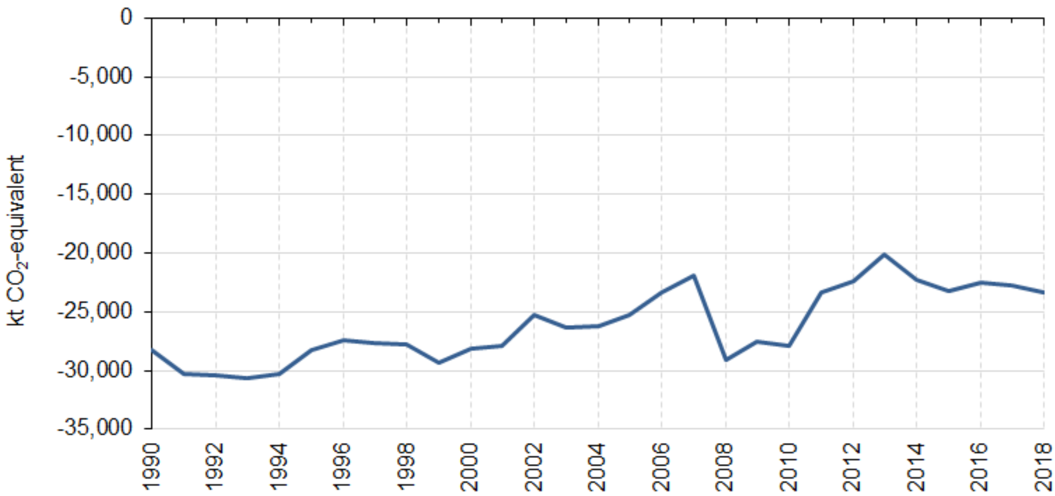
1990–2018

For the entire period 1990–2018, 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 2018, net emissions from LULUCF increased by 4,903.0 kt CO_2-e (17.3 per cent) from the 1990 level of –28,297.0 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 2018, 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 2018 than in 1990.

The fluctuations in net emissions from the LULUCF sector (see figure 2.2.6) are influenced by harvesting and deforestation rates. Harvesting rates are driven by a number of factors, particularly forest 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.[31] Emissions were subsequently markedly lower in 2008. The level of harvesting initially remained fairly flat but has been on an increasing trend since 2010.

Figure 2.2.10 New Zealand's LULUCF sector net emissions from 1990 to 2018



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

2017–2018

Between 2017 and 2018, net emissions from the LULUCF sector decreased by 684.0 kt CO_2-e (3.0 per cent). The largest change occurred within the *Harvested wood products* category due to an increase in the production of harvested wood products, resulting in a decrease in emissions. The increased production of harvested wood products resulted from an increase in the rate of harvesting of planted forests between 2017 and 2018. This increase in harvesting also contributed to an increase in emissions from *Forest land* by 2,150.9 kt CO_2-e over this period, the second-largest change in emissions for the LULUCF sector.

Waste sector

The Waste sector in New Zealand produces mainly CH_4 emissions (96.7 per cent) followed by N_2O emissions (3.3 per cent) and CO_2 emissions (0.1 per cent). There are additional CO_2 emissions from the disposal of solid waste. These additional CO_2 emissions are biogenic in origin and, therefore, are not reported in line with the 2006 Intergovernmental Panel on Climate Change Guidelines (IPCC, 2006).

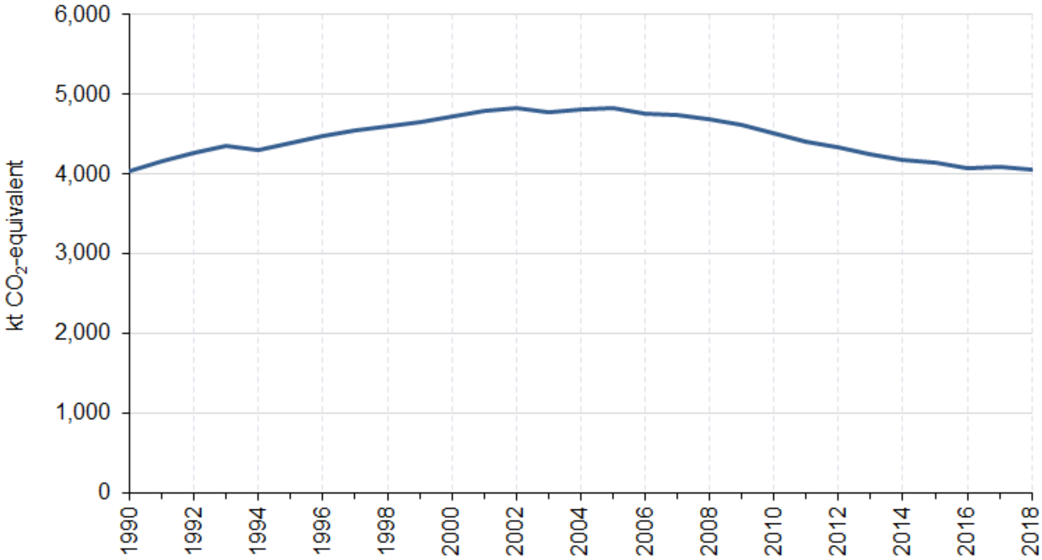
2018

In 2018, emissions from the Waste sector contributed 4,057.4 kt CO_2-e or 5.1 per cent of New Zealand's gross GHG emissions. The largest source category is the *Solid waste disposal* category.

1990–2018

Total Waste sector emissions in 2018 were 9.8 kt CO_2-e (0.2 per cent) above 1990 emissions of 4,047.6 kt CO_2-e. Annual emissions increased between 1990 and 2002, peaking at 4,838.2 kt CO_2-e in 2002, and have generally 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 2018



2017–2018

Total Waste sector emissions in 2018 were 35.2 kt CO_2-e (0.9 per cent) lower than in 2017. This decrease is largely the result of decreases in CH_4 emissions in the *Solid waste disposal* category, due to an increase in CH_4 recovery and a slight reduction in farm waste.

Other sector (Tokelau)

Beginning with the 2019 submission, New Zealand's national inventory includes emissions from Tokelau, which is an overseas dependent territory of New Zealand. Table 2.2.2 shows the contribution of emissions from Tokelau. Generally in New Zealand's inventory, net and gross emissions will be reported as a total of emissions from New Zealand's mainland territory, plus emissions from Tokelau where applicable. Because emissions from Tokelau are small, and the methodology varies greatly between Tokelau and the rest of New Zealand's inventory, emissions from Tokelau are reported in the Other sector, and methodological issues for Tokelau are detailed in chapter 8 of the National Inventory Report, separately from the sectoral chapters that focus on methods for New Zealand's mainland territory only. A set of tables in annex 7 provides details on time series for emissions, activity data, and information on methods and emission factors for each sector and category contributing to the gross emissions from Tokelau.

Table 2.2.2 Emissions from Tokelau

Sector	kt CO_2-equivalent		Change from 1990		Contribution to gross for Tokelau (%)	Contribution to gross NZ (incl Tokelau) (%)
	1990	2018	kt CO_2-equivalent	%		
Energy for Tokelau	1.26	1.85	0.59	46.5	51.2	0.0023
IPPU for Tokelau	0.05	0.25	0.20	432.5	6.9	0.0003
Agriculture for Tokelau	1.15	0.82	–0.33	–28.3	22.8	0.0010
Waste for Tokelau	0.71	0.69	–0.02	–2.4	19.1	0.0009
Gross emissions for Tokelau	**3.17**	**3.62**	**0.45**	**14.2**	**100.0**	**0.0046**

Note: The 2020 submission includes emissions from Tokelau's largest contributing sectors, which are the Energy, IPPU, Agriculture, and Waste sectors. The LULUCF sector is not estimated as it is expected to contribute a miniscule amount of emissions and removals, because there are no planted or managed forests in Tokelau. The percentages may not add up to 100 per cent due to rounding.

Due to the small land area, small population and absence of industry, Tokelau has a very low impact on the environment and emits very small amounts of GHGs. Tokelau produces mainly CO_2 emissions (51.7 per cent) and CH_4 emissions (40.7 per cent) followed by HFCs (6.5 per cent) and N_2O emissions (1.1 per cent). Emissions from HFCs are largely coming from the use of domestic fridges and freezers.

2018

In 2018, emissions from Tokelau contributed 3.62 kt CO_2-e or 0.005 per cent of New Zealand's gross GHG emissions. The largest source category is the *Domestic navigation* category.

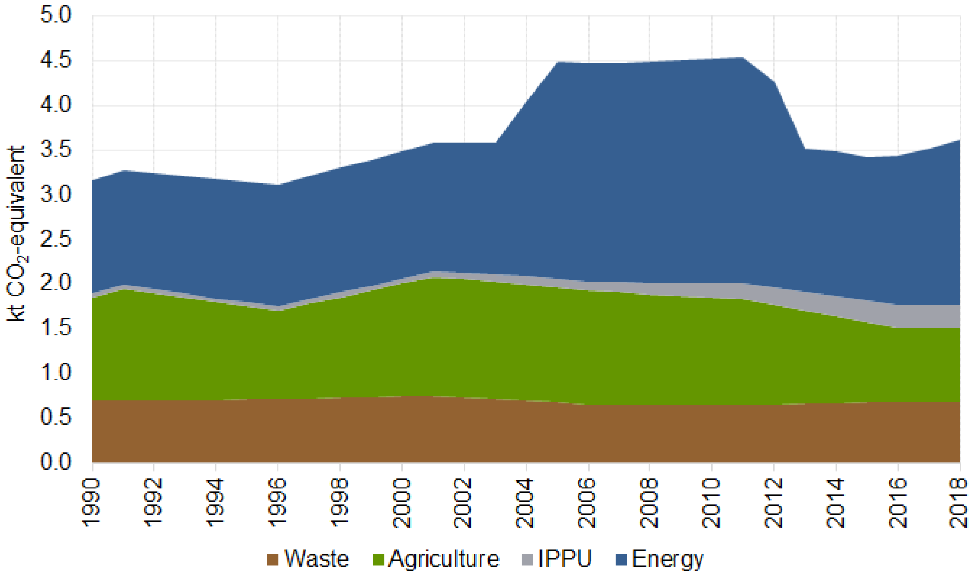
1990–2018

In 1990, gross emissions from Tokelau were 3.17 kt CO_2-e. Between 1990 and 2018, gross emissions from Tokelau increased by 14.2 per cent (0.45 kt CO_2-e) to 3.62 kt CO_2-e in 2018.

The emission categories that contributed the most to this change were *Domestic navigation* and *Refrigeration and air conditioning*. The changes in *Domestic navigation* are a result of

Tokelau gaining ownership and use of the ferry *Mataliki* in 2016 and cargo vessel *Kalopaga* in 2018, leading to an increasing number of sea voyages between the atolls, which increased transport emissions. Emissions from Tokelau's IPPU sector have also increased slightly as fridges and freezers have become more commonly used. Further changes in Tokelau's Energy sector emissions are a significant rise, then drop (by approximately 400 per cent and 82.5 per cent, respectively) in consumption of imported petroleum products used for electricity production in Tokelau. Emissions from Tokelau's Agriculture sector have decreased slightly as a result of a reduced population of pigs (figure 2.2.12). The trends are shown in figure 2.2.12 and in chapter 8.

Figure 2.2.12 Emissions by sector for Tokelau from 1990 to 2018



2017–2018

Total Tokelau emissions in 2018 were 0.10 kt CO_2-e (2.8 per cent) higher than emissions in 2017. This increase is largely the result of increases in CO_2 emissions in the *Domestic navigation* category, due to increasing shipping within Tokelau.

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

In 2018, net emissions from land subject to Article 3.3 and Article 3.4 activities under the Kyoto Protocol were –29,346.0 kt CO_2-e[32] (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.

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32 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.

New Zealand's estimates for emissions and removals from activities under Article 3.3 and Article 3.4 of the Kyoto Protocol do not include emissions associated with nitrogen-containing 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. Application of one of these rules, 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 2018 is 698,497 hectares.[33] The net area is the total area of new forest established since 1990 (729,769 hectares) minus the *Deforestation* of post-1989 forest that has occurred since 1 January 1990 (31,272 hectares). Net removals from land included under *Afforestation and reforestation* in 2018 are 17,593.2 kt CO_2-e, including 2,804.5 kt CO_2-e from the *Harvested wood products* category.

Deforestation

The area deforested between 1 January 1990 and 31 December 2018 is 201,206 hectares.[34] The area subject to *Deforestation* in 2018 is estimated as 3,740 hectares.[8] In 2018, net emissions from *Deforestation* were 2,146.2 kt CO_2-e, compared with 1,977.1 kt CO_2-e in 2017 (8.6 per cent increase).

Forest management

The total area reported under *Forest management* at the end of 2018 was 9,208,933 hectares, equivalent to 34.2 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 2018 were 13,898.9 kt CO_2-e, including net removals of 12,006.8 kt CO_2-e from the *Harvested wood products* category.

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

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[33] The carbon equivalent forest provision creates a misalignment for the afforestation and deforestation area reported under the Kyoto Protocol and the Convention sections of the inventory. The carbon equivalent forest provision under the Kyoto Protocol is reported in the categories *Land converted to forest land* (afforestation) and *Forest land converted to other land* uses (deforestation) under the Convention.

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

- 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	2017P	2018P
Afforestation and reforestation						
Net cumulative area since 1990 (ha)	677,229	679,128	680,963	683,921	689,747	698,497
Area in calendar year (ha)	4,530	3,447	3,502	4,281	6,461	9,443
Net emissions in calendar year (kt CO_2-e)	–17,542.2	–17,824.5	–18,066.9	–17,790.2	–17,790.2	–17,593.2
Deforestation						
Net cumulative area since 1990 (ha)	176,101	184,637	190,560	193,974	197,466	201,206
Area in calendar year (ha)	14,232	8,536	5,923	3,414	3,493	3,740
Net emissions in calendar year (kt CO_2-e)	9,525.6	5,667.4	3,640.3	1,821.5	1,977.1	2,146.2
Forest management						
Area included (ha)	9,224,080	9,217,093	9,212,837	9,211,357	9,210,186	9,208,933
Net emissions in calendar year (kt CO_2-e)	–18,487.6	–16,962.0	–15,470.4	–13,119.5	–13,136.0	–13,898.9
Total area included (ha)	**10,077,410**	**10,080,857**	**10,084,359**	**10,089,252**	**10,097,399**	**10,108,636**
Net emissions in calendar year (kt CO_2-e)	**–26,504.2**	**–29,119.1**	**–29,897.0**	**–29,088.2**	**–28,949.2**	**–29,346.0**
Accounting quantity (kt CO_2-e)	**–8,016.6**	**–12,157.1**	**–14,426.6**	**–15,968.7**	**–15,813.2**	**–15,447.0**

Note: ha = hectares; P = provisional figure (all figures for 2017 and 2018 are provisional). Where net emissions result in removals, they are expressed as a negative value as per section 2.2.3 of the IPCC Guidelines (IPCC, 2006). The accounting quantity excludes net emissions from forest management because 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. Columns may not total due to rounding. Afforestation and deforestation differs from that in chapter 6 due to carbon equivalent forests being reported separately.

Chapter 2: References

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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 2017). Most freight is transported by trucks, with smaller quantities transported by rail and 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 2018, fossil fuel thermal plants provided 16 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).

New Zealand reports emissions from Tokelau, which is a dependent territory of New Zealand. Emissions from Tokelau for all activities are reported in chapter 8 and annex 7 of the National Inventory Report, and within the 'Other' sector in the common reporting format (CRF) tables. This is due to the significantly different methods applied and prohibitive complexity of integrating emissions within the main sectors. Therefore, all emissions reported in this sector are from New Zealand excluding Tokelau. Please refer to chapter 8 of the National Inventory Report for details of methods applied and the emissions for Tokelau.

2018

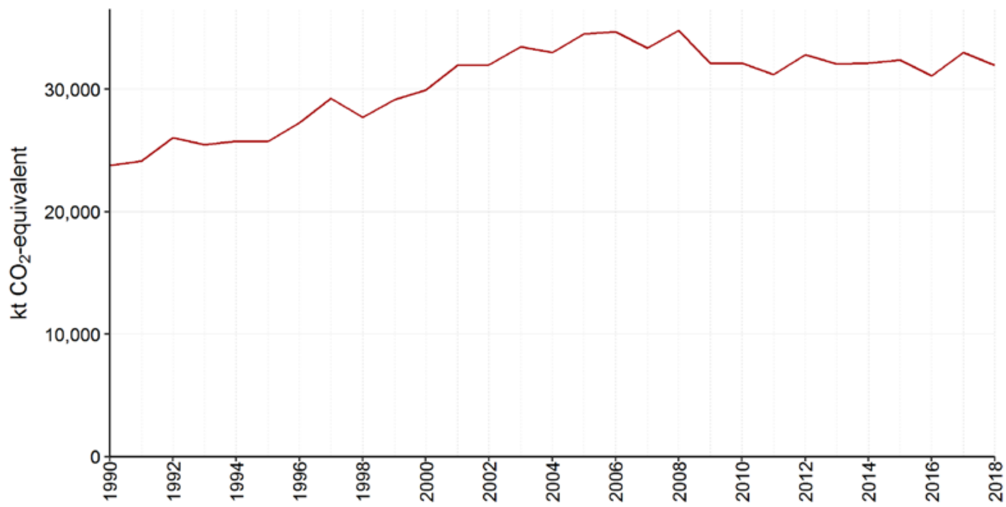
In 2018, the Energy sector produced 31,946.2 kilotonnes carbon dioxide equivalent (kt CO_2-e) emissions, representing 40.5 per cent of New Zealand's gross greenhouse gas emissions. The largest sources of emissions in the Energy sector were *Road transportation*, contributing 15,070.9 kt CO_2-e (47.2 per cent), and *Public electricity and heat production*, contributing 3,310.8 kt CO_2-e (10.4 per cent) to energy emissions.

1990–2018

In 2018, emissions from the Energy sector were 34.3 per cent higher (8,167.8 kt) than the 1990 level of 23,778.3 kt CO_2-e. This growth in emissions is primarily from *Road transportation*, which increased by 7,595.6 kt CO_2-e (101.6 per cent), *Chemicals*, which increased by 708.6 kt CO_2-e (129.0 per cent), and *Food processing, beverages and tobacco*, which increased by 1,249.7 kt CO_2-e (75.4 per cent). In 2018, emissions from 1.A.1.c *Manufacture of solid fuels and other energy industries* were much lower than the 1990 level, by 1,464.1 kt CO_2-e (85.0 per cent). This decrease is primarily due to the cessation of synthetic gasoline production in 1997.

Figure 3.1.1 shows the time series from 1990 to 2018. Emissions increased until around 2005, after which there has been a general decline.

Figure 3.1.1 New Zealand's Energy sector emissions (1990–2018)



2017–2018

Between 2017 and 2018, emissions from the Energy sector decreased by 1,058.4 kt CO_2-e (3.2 per cent). This is primarily due to emissions from category 1.A.2.c *Chemicals*, which decreased by 472.6 kt CO_2-e (27.3 per cent). The decrease was partially offset by an increase from category 1.A.3.b *Road transport*, which increased by 295.2 kt CO_2-e (2.0 per cent).

There was also a 305.4 kt CO_2-e (8.4 per cent) decrease in emissions for category 1.A.1.a *Public electricity and heat production*. This was primarily due to a decrease in natural gas-fired generation in response to higher levels of hydro generation.

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	L1, 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, T1
1.A.2.d	Manufacturing Industries and Construction – Pulp, Paper and Print Solid Fuels	CO_2	T1
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.a	Other Sectors – Commercial/Institutional Solid Fuels	CO_2	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.A.4.c	Other Sectors – Agriculture/Forestry/Fishing Solid Fuels	CO_2	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	T1
1.B.2.c.1.ii	Venting – Gas	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 also applies the Intergovernmental Panel on Climate Change (IPCC) reference approach to estimate CO_2 emissions from fuel combustion for the time series 1990–2018 (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, 2019). 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 (2019). This data release uses information from oil company 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 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 CO_2. 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[35]	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.

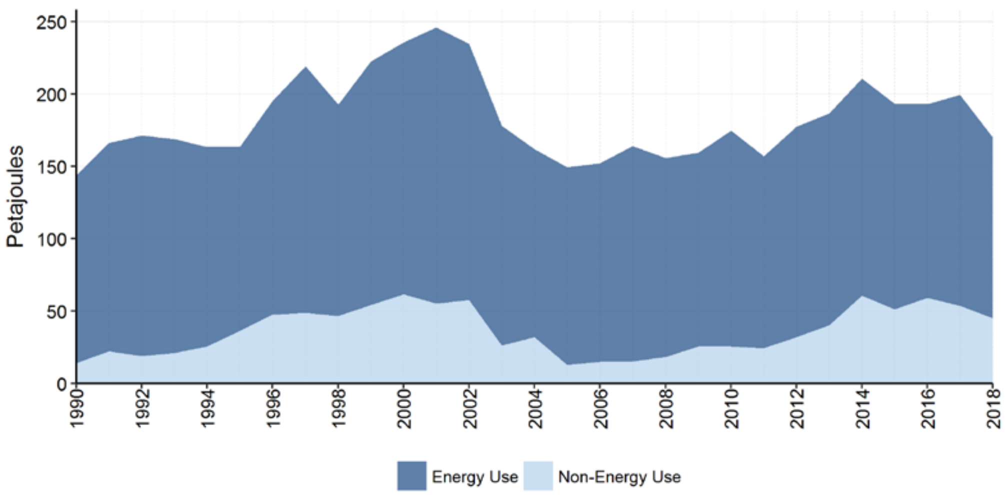
Regarding urea, the split of feedstock gas and fuel gas is provided by the company. Although most of the carbon in feedstock gas used for urea production is stored in the product, this carbon is later emitted when the urea is used on farms as fertiliser. These emissions are reported in the Agriculture sector under urea application (all ammonia produced in New Zealand is processed into urea).

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

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, and a table giving the energy versus non-energy use data for natural gas is included in annex 4, section A.4.4. Details of natural gas use for the various non-energy uses are covered under the IPPU sector (chapter 4).

Figure 3.2.1 Natural gas consumption by end use type (1990–2018)



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 2018.

3.2.5 Country-specific issues

Reporting for the Energy sector presents an issue related to the IPCC Guidelines (IPCC, 2006). The issue is described below.

Sectoral approach – Methanol production

The sector activity data do 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. 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, 2019). 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/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-publications-and-technical-papers/energy-in-new-zealand/.

3.3 Fuel combustion (CRF 1.A)

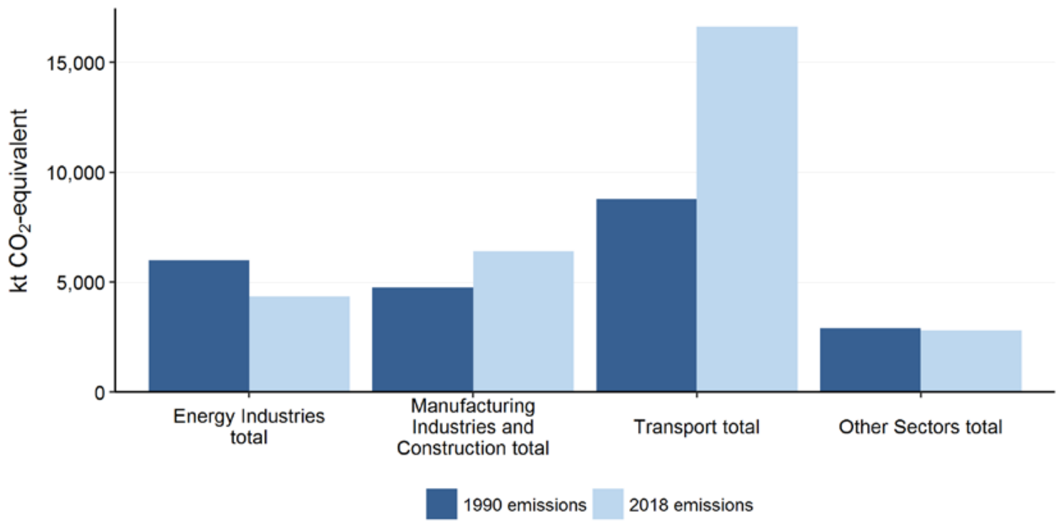
3.3.1 Sector-wide information

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 (1990–2018)



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 (Stats NZ). The quarterly survey includes liquid fuel sales data collected from the four oil companies importing and selling fuel. 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. Furthermore, it found that this on-selling resulted in over-allocation of liquid fuel activity data to the *Transport* category, because 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, because 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 Stats NZ. 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 Stats NZ ran the survey, coal sales were surveyed for only seven higher level 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 the operator of the Kapuni Gas Treatment Plant and gas distribution networks.

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 expert review team (ERT) recommendations, all fuel combustion for electricity auto-production was disaggregated into the appropriate sector, rather than reported in 1.A.2.g *Manufacturing industries and construction – other*. This improvement was implemented in the 2013 submission and 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, 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 MBIE 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 data that have been collected are for 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).

Gas biomass emissions estimates are 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. A new trigeneration facility has since been built)
  - 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 7 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 lower than the gross emission factor)
    - methane (CH_4) – 0.9 t/PJ
    - nitrous oxide (N_2O) – 0.09 t/PJ.
- Emissions from gas biomass comprise 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 and industrial solid biomass activity data are taken from the annual *Energy in New Zealand* publication (MBIE, 2019). The residential values are estimated by MBIE based on information on the proportion of households with wood burning heaters (from census data) 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. The industrial biomass estimation is based on the report *Heat Plant in New Zealand* (Bioenergy Association of New Zealand, 2011).

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

All combustion activity for electricity auto-production is allocated into the appropriate manufacturing sub-sector.

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 2018 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.c.

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

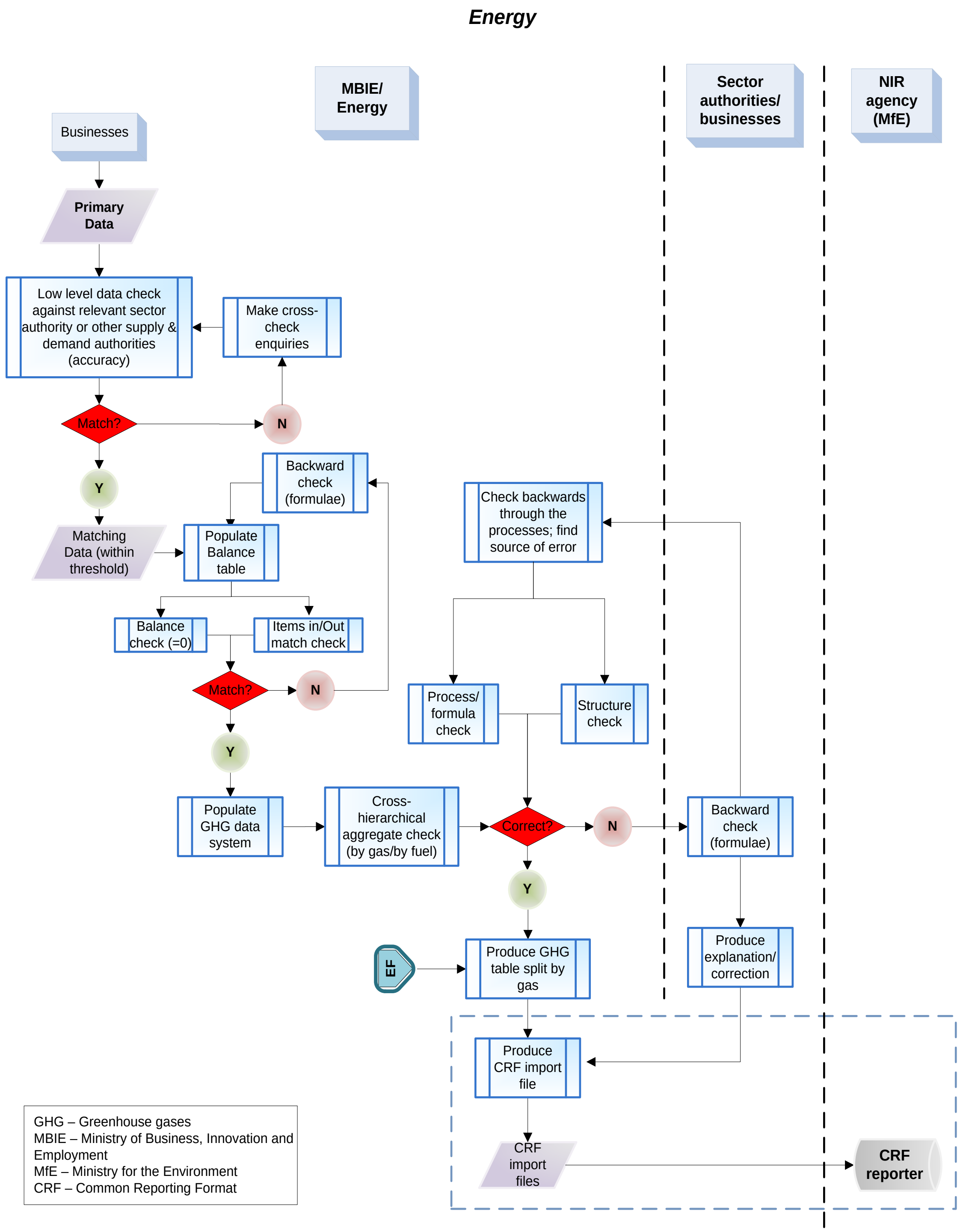
All source-specific planned improvements are discussed in their corresponding sections.

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



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 (1990–2018)

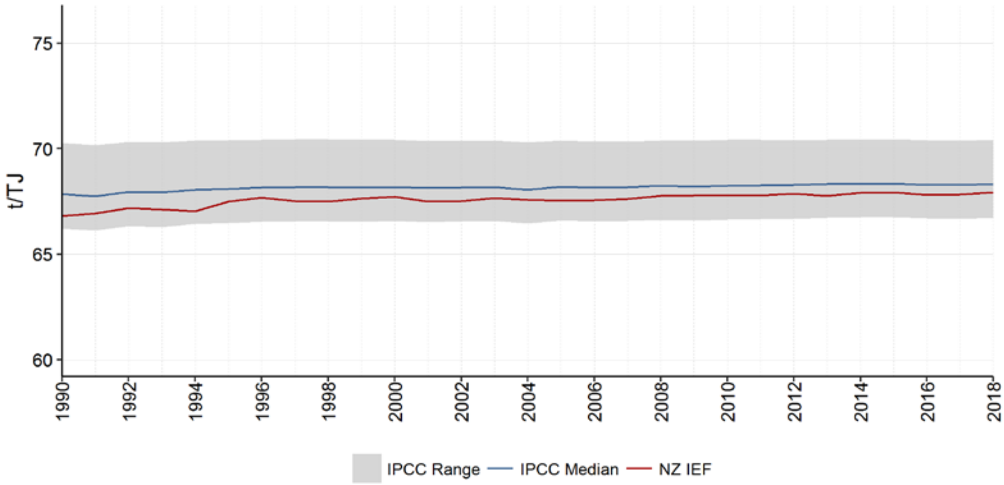


Figure 3.3.4 Carbon dioxide implied emission factor (IEF) – Solid fuel combustion (1990–2018)

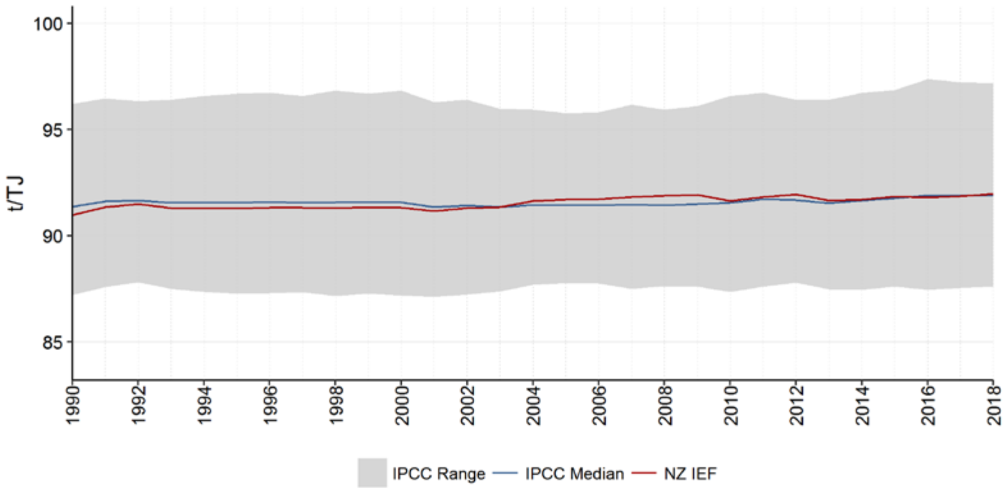
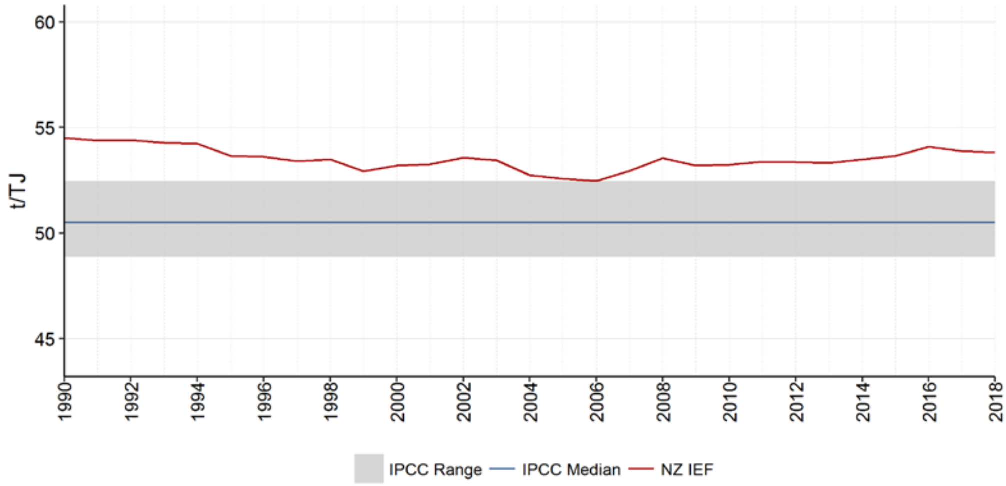


Figure 3.3.5 Carbon dioxide implied emission factor (IEF) – Gaseous fuel combustion (1990–2018)



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 in CO_2 emissions is relatively low. This is important because CO_2 emissions comprise around 96–97 per cent of CO_2-e emissions from fuel combustion in New Zealand. 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

	Category	Activity data uncertainty (%)	Emission factor uncertainty (%)
CO_2	Liquid fuels	2.2	±0.5
	Solid fuels	–3.0	±2.2
	Gaseous fuels	–0.1	±2.4
	Fugitive – geothermal	5.0	±5.0
	Fugitive – venting/flaring	–0.1	±2.4
	Fugitive – oil and gas production and transport	5.0	±100.0
	Fugitive – transmission and distribution	–0.1	±100.0
CH_4	Liquid fuels	2.2	±50.0
	Solid fuels	–3.0	±50.0
	Gaseous fuels	–0.1	±50.0
	Biomass	50.0	±50.0
	Fugitive – geothermal	5.0	±5.0
	Fugitive – venting/flaring	–0.1	±50.0
	Fugitive – coal mining and handling	–3.0	±50.0
	Fugitive – transmission and distribution	–0.1	±100.0
	Fugitive – oil and gas exploration and production	–0.1	±100.0

	Category	Activity data uncertainty (%)	Emission factor uncertainty (%)
	Fugitive – oil transportation	5.0	±50.0
N_2O	Liquid fuels	2.2	±50.0
	Solid fuels	–3.0	±50.0
	Gaseous fuels	–0.1	±50.0
	Biomass	50.0	±50.0
	Fugitive – venting/flaring	5.0	±100.0

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 Gas Treatment Plant has also been reported under the *Manufacture of solid fuels and other energy industries* category because of confidentiality concerns.

In 2018, emissions in category 1.A.1 *Energy industries* totalled 4,355.4 kt CO_2-e (13.6 per cent of the Energy sector emissions). Emissions from energy industries in 2018 were 1,648.5 kt CO_2-e (27.5 per cent) lower than the 1990 level of 6,003.9 kt CO_2-e. Category 1.A.1.a *Public electricity and heat production* accounted for 3,310.8 kt CO_2-e of emissions from the *Energy industries* category in 2018. This is 191.4 kt CO_2-e (5.5 per cent) lower than the 1990 level of 3,502.3 kt CO_2-e.

Changes in emissions between 2017 and 2018

Between 2017 and 2018, there was a decrease of 305.4 kt CO_2-e (8.4 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 84.0 per cent in 2018, up from 81.8 per cent in 2017. This resulted in decreased gas and coal-fired generation over the year, which together decreased 11.8 per cent from 2017.

Key categories identified in the 2018 level and trend assessment for the *Energy industries* category are given in table 3.3.2.

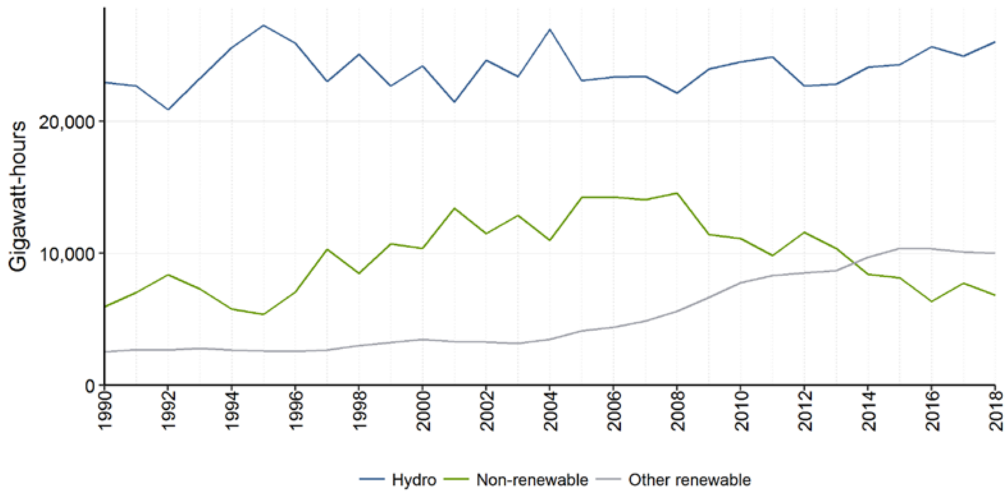
Table 3.3.2 Key categories for 1.A.1 Energy industries

	Liquid fuels	Solid fuels	Gaseous fuels
Public electricity and heat production – CO_2		Level, trend	Level, trend
Petroleum refining – CO_2	Level, trend		Trend
Manufacture of solid fuels and other energy industries – CO_2			Level, trend

New Zealand's electricity generation is dominated by hydroelectric generation. For the 2018 calendar year, hydro generation provided 60.4 per cent of New Zealand's electricity generation. A further 17.4 per cent came from geothermal, 4.7 per cent from wind, 1.3 per cent from biomass and 0.2 per cent from solar. The remaining 15.9 per cent was provided by fossil fuel thermal generation plants using gas, coal and oil (MBIE, 2019).

Greenhouse gas emissions from the *Public electricity and heat production* category show large year-to-year fluctuations between 1990 and 2018. 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 10 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.

Activity data

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

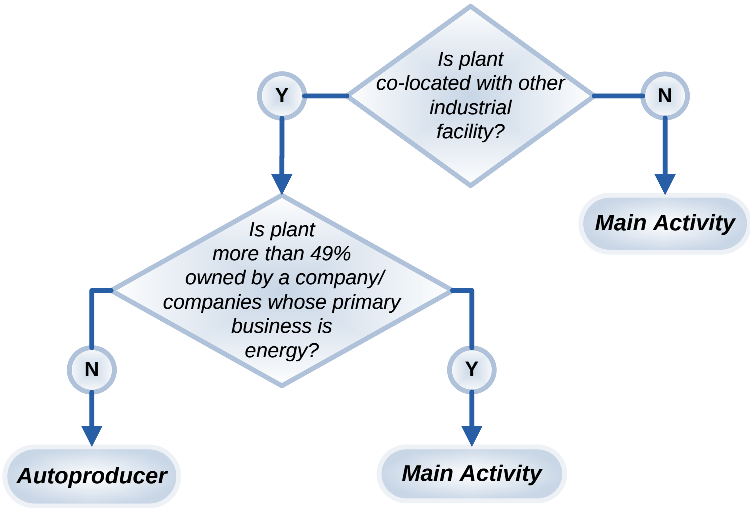
All thermal electricity generators provide figures to MBIE for the amount of coal, natural gas and oil used for electricity generation. Greenhouse gas emissions from geothermal electricity generation are reported under 1.B.2.d.

Around 5 per cent of New Zealand's electricity is supplied by co-generation (also known as combined heat and power) (MBIE, 2019). 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.

Losses and own use of coal by coal mining entities are reported as a single item, so data on on-site coal use are not available. Coal mines often provide a bathhouse for miners to bathe and unwind after a hard shift at the coalface. In the past, hot water was supplied by a coal-fired boiler; however, the last of these at the Stockton mine closed in the mid-1980s. The expert opinion of coal industry specialists is that on-site coal use does not occur because any water boilers on site are now fuelled by natural gas or electricity.

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 2018, emissions from the 1.A.2 *Manufacturing industries and construction* category accounted for 6,390.4 kt CO_2-e (20.0 per cent) of emissions from the Energy sector. Emissions from this category were 1,630.1 kt CO_2-e (34.2 per cent) higher than the 1990 level of 4,760.3 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 restarted previously mothballed plants in 2012/13 and operated all three of its plants during 2018.

Changes in emissions between 2017 and 2018

Between 2017 and 2018, emissions from the *Manufacturing industries and construction* category decreased by 699.9 kt CO_2-e (–9.9 per cent). This was driven chiefly by a decrease in emissions from the *Chemicals* category, down 472.6 kt CO_2-e (27.3 per cent) from 2017. A significant driver behind the fall were outages at the Pohokura natural gas field, which saw 2018 production drop 34 per cent from 2017 levels – see *Energy in New Zealand* (MBIE, 2019, page 54), for further information.

Key categories identified in the 2018 level and trend assessment for the *Manufacturing industries and construction* category are given in table 3.3.3.

Table 3.3.3 Key categories for 1.A.2 Manufacturing industries and construction

Category	Liquid fuels	Solid fuels	Gaseous fuels
Chemicals – CO_2			Level, trend
Pulp, paper and print – CO_2			Level, trend
Food processing, beverages and tobacco – CO_2	Level, trend	Level, trend	Level, trend
Other – mining and construction – CO_2	Level, trend		
Other – non-metallic minerals – CO_2		Level, trend	
Other – other non-specified – CO_2	Level, trend	Trend	

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

Energy balance tables released with *Energy in New Zealand* (MBIE, 2019) split out industrial uses of energy using the Australian and New Zealand Standard Industrial Classification (ANZSIC) 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 the 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 3.3.4). 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 3.3.4 Solid biomass splits for 2006 that were used to disaggregate the Manufacturing industries and construction category between 1990 and 2018

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 was subsequently extended to include fuel oil.

While data are not collected at this level of detail in energy surveys for liquid fuels, New Zealand has produced estimates based on Stats NZ survey data. Stats NZ conducted an industrial and trade energy use survey (Stats NZ, 2018), 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 Stats NZ 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 Stats NZ 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 (1990–2018)

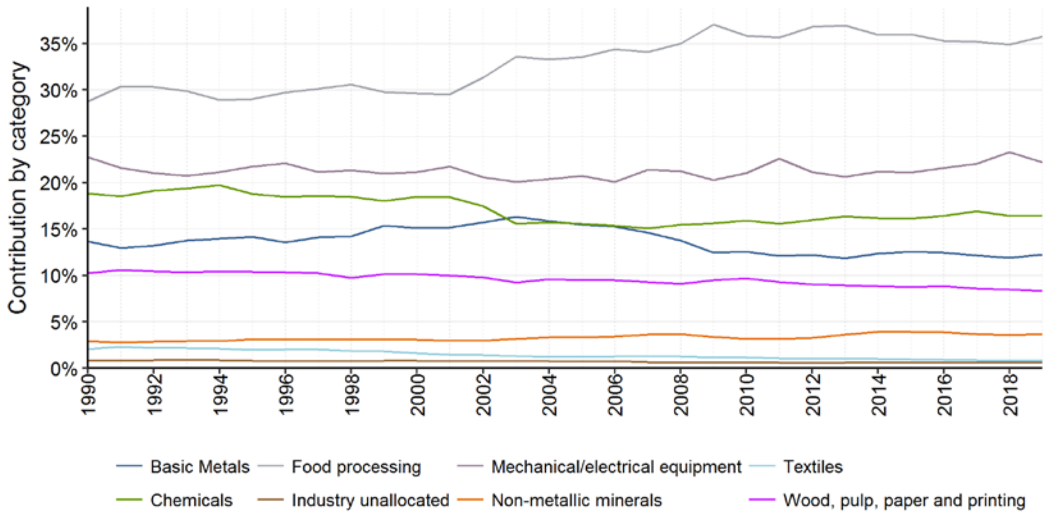


Figure 3.3.9 Splits used for Manufacturing industries and construction category – Diesel (1990–2018)

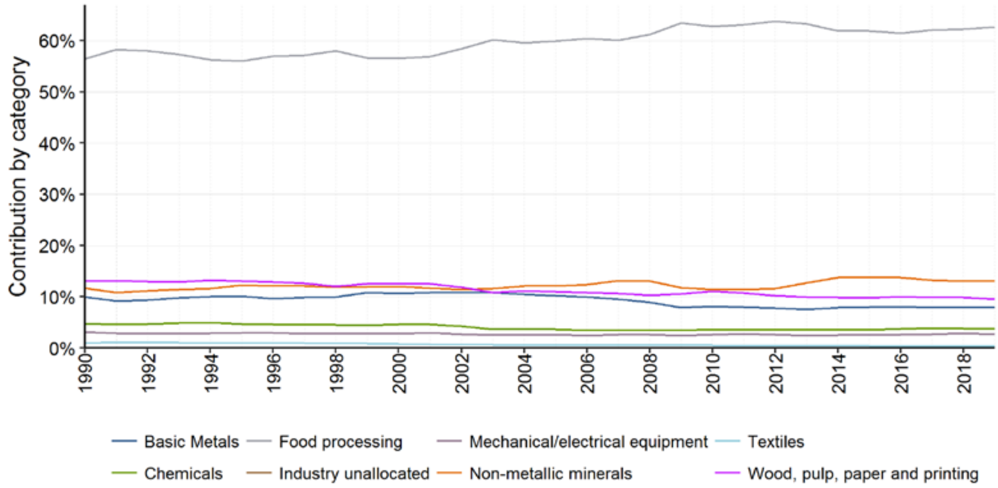
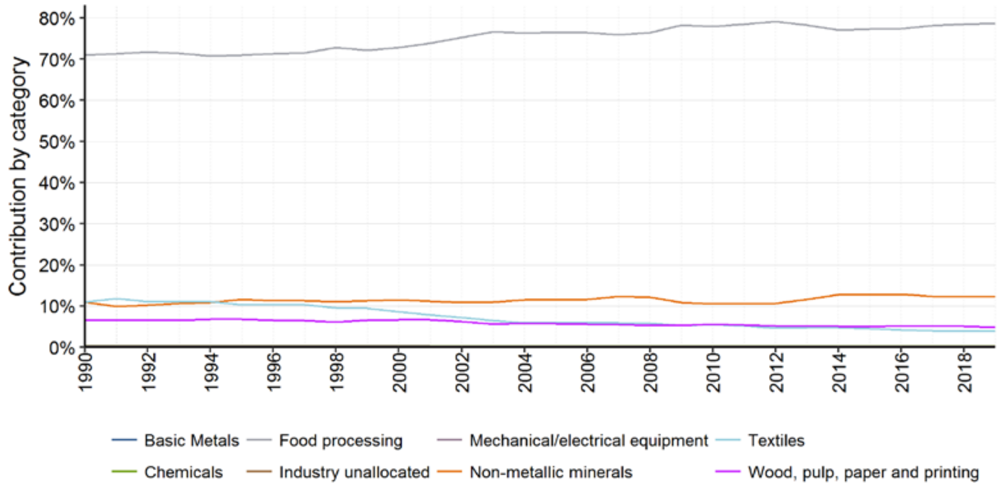


Figure 3.3.10 Splits used for Manufacturing industries and construction category – Fuel oil (1990–2018)



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 a number of sector classifications are 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.

On-site electricity generation

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 2018, category 1.A.3 *Transport* was responsible for 16,624.7 kt CO_2-e (52.0 per cent of emissions from the Energy sector), or 21.1 per cent of gross national emissions. Emissions in 2018 were 7,859.8 kt CO_2-e (89.7 per cent) higher than the 8,764.9 kt CO_2-e emitted from the transport sector in 1990. The transport emissions profile in 2018 was dominated by emissions from category 1.A.3.b *Road transportation*. In 2018, road transport accounted for 15,070.9 kt CO_2-e (90.7 per cent) of total transport emissions. This is 7,595.6 kt CO_2-e (101.6 per cent) higher than the 1990 level of 7,475.3 kt CO_2-e.

Changes in emissions between 2017 and 2018

Between 2017 and 2018, emissions from transport increased by 370.1 kt CO_2-e (2.3 per cent).

Key categories identified in the 2018 level and trend assessment for the *Transport* category are given in table 3.3.5.

Table 3.3.5 Key categories for 1.A.3 Transport

	Liquid fuels	Solid fuels	Gaseous fuels
Domestic Aviation – CO_2	Level, trend		
Road Transportation – CO_2	Level, trend		Trend
Domestic Navigation – CO_2	Level		

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[36] 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.

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

36 As of 2018, New Zealand only manufactures a small number of buses and heavy trucks.

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.

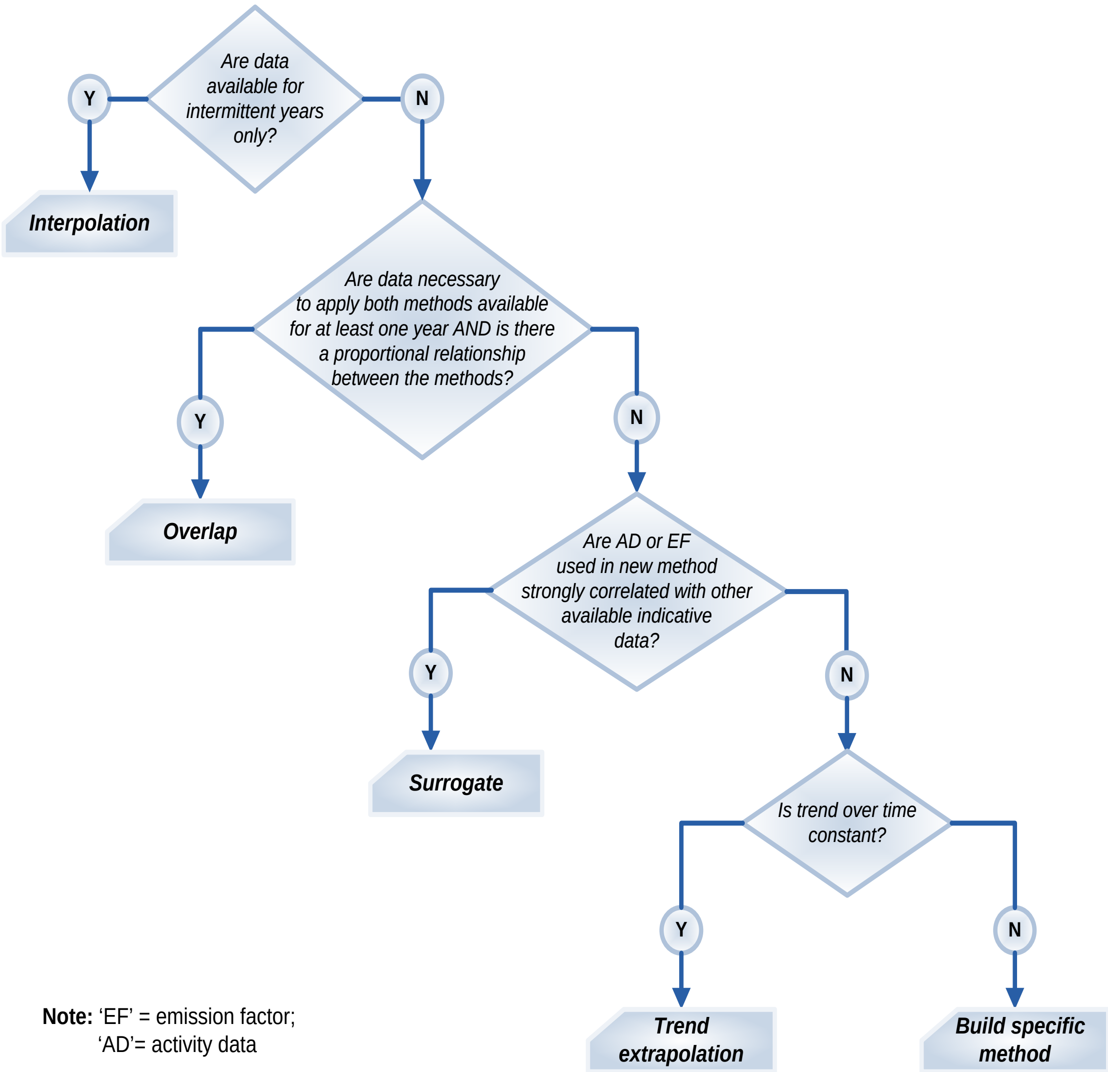
The *New Zealand Travel Survey* (Ministry of Transport, 2010) is used to further split the 'urban' travel type into cold and hot starts. This survey provides detailed trip-by-trip information on travel type. These data were used to establish the percentage of light-vehicle urban travel that was cold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

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 3.3.11). The guidance for the method selection process is provided in table 5.1 (volume 2) of the 2006 IPCC Guidelines.

Figure 3.3.11 Splicing method decision tree for gasoline emissions



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:

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

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.

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 2018. In 2018, 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 (data exists from 2007 onwards). 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 2018 centralised review.

A recent development in New Zealand is the emergence of a nascent aerospace industry. In New Zealand, space-related activities (launches into outer space, launch facilities, high-altitude vehicles and payloads) are overseen by the New Zealand Space Agency, based within MBIE, as regulated in legislation by the Outer Space and High-altitude Activities Act 2017. Currently, one private company is actively launching rockets from a launch complex on the Māhia Peninsula (on the east coast of New Zealand's North Island) to put small satellites in orbit around Earth. The rockets use liquid oxygen and RP-1 as propellants. RP-1 is a form of highly refined kerosene. The specific categorisation within energy statistics is yet to be determined, although this type of kerosene is likely classified as jet kerosene under ANZSIC code *I49 Air and Space Transport*, and so would be included within *1.A.3.a Civil aviation*. While the combustion characteristics of rocket engines are likely to differ somewhat from other jet-fuelled activities, no specific emission factors are provided in the 2006 IPCC Guidelines.

The 2006 IPCC Guidelines cover emissions from civil aviation, but do not specifically refer to aeronautics or aerospace. Ballistic vehicles, such as rockets, are usually considered to be included under aeronautics but not aviation. Presumably aerospace activities should be considered as a type of off-road transport because the 2006 IPCC Guidelines (in table 3.1.1) state that emissions from all remaining transport activities should be reported under *1.A.3.e Other transportation*, and that *1.A.3.e.ii Off-road* should include emissions from *Other transportation* excluding *Pipeline transport*. However, as mentioned above, the aerospace fuel activity data are currently included in *1.A.3.a Civil aviation*. Further justification for not disaggregating the category is commercial data confidentiality concerns due to the small number of companies operating in the sector.

An important methodological issue concerning water-borne navigation and civil aviation is to make a distinction between domestic and international transport. The 2006 IPCC Guidelines clearly state that the international–domestic split should be determined on the basis of port of departure and port of arrival. By extension, that same principle should apply to aerospace transport. However, it is not clear in the 2006 IPCC Guidelines whether a journey of a craft that departs from one country but does not arrive in any other country should be defined as domestic or international transport. It is also unclear whether emissions occurring outside Earth's atmosphere should be included in either category. Furthermore, the classification of ground-based rocket testing as a form of either stationary or mobile combustion poses a methodological issue and activity data disaggregation challenge.

Activity data

1.A.3.a Civil aviation

MBIE currently collects data on aviation fuels used for international and domestic aviation through the DPFI. The respondents to this survey are New Zealand's four main oil companies, namely: BP, Z Energy, ExxonMobil 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 Energy and ExxonMobil supply 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 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. A number of factors 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 difference is 1.5 per cent for petrol and 4.8 per cent for diesel, which shows that the methods align very closely. This level of agreement compares favourably with the fuel data of other countries.

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 diesel consumption data provided by KiwiRail (the operator of inter-island 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 estimate. 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

For this submission, biodiesel has been disaggregated into the biogenic fraction and the fossil fraction. The biodiesel biogenic fraction continues to be classified as *Biomass*, while the biodiesel fossil fraction is classified as *Other fossil fuels*. Biodiesel produced and consumed in New Zealand is generally fatty acid methyl ester (FAME). To produce FAME, vegetable oil or animal fat is trans-esterified with methanol, which is assumed to be of fossil origin. Consequently, every single molecule of FAME contains one fossil carbon atom. While the exact fraction of fossil carbon in FAME depends on the nature of the feedstock oil, a value of 5.4 per cent is assumed based on measurements of a range of biodiesels from Reddy et al. (2008). As a result, part of the CO_2 emissions previously reported as biomass memo items are now included in the national total emissions.

For the 2019 submission, the Ministry of Transport has implemented several improvements for its estimates of non-CO_2 emissions from road transport: First, new emission factors for Euro 5 and 6 vehicles have been used, where previously these vehicles were treated as Euro 4/IV. Second, the European Monitoring and Evaluation Programme/European Environment Agency emission inventory guidebook was updated in late 2016 (European Environment Agency, 2016). Some of the emission factors for Euro 4 and earlier vehicles were also updated in the latest version of the guidebook. Moreover, detailed emission factors were provided for heavy duty trucks in different gross vehicle mass bands.

Source-specific planned improvements

MBIE is discussing with the Ministry of Transport the possibility of incorporating the results of a new aviation emissions model in the inventory estimates (for CH_4 and N_2O emissions). This will require time and resources to progress if it is deemed to be a worthwhile improvement. An update 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 2018, the *Fuel combustion – other sectors* category accounted for 2,796.1 kt CO_2-e (8.8 per cent of the emissions from the Energy sector). This is 116.0 kt CO_2-e (0.4 per cent) lower than the 1990 value of 2,912.1 kt CO_2-e.

Changes in emissions between 2017 and 2018

Between 2017 and 2018, emissions from 1.A.4 *Other sectors* decreased by 155.8 kt CO_2-e (5.3 per cent).

Key categories identified in the 2018 level and trend assessment for the *Other sectors* category are given in table 3.3.6.

Table 3.3.6 Key categories for 1.A.4 Other sectors

	Liquid fuels	Solid fuels	Gaseous fuels
Commercial/institutional – CO_2	Level, trend		Level, trend
Residential – CO_2	Level	Trend	Level, trend
Agriculture/forestry/fishing – CO_2	Level, trend		

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 2006 IPCC Guidelines, this inventory uses data provided by Stats NZ’s *Energy Use Survey* (Stats NZ, 2018) to estimate the split of historical ‘other primary industry’ activity for fuel oil between forestry and logging, and mining (see table 3.3.7). 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 3.3.7 Split of fuel oil activity for ‘other primary industry’

Activity	Energy Use Survey 2008 (%)	Energy Use Survey 2016 (%)
Forestry and logging	51.3	9.1
Mining	48.7	90.9

Solid fuels

In 2010, it was discovered that some coal reported as sold to the commercial sector was in fact being on-sold to re-sellers rather than directly to end-users. 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 1990–2018.

A number of synthetic solid fuels are used as lightweight cooking fuels by hikers and the military. Examples include hexamethylenetetramine, metaldehyde and trioxane, which are derived from chemical feedstocks such as aldehydes and ammonia, and hence contain fossil carbon. These fuels are not covered by the national energy balance and the emissions associated with their combustion have not been estimated.

Mixtures of solid fuels are combined with a wide range of metal, organic and non-organic compounds in the formulation of low explosive pyrotechnic devices that are used for entertainment purposes (fireworks). In New Zealand, most towns and cities hold public fireworks displays for the folkloric festival known as Guy Fawkes Night (5 November) and increasingly on other days to celebrate religious and cultural festivals, such as Diwali, Matariki and Lunar New Year, as well as at major sporting events. Consumer fireworks are also available for sale to the general public during the four-day period between 2 and 5 November; however, there is no restriction on the days of use. Fireworks are imported from overseas, generally China. The solid fuel in fireworks is combusted as a propellant for aerial fireworks and used to provide heat, light and sparks. Common fossil–carbon based fuels include carbon black and gilsonite. In addition to CO_2, greenhouse gas emissions also potentially include CH_4 and N_2O, although emission factors for these gases have not been sighted in the literature. Due to the wide range of chemical formulations, the precise quantity of solid fuel in fireworks is not known. In the absence of specific fuel data, any estimate of emissions will be highly uncertain. Nevertheless, a number of international reports have attempted to estimate CO_2 emissions and have suggested the level could be significant. Due to the current lack of an established methodology, an estimate of emissions for New Zealand has not been undertaken.

Solid biomass

Residential combustion of biomass is estimated using household number estimates from Stats NZ, 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 census data indicate that the popularity of woodburners is decreasing slowly over time. The energy content of biomass burned in each household was estimated by the study *Energy Use in New Zealand Households* (BRANZ, 2002).

The controlled outdoor combustion of biomass is a common pastime activity across New Zealand backyards, beaches and other public spaces as part of a celebration or to provide heat for warmth or cooking. Examples include bonfires, campfires, pizza ovens, braziers, fire pits and chimeneas. Traditional methods of cooking food using heated rocks buried in a pit oven include hāngī, umu and lovo. These activities are distinct from open-burning of unwanted biomass that is not used for energy purposes, which would be reported under the Waste sector. While activity data are not available, expert opinion indicates that the likely level of activity is relatively minor compared with the indoor residential combustion of biomass; therefore, emissions associated with these outdoor activities have not been estimated.

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 type (stationary combustion, mobile use, and fishing).

Source-specific planned improvements

There are no planned improvements for this category.

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 2018, fugitive emissions from fuels accounted for 1,779.6 kt CO_2-e (5.6 per cent) of emissions from the Energy sector. This is 442.5 kt CO_2-e (33.1 per cent) higher than the 1990 level of 1,337.1 kt CO_2-e.

Changes in emissions between 2017 and 2018

Between 2017 and 2018, fugitive emissions from fuels decreased by 160.5 kt CO_2-e (8.3 per cent). This was primarily the result of decreased activity in category 1.B.2.c.1 *Venting.*

Key categories identified in the 2018 level and trend assessment for the *Fugitive emissions* category are given in table 3.4.1.

Table 3.4.1 Key categories for 1.B Fugitive emissions

Category	CO_2	CH_4
Coal mining and handling – underground		Trend
Natural gas – distribution		Trend
Venting – gas	Level, trend	
Other – geothermal	Level, trend	Trend

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

Description

In 2018, fugitive emissions from the *Solid fuels* category accounted for 127.4 kt CO_2-e (7.2 per cent) of emissions from the *Fugitive emissions* category. This is 200.8 kt CO_2-e (61.2 per cent) lower than the 328.2 kt CO_2-e reported for 1990.

Between 2017 and 2018, fugitive emissions from the *Solid fuels* category decreased by 4.6 kt CO_2-e (3.5 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. This includes the emissions from post-underground mining activities such as coal processing, transportation and use. In 2018, New Zealand coal production was 3.2 million tonnes, similar to the 2015 production level. There are less than 20 active coal mines operating New Zealand; as of 2019, none are underground. The two largest open-cast operations, at Stockton and Rotowaro, account for the majority of national production. For further information and data on the coal mining industry refer to *Energy in New Zealand* (MBIE, 2019).

At the end of 2018, there was no known flaring or capture of CH_4 at coal mines in New Zealand. Pilot schemes of both coal seam gas and underground coal gasification began in 2012, but these projects have not progressed.

Methodological issues

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 (in 1988) of only 125 kt and so represent a very small sample size (compared 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 has been conducting an investigation (including 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 3.4.2. The second stage of the project, focusing on collating and digitising mine data for the South Island, commenced in December 2019 and is ongoing. Results will be reported in the 2021 submission. A mine plans database has been made available online (www.nzpam.govt.nz/maps-geoscience/nz-mine-plans), although this is still a work in progress.

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. Those mines have now closed and are flooded. Source-specific details are not provided so as to maintain confidentiality. Recovery and/or flaring of CH_4 from abandoned mines does not occur.

Table 3.4.2 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

As described above, the project to enable the more accurate estimation of emissions associated with abandoned coal mines is under way, and results will be included 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 2018, fugitive emissions from the *Oil and natural gas* category contributed 1,652.2 kt CO_2-e (92.8 per cent) to emissions from the *Fugitive emissions* category. This is 643.3 kt CO_2-e (63.8 per cent) higher than the 1990 level of 1,008.9 kt CO_2-e.

A source of emissions from the production and processing of natural gas is the Kapuni Gas Treatment Plant. 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. This is reported in CRF table 1.B.2.c.2.

The large increase in CO_2 emissions from the Kapuni plant 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 plant.

While emissions from the Kapuni plant 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 2018, emissions from geothermal operations were 736.9 kt CO_2-e, which is 453.5 kt CO_2-e (160.0 per cent) higher than the 1990 level of 283.4 kt CO_2-e.

Between 2017 and 2018, emissions from geothermal sources decreased by 9.6 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.

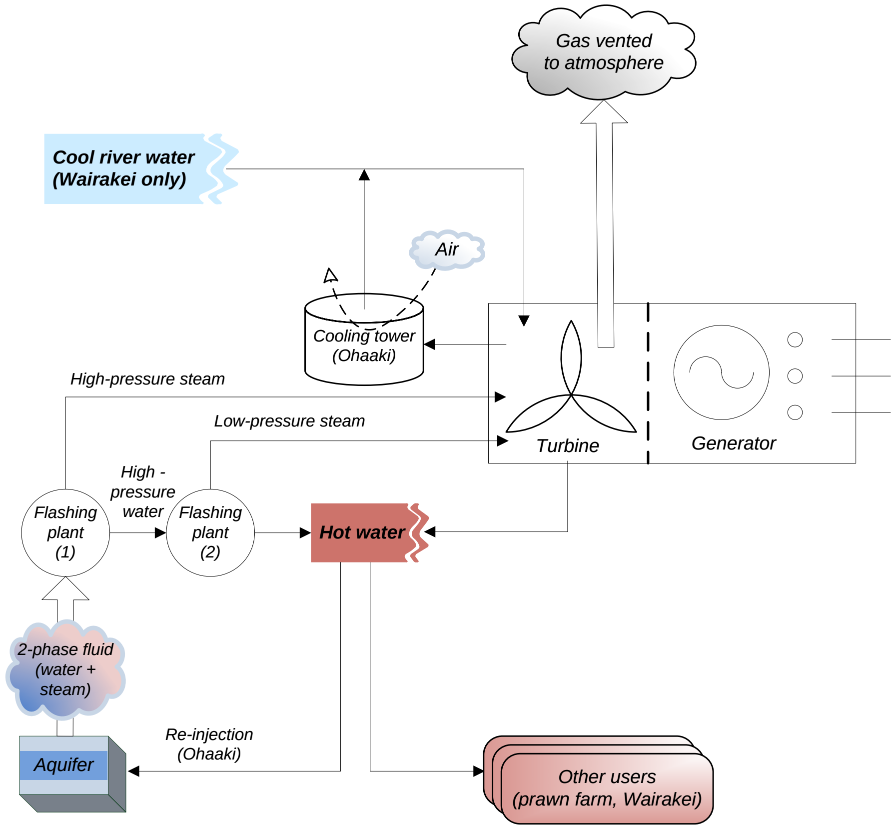
Venting of CO_2 resulting from hydrogen production at oil refineries is included in the IPPU sector so as to protect the confidentiality of individual companies (see chapter 4, for further information).

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 around 15 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 activities have stepped up incrementally over time. 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.

Because 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:

$$5823 \frac{tonnes of\ steam}{hour} x \frac{0.612 CO_2}{100} by weight of\ steam = 3.565 \frac{tonnes of\ CO_2}{hour}$$

And the total discharge per year is:

$$3.565 \frac{tonnes\ of\ CO_2}{hour} x 8760 \frac{hours}{year} = 31{,}230 \text{ tonnes of } CO_2.$$

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, 2019). 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, 2019).

1.B.2.a.4 Refining

Activity data are total intake at New Zealand's sole oil refinery (MBIE, 2019).

1.B.2.a.5 Distribution of oil products

Activity data are New Zealand's total consumption of gasoline (MBIE, 2019).

1.B.2.b.3 Processing

Venting of CO_2 is reported under 1.B.2.c.2 in accordance with a previous ERT recommendation. No activity data are available.

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 the system 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. Data are provided for gigajoules (GJ) of CH_4 and tonnes of CO_2. Gigajoules of CH_4 are converted to tonnes of CH_4 using the conversion factor of 55.6 GJ/t. New Zealand has a high-pressure transmission network nearly 3,500 kilometres in length. It joins most North Island cities (natural gas is available only 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.4 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. A significant portion of 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.

The operator of the Kapuni Gas Treatment Plant, supplies estimates of CO_2 vented during the processing of natural gas.

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 historical data are not available. The individual geothermal fields each produce varying levels of output and emissions so the overall implied emission factors display a certain amount of natural variation.

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 including 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 for small-scale medical and scientific applications. Historically, a very small amount of SF_6 has 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.

New Zealand reports emissions from Tokelau, which is a dependent territory of New Zealand. Emissions from Tokelau for all activities are reported in annex 7 of the National Inventory Report and within the 'Other' sector in the common reporting format (CRF) tables. This is due to the significantly different methods applied and the prohibitive complexity of integrating emissions within the main sectors. Therefore, all emissions reported in this sector are from New Zealand excluding Tokelau. Please refer to chapter 8 and annex 7 for details of methods applied and the emissions for Tokelau.

4.1.2 Emissions summary

The IPPU sector in New Zealand produces CO_2 emissions (59.7 per cent), fluorinated gases (36.9 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.

2018

In 2018, emissions in the IPPU sector contributed 5,158.1 kilotonnes carbon dioxide equivalent (kt CO_2-e), or 6.5 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.

1990–2018

IPPU sector emissions in 2018 were 1,578.3 kt CO_2-e (44.1 per cent) higher than emissions in 1990 (3,579.9 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 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 figures 4.1.1 and 4.1.2.

2017–2018

IPPU sector emissions in 2018 were 36.8 kt CO_2-e (0.7 per cent) higher than emissions in 2017. This change was the net result of an increase in emissions from the *Product uses as substitutes for ODS* category (157.5 kt CO_2-e or 9.5 per cent) offset by small decreases in all other significant categories driven by varying production rates.

Table 4.1.1 New Zealand's greenhouse gas emissions for the IPPU sector by source category in 1990 and 2018

	Emissions (kt CO_2-e)		Difference (kt CO_2-e)	Change (percentage)	Share (percentage)	
Source category	**1990**	**2018**	**1990–2018**	**1990–2018**	**1990**	**2018**
Mineral industry (2.A)	561.9	615.1	53.3	9.5	15.7	11.9
Chemical industry (2.B)	203.0	260.0	57.0	28.1	5.7	5.0
Metal industry (2.C)	2,670.2	2,321.7	–348.5	–13.1	74.6	45.0
Non-energy products from fuels and solvent use (2.D)	25.1	48.9	23.8	94.7	0.7	0.9
Product uses as substitutes for ODS (2.F)	–	1,815.9	1,815.9	–	–	35.2
Other product manufacture and use (2.G)	119.7	96.4	–23.3	–19.5	3.3	1.9
Total	**3,579.9**	**5,158.1**	**1,578.3**	**44.1**	**–**	**–**

Note: Columns may not sum due to rounding.

Figure 4.1.1 New Zealand's annual emissions from the IPPU sector from 1990 to 2018

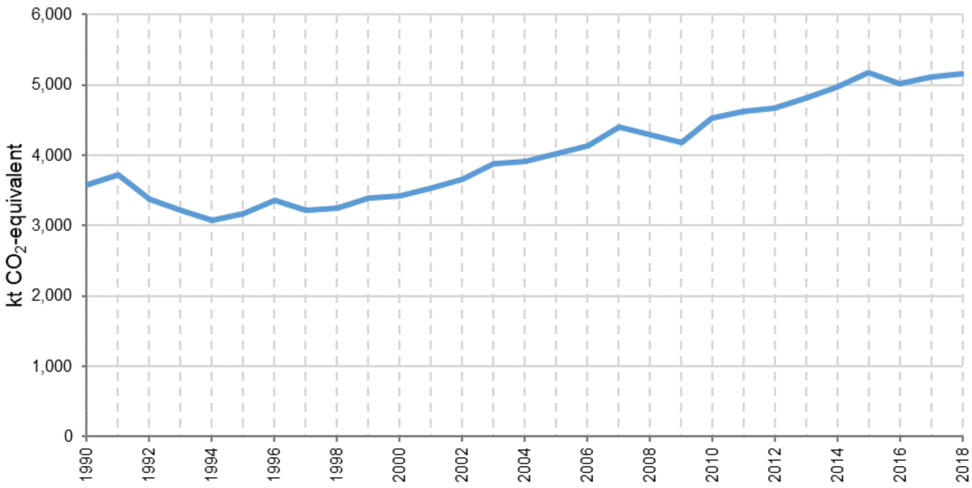
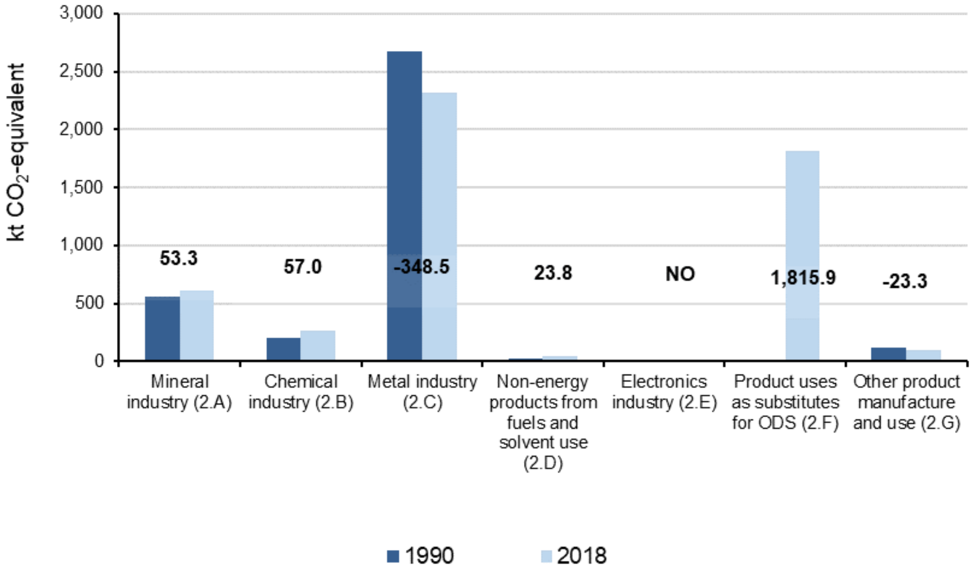


Figure 4.1.2 Change in New Zealand's emissions from the IPPU sector from 1990 to 2018



Note: Emissions from the *Electronics industry* are not occurring (NO).

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.

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, T1
2.C.1	Metal Industry – Iron and Steel Production	CO_2	L1, T1
2.C.3	Metal Industry – Aluminium Production	CO_2	L1, T1
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

Note: 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 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 this submission, emissions from refrigeration and air conditioning for all years have been recalculated to better account for import volumes and refrigerant stockpiled by importers.

Expert review team comments

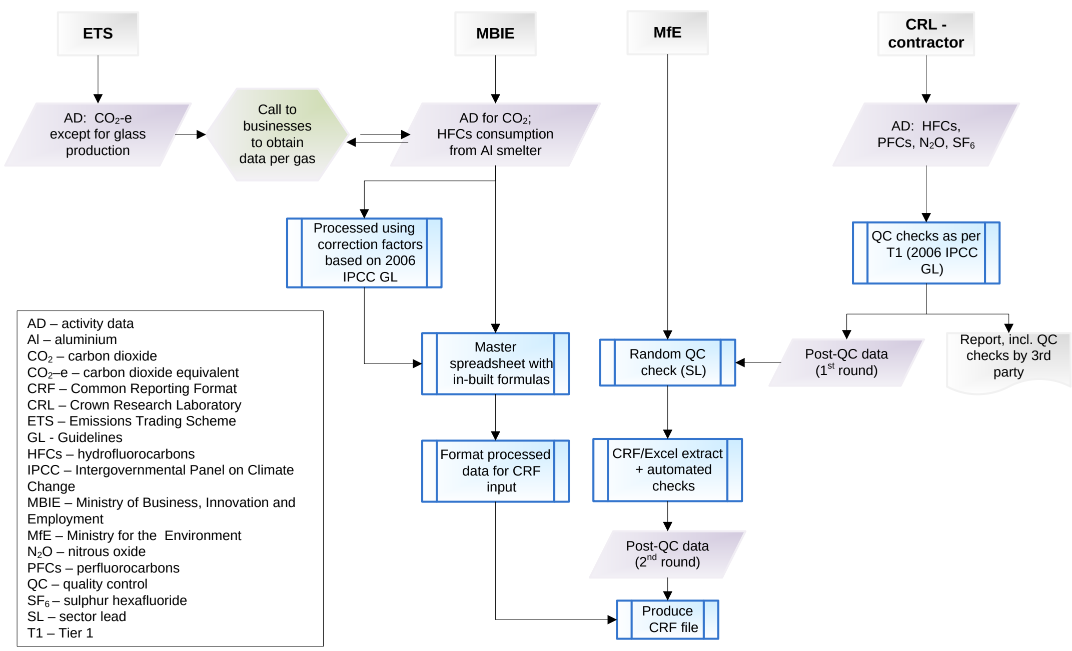
Expert review teams (ERTs) have recommended that New Zealand continue efforts to address the transparency of activity data in the *Mineral industry*, *Chemical industry* and *Metal industry* categories. This relates to activity data that are reported as confidential. Commercial confidentiality remains 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: Tier 1 quality checks for the IPPU sector



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 glass, aluminium, and iron and steel. 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.

Only one cement production facility is now operating in New Zealand, a dry-process plant operated by Golden Bay Cement Ltd near Whangarei. Holcim New Zealand Ltd 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), 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 2018, the *Mineral industry* source category accounted for 615.1 kt CO_2-e (11.9 per cent) of emissions from the IPPU sector. This is 53.3 kt (9.5 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 since 2015 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). These improvements have been continued over time.

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 2018, the *Cement production* category accounted for 418.0 kt CO_2-e (67.9 per cent) of emissions from the *Mineral industry* category. The activity data used are the amounts 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 tables. 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 2018, the *Lime production* category accounted for 109.6 kt CO_2-e (17.8 per cent) of emissions from the *Mineral industry* category. The activity data used are the amounts of burnt lime or 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 produce 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 2010–18, the glass companies' NZ 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 CO_2 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, 2006a).

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, 2018). 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 volume 3, Industrial Processes and Product Use, of the IPCC Guidelines (IPCC, 2006a) 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 2014–18, NZ ETS returns are the data source. The companies carry out analysis and report the net amount of pure CaO as well as gross amounts 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 for the *Mineral industry* source category in this submission.

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 cement and 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. The consistent reporting of activity data for 2.A.2 *Lime production* is also an ongoing issue, due to different methods being applied at different times, and will be reviewed for the 2021 submission.

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 therefore all 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 2018 were 260.0 kt CO_2-e (5.0 per cent) of emissions from the IPPU sector. This is 57.0 kt CO_2-e (28.1 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 and 2017 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, Evonik Limited, 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 ethanol for purposes other than food and drink, superphosphate fertiliser, and formaldehyde.

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, 2006a). 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, 2006a). Any small amount of process 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, 2006a). 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.

In some years, these emission factors are higher 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. Kapuni gas has, however, not been used in the years 2015 to 2018.

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.

IPCC default emission factors are used to estimate emissions of CH_4 from methanol manufacture and CO_2 from calcium carbide use (IPCC, 2006a). 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 methanol 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.

New Zealand has two steel producing sites. 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 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) from 1990 to 2015 and from use of SF_6 in a magnesium foundry from 1990 to 1999.

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 2018 were 2,321.7 kt CO_2-e (45.0 per cent) of emissions from the IPPU sector. This is 348.5 kt CO_2-e (13.1 per cent) below the 1990 level. The decrease was 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. A small decrease in emissions occurred 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 2018, the *Iron and steel production* category accounted for 1,694.4 kt CO_2-e (73.0 per cent) of emissions from the *Metal industry* source category. The activity data (tonnes of steel produced) are provided to MBIE, by two steel producers up to 2015 and now by one; they are regarded as commercially confidential and are reported as confidential in the CRF.

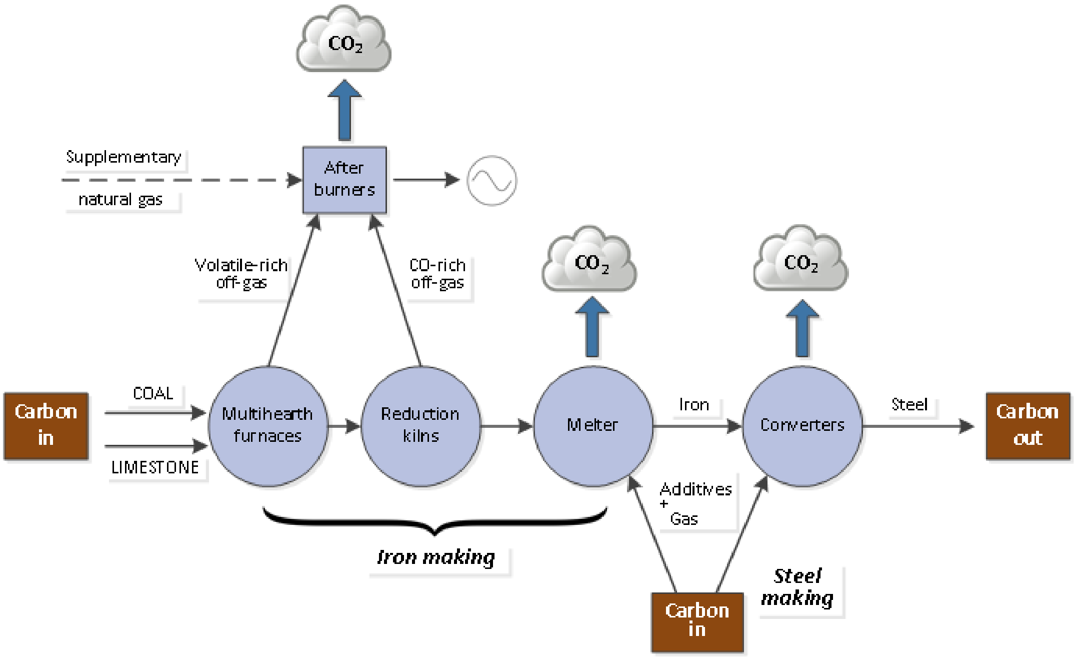
Most of the CO_2 emissions from the *Iron and steel production* category are produced through the production of iron from titanomagnetite iron sand. Nearly all of the emissions in this process come from the use of sub-bituminous coal as a reducing agent. There is no carbon in the iron sand used by New 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 4.4.1 shows a simplified illustration of steel production in New Zealand.

Figure 4.4.1 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 are derived 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 perfluoromethane (CF_4) and perfluoroethane (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 2018, the *Aluminium production* category accounted for 627.3 kt CO_2-e (27.0 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 2018, the CO_2 and PFC emissions data and activity data have been sourced from the company's NZ 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 have also been estimated using the Tier 2 mass balance approach. The average carbon content (0.2 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 2006a 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 and later years. 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) from 1993 to 2018. This methodology is replicated in the reporting requirements the company now uses in its NZ 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

There are no recalculations for this source category.

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, a small amount of CO_2 is reported from the use of urea-based catalysts in diesel exhaust fluid (DEF) for control of NO_x emissions in diesel engine exhaust gas. These emissions are associated with transport, and the method used is given in volume 2, Energy, of the 2006 IPCC Guidelines (IPCC, 2006b); however, the CRF does not appear to allow for them to be reported in the Energy sector, so they are placed in 2.D.3.

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 2018 were 48.9 kt CO_2-e (0.9 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 from the years 2011 on, and is considered to be unreliable for 2011 to 2014 due to under-reporting of imports. 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 unlikely such variations are reflected in actual lubricant use and emissions, averaging is used to estimate emissions for 2015–18.

Paraffin wax use (2.D.2)

A 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.

Use of urea-based catalysts in transport (2.D.3)

The activity data (quantity of DEF used) are estimated from total sales of diesel, with the assessment that 33 per cent of fuel is used in heavy vehicles and 51 per cent of the heavy vehicle fleet currently uses DEF. The amounts for years up to 2016 are estimated by back-casting the uptake of vehicles that require DEF over time.

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 2006–18 in the absence of any updated information.

Choice of methods

Tier 1 methods (IPCC, 2006a and 2006b) 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, 2006a).

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.

Use of urea-based catalysts in transport (2.D.3)

Default emission factors are used. DEF sold in New Zealand conforms with international norms and contains 32.5 per cent urea, which is the default value.

Asphalt paving and roofing and solvent use (2.D.3)

The bitumen content of road paving used in New Zealand is about 6 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 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 by weight of bitumen in asphalt (B above)
1990–2001	0.80
2002–2003	0.65
2004–2018	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 were reassessed for the 2019 submission resulting in small changes to the entire time series. There are no recalculations for the 2020 submission.

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 and urea-based catalysts.

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 2018, emissions in the *Product uses as substitutes for ODS* category were 1,815.9 kt CO_2-e or 35.2 per cent of emissions from the IPPU sector. This was an increase of 157.5 kt CO_2-e (9.5 per cent) from the 2017 level of 1,658.4 kt CO_2-e. No HFCs or PFCs were used 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 the *Aerosols* category (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 (2006a) (see box 4.1).

Box 4.1

IPCC (2006a) 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 are no refrigerant chemicals manufactured domestically 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 large year-to-year variations in the amounts imported. Imports to New Zealand are variable at any time, due to the small amounts of some refrigerants that are used. In addition, import volumes have fluctuated at various times due to price changes.

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 2010–18. Limited information on some of the models imported indicates that the ongoing trend to reduce these charges has continued after 2009 (CRL Energy Ltd, unpublished(c)).

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. Small quantities of HFC-245fa are estimated to be contained in insulating foam in refrigerators and freezers that are imported from Mexico and the United States of America. Imported items from other source countries are unlikely to contain HFCs.

Fire protection (2.F.3)

Three companies in New Zealand import and supply fire protection equipment that contains HFC-227ea, with two other firms installing small amounts in marine fire protection systems. 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, approximately 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 per cent in 2000
- 1 per cent (approximately 17 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 (2006a) (box 4.2).

Box 4.2

IPCC (2006a) equation 7.9

Emissions = Annual Sales of New Refrigerant — Total Charge of New Equipment + Original Total Charge of Retiring Equipment — Amount of Intentional Destruction

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.

Table 4.7.2 summarises the methodological tiers that are used for each sub-application.

Table 4.7.2 Summary of methodological tiers by sub-application

Sub-application	Chemical	Method used (Tier)
Household refrigeration	HFC-134a	2a
Commercial refrigeration	HFC-32	2a
	HFC-125	2b to 2006, 2a for 2007–18
	HFC-134a	2a
	HFC-143a	2b
Industrial refrigeration	HFC-32	2a
	HFC-125	2a
	HFC-134a	2b
	HFC-143a	2a
Transport refrigeration	HFC-32	2a
	HFC-125	2a
	HFC-134a	2a
	HFC-143a	2a
Stationary air conditioning	HFC-32	2b
	HFC-125	2a to 2006, 2b for 2007–18
	HFC 134a	2a
Mobile air conditioning	HFC-134a	2b

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, 2006a, 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 4.7.3.

Table 4.7.3 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, and uncertainties are estimated for each sub-application based on expert judgement.

Uncertainties in this source category have been estimated for each sub-application, and table 4.7.4 summarises the uncertainties for each category. For the *Refrigeration and air conditioning* category, uncertainty is attributed only to the activity data.

Table 4.7.4 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	±32	N/A
Foam blowing agents	±12	±50
Aerosols	±25	±10
Fire protection	±10	±41

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 QA/QC 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 survey information on import volumes where possible.

There are no other key categories. Data underwent Tier 1 quality checks.

4.7.5 Source-specific recalculations

In the 2018 and 2019 inventory submissions, emissions from the *Refrigeration and air conditioning* source category were recalculated as a result of small changes to the amounts of chemical in banks, following stockpiling by importers, and to ensure the reported emissions are not unduly affected by stockpiling. Also, as in the 2018 submission, HFCs exported for destruction are reported as intentional destruction. In earlier submissions, this was excluded from the CRF tables because the destruction does not take place in New Zealand.

For this submission, stock levels of R125a, R134a and R1434a, held between 2013 and 2017, have been further reassessed on the basis of survey responses. This removed some implausible discontinuities in use and emissions. Such assessments are needed from time to time because data on imports and stockpiling are sometimes incomplete.

The impact of this recalculation is to increase the 2017 emissions by 156.6 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 be likely to affect total emissions if they are averaged over a longer period.

4.7.6 Source-specific planned improvements

No specific improvements are planned for this source category. There are still some year-to-year variations in emissions from the *Refrigeration and air conditioning* source category, which may be 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 2018, net emissions of SF_6 and N_2O from the *Other product manufacture and use* category totalled 96.4 kt CO_2-e or 1.9 per cent of emissions from the IPPU sector. This is a decrease of 23.3 kt (19.5 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 tonne of the gas in operating equipment, report their holdings and emissions in NZ 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.

Enquiries to importers and the tyre industry indicate that there is no use of SF_6 in New Zealand for other applications such as tyres and shoes.

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 2018. 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, 2006a).

Improved information from surveys has allowed the use of these two different equipment types in New Zealand to be better disaggregated over time, and the choice of emission factors is now more accurate than in previous submissions (CRL Energy, unpublished(c)). However, this distinction is not always clear and remains a source of 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 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 (2006a) 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 (2005–18 ±80 (2000–04)	–
Medical and other product use (PFCs)	±80	–
N_2O from other product uses	±30 (2002–12) ±5 (2013–18)	–

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 and other users over time.

4.8.4 Source-specific QA/QC and verification

Other product manufacture and use was a non-key category.

4.8.5 Source-specific recalculations

For the 2019 submission, one of the electricity network companies reported on a reassessment of its equipment and SF_6 stocks, which resulted in a small recalculation. For the 2020 submission, several users reported more detailed information, which allowed a small revision of their emissions for 2011 to 2017. This has reduced 2017 emissions by 2.1 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 submissions.

Chapter 4: References

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Chapter 5: Agriculture

5.1 Sector overview

The Agriculture sector produced an estimated 37,697.0 kilotonnes carbon dioxide equivalent (kt CO_2-e) emissions, representing 47.8 per cent of New Zealand's gross emissions in 2018.

Enteric fermentation was the main source of agriculture emissions, contributing 74.1 per cent (27,939.0 kt CO_2-e) of the sector's emissions. *Agricultural soils* (18.6 per cent) was the second largest source followed by *manure management* (4.3 per cent). *Urea application* and *liming* contributed 1.6 and 1.3 per cent respectively. *Field burning of agricultural residues* contributed the remaining 0.1 per cent.

Methane (CH_4) emissions from *Enteric fermentation* were 35.4 per cent of New Zealand's gross emissions, and nitrous oxide (N_2O) emissions from the *Agricultural soils* category were 8.9 per cent of New Zealand's gross emissions.

New Zealand reports emissions from Tokelau, which is a dependent territory of New Zealand. These are reported for all activities in annex 7 of the National Inventory Report and within the 'Other' sector in the common reporting format (CRF) tables. Therefore, all emissions reported in this sector are from New Zealand excluding Tokelau. Please refer to chapter 8 and annex 7 for details of methods applied and the emissions for Tokelau.

Trends

Emissions from agriculture increased by 17.1 per cent (5,515.0 kt CO_2-e) between 1990 and 2018 and increased by 0.7 per cent between 2017 and 2018.

Table 5.1.1 Trends and relative contribution of New Zealand's agricultural greenhouse gas emissions by category between 1990 and 2018

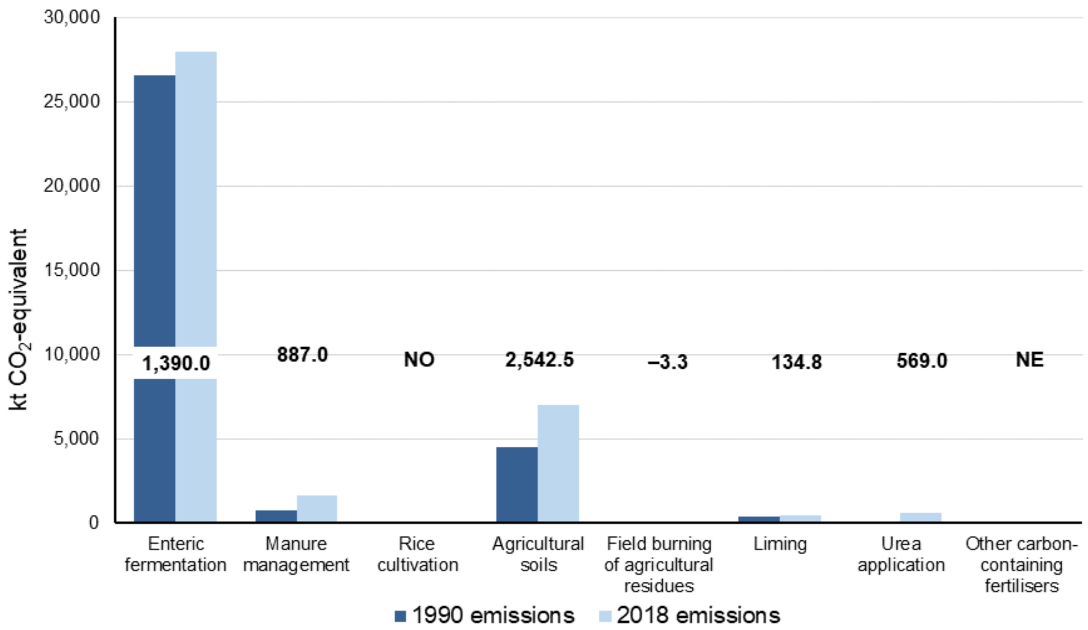
	Emissions (kt CO_2-e)		Change (percentage)	Difference (kt CO_2-e)	Share (percentage) of sector	
Category	**1990**	**2018**	**1990–2018**	**1990–2018**	**1990**	**2018**
Enteric fermentation (CRF 3.A)	26,548.9	27,939.0	5.2	1,390.0	82.5	74.1
Manure management (CRF 3.B)	722.6	1,609.7	122.7	887.0	2.2	4.3
Rice cultivation (CRF 3.C)	NO	NO	–	–	–	–
Agricultural soils (CRF 3.D)	4,483.8	7,026.3	56.7	2,542.5	13.9	18.6
Field burning of agricultural residues (CRF 3.F)	27.4	19.0	–30.7	–8.4	0.1	0.1
Liming CO_2 emissions (CRF 3.G)	360.1	494.9	37.4	134.8	1.1	1.3
Urea application CO_2 emissions (CRF 3.H)	39.2	608.2	1,451.7	569.0	0.1	1.6
Other carbon-containing fertilisers (CRF 3.i)	NE	NE	–	–	–	–

Note: NO = not occurring, NE = not estimated. Percentages presented are calculated from unrounded values.

The greatest contributions to the increase since 1990 are a 56.7 per cent (2,542.5 kt CO_2-e) increase in N_2O emissions from *Agricultural soils* and a 5.2 per cent (1,390.0 kt CO_2-e) increase in CH_4 emissions from *Enteric fermentation*.

The application of synthetic nitrogen fertiliser has increased by about 672 per cent since 1990 driving the increase in N_2O emissions from *Agricultural soils*. The increase in emissions from *Enteric fermentation* is driven by increases in dairy cattle numbers, which have been partially offset by a decrease in non-dairy cattle and sheep. The change in animal populations since 1990 reflects relative financial returns to each industry (it has been more profitable to farm dairy cattle than beef cattle or sheep in New Zealand over the reporting period).

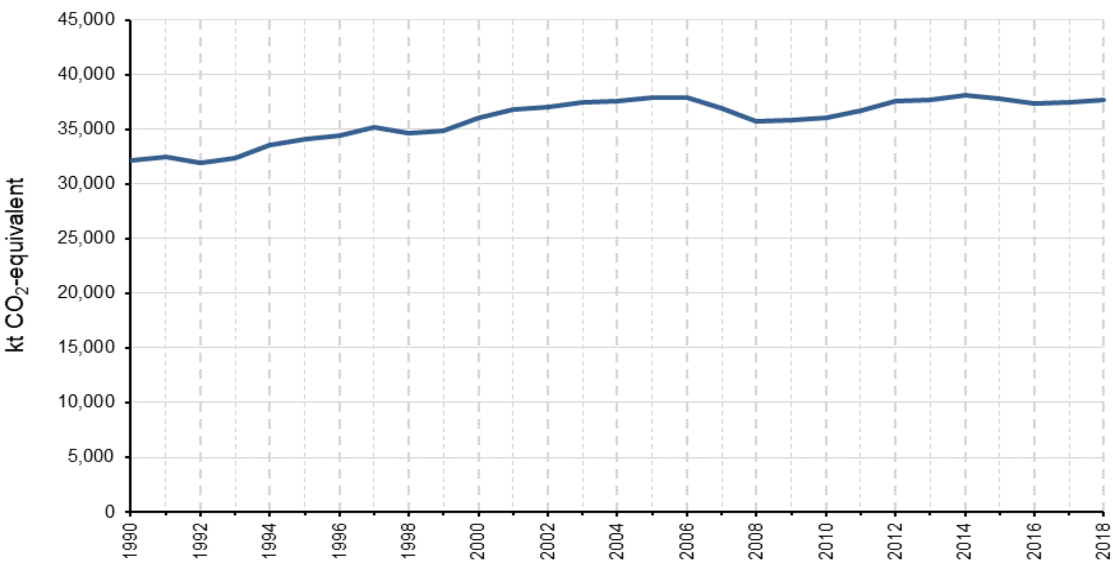
Figure 5.1.1 Change in New Zealand's emissions from the Agriculture sector from 1990 to 2018



Note: Rice cultivation does not occur (NO) in New Zealand. Emissions from other carbon-containing fertilisers are not estimated (NE).

Agriculture emissions peaked at 38,131.6 kt CO_2-e in 2014, corresponding to a peak in dairy cattle (and total cattle overall). Agriculture emissions previously peaked in 2005 but dropped significantly during the Global Financial Crisis (2007 to 2008). Agriculture emissions have remained slightly below the 2014 peak in the years 2015 to 2018, this is due to a drop in the profitability of dairy (relative to other primary exports) in 2015 (figure 5.1.2).

Figure 5.1.2 New Zealand's Agriculture sector emissions from 1990 to 2018



Changes in emissions between 2017 and 2018

Total agricultural emissions in 2018 were 0.7 per cent (278.2 kt CO_2-e) higher than 2017 emissions, because emissions from non-dairy (beef) cattle, dairy cattle, sheep, and fertiliser use all increased. This included:

- *Non-dairy cattle* emissions, which increased 1.3 per cent (82.0 kt CO_2-e) due to an increase in the non-dairy cattle population
- *Dairy cattle* emissions, which increased 0.3 per cent (49.3 kt CO_2-e), as a small fall in the national dairy herd population was offset by a small increase in total milk production (LIC and DairyNZ, 2019)
- *Sheep* emissions, which increased 0.4 per cent (41.7 kt CO_2-e), as average slaughter weights for sheep increased
- *Synthetic nitrogen fertiliser* emissions (N_2O), which increased 3.3 per cent (54.0 kt CO_2-e)
- *Urea* application CO_2 emissions, which increased 3.4 per cent (19.9 kt CO_2-e)
- *Liming* CO_2 emissions, which rose by 7.7 per cent (35.3 kt CO_2-e).

5.1.1 New Zealand farming practices and trends

Agriculture is a major component of the New Zealand economy, and exports from agricultural products (excluding fisheries and forestry) comprise 60.2 per cent of the total free on board value of merchandise exports (Statistics New Zealand, 2019).The production of land-based agricultural products in New Zealand is helped by the favourable temperate climate, access to natural water resources, 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, complemented by synthetic nitrogen fertiliser use. The common use of outdoor pastoral grazing systems means that New Zealand's agricultural production is more sensitive to climatic events than countries that use intensive and indoor feedlots.

Dairy cattle, non-dairy cattle (beef), sheep and deer are grazed outdoors all year round, and intensive housing of major ruminant livestock species is not practised widely 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 off-paddock 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 (Ministry for the Environment, 2017).

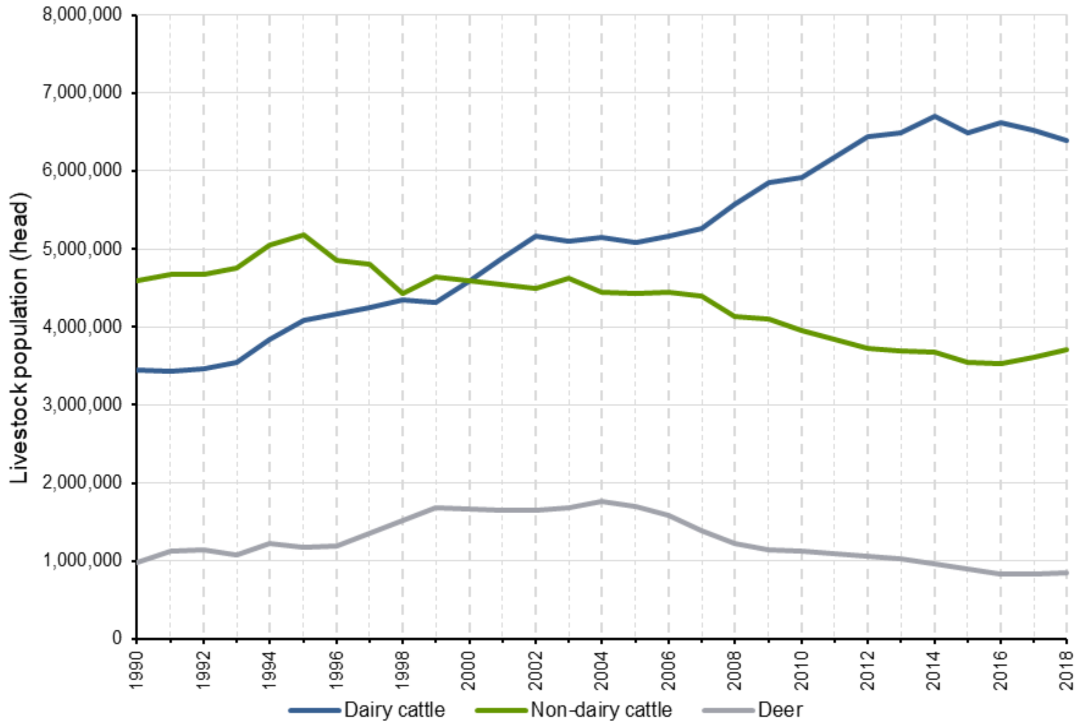
Trends in Agriculture sector emissions are largely driven by the populations of the ruminant livestock categories (dairy cattle, non-dairy cattle, sheep and deer). In 1990 and 2018 respectively, 95.7 per cent and 91.2 per cent of agricultural emissions originated from these ruminant livestock categories.

Agriculture and horticulture activities (excluding forestry) use approximately 45 per cent of New Zealand's land area, and approximately 38 per cent (of New Zealand's land area) is used for grazing livestock. 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 the relative profitability of these farming enterprises. The land area used for sheep, beef and deer grazing has decreased by 34.2 per cent (4,257,525 hectares) (Beef + Lamb

New Zealand Ltd, 2019), while the area used for dairy grazing has increased by 70.4 per cent (720,128 hectares) (LIC and Dairy NZ, 2019) between 1990 and 2018.

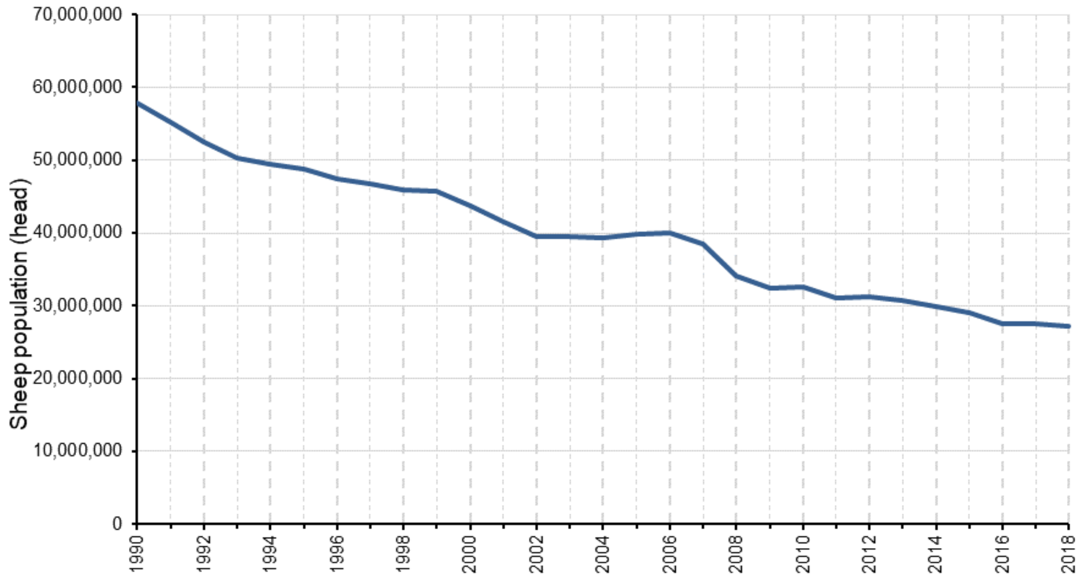
The use of synthetic nitrogen fertiliser in the Agriculture sector increased by 672.5 per cent since 1990. Total emissions from synthetic nitrogen fertiliser (including CO_2 from urea) have increased from 1.0 per cent (1990) to 6.2 per cent (2018) of agricultural emissions. Increases in New Zealand's agricultural productivity and changes in farming practices (shift from sheep and beef to dairy) over this period are responsible for this increase.

Figure 5.1.3a **Populations of New Zealand's dairy cattle, non-dairy cattle and deer from 1990 to 2018 (June year ending)**



Source: Statistics New Zealand

Figure 5.1.3b **Population of New Zealand's sheep from 1990 to 2018 (June year ending)**



Source: Statistics New Zealand

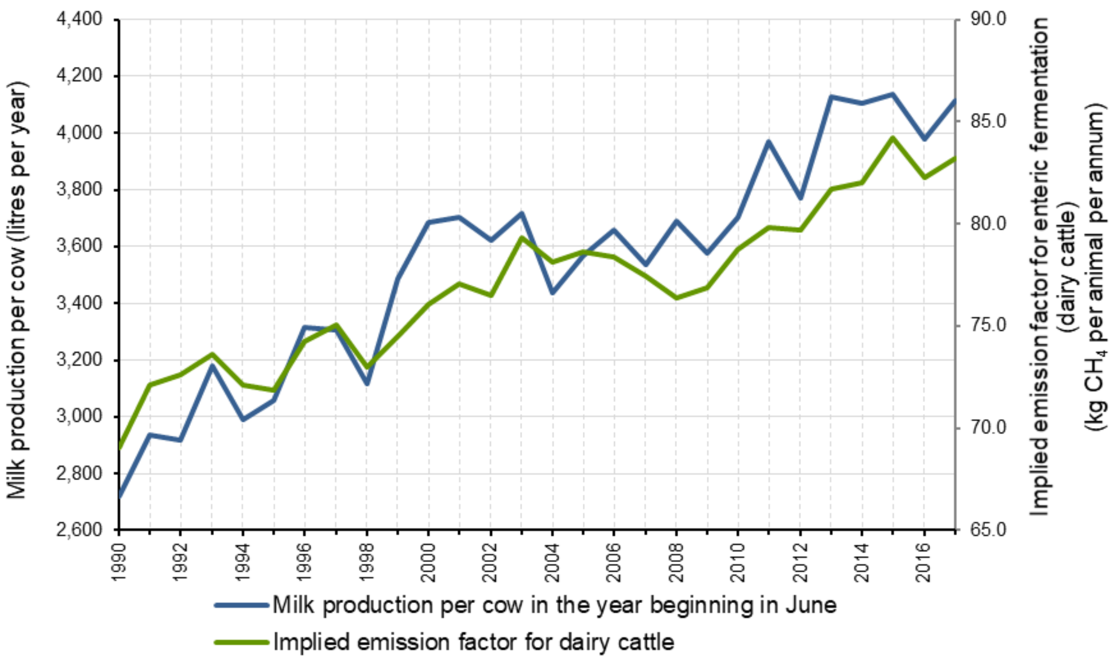
Effect of productivity improvements and climatic events on implied emission factors

There has been a gradual increase in the implied CH_4 and N_2O emission factors[37] per head of the major livestock species farmed in New Zealand. This trend reflects the increased levels of productivity (milk and meat yield per head and lambing percentage) achieved by New Zealand farmers between 1990 and 2018. 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)). Since 1990, emissions per unit of product (i.e., milk and meat emissions intensity) have decreased.

The use of year-round extensive outdoor pastoral grazing systems means New Zealand production is dependent on the quantity and quality of pasture that can be grown on land managed by farmers. Pasture growth is strongly influenced by weather and climatic events, such as droughts and floods. These factors can cause changes in per-animal productivity and mean that IEFs can be noticeably different in adjacent years. In 2008, a major 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.

An example of this is included in figure 5.1.4, which overlays milk production per dairy cow with the IEFs (enteric fermentation) for dairy cattle from 1990 to 2018. The figure shows that, while per cow productivity has trended upward, there is a significant amount of inter-annual variability (influenced by climatic conditions). It also shows that the IEFs are affected by these changes in productivity.

Figure 5.1.4 Dairy milk productivity and implied enteric fermentation methane emission factors for dairy cows from 1990 to 2018



Note: Milk production per cow is calculated by dividing total milk production by the milking dairy cattle population (i.e., excluding replacements and breeding bulls).

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37 Implied emission factors (IEFs) are calculated by dividing the total emissions of a particular animal species and sector (e.g., enteric fermentation from sheep) by the number of animals.

5.1.2 Key categories for Agriculture sector emissions

Details of New Zealand's analysis of key categories are in chapter 1, section 1.5. The key categories in the Agriculture sector are listed in table 5.1.2.

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, T1
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, T1
3.D.2.2	Indirect N_2O Emissions from Managed Soils – Nitrogen Leaching and Runoff	N_2O	L1
3.G	Agriculture – Liming	CO_2	L1
3.H	Agriculture – Urea Application	CO_2	L1, 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.

5.1.3 Methodological issues for the Agriculture sector

The Agriculture sector includes emissions of CH_4 and N_2O from livestock industries (estimated in *Enteric fermentation* and *Manure management*). In New Zealand, the predominant species (in terms of population) are sheep, followed by dairy cattle, non-dairy cattle and deer. New Zealand breeds are selected to operate under outdoor pastoral farming systems.

Other agricultural emission sources include N_2O from *Agricultural soils*, CH_4 and N_2O from *Field burning of agricultural residues* and CO_2 from *Liming* and *Urea application.*

New Zealand uses a range of models and tiers appropriate to the size of the different emission categories. For example, 91.2 per cent of New Zealand's livestock emissions come from *Dairy cattle*, *Non-dairy cattle*, *Deer* and *Sheep* ('major' livestock categories). Emissions from major livestock categories are estimated using Tier 2 methodologies. Other livestock species, including *Swine*, *Goats*, *Horses*, *Llamas and alpacas*, *Mules and asses* and *Poultry* ('minor' livestock categories) account for only 0.5 per cent of agriculture emissions, and are estimated using Tier 1 methodologies.

Table 5.1.3 summarises methods and emission factors for agriculture categories.

Table 5.1.3 Methods and emission factors in the Agriculture sector

		CH_4		N_2O		CO_2	
	Source category	**Method applied**	**Emission factor**	**Method applied**	**Emission factor**	**Method applied**	**Emission factor**
A	**Enteric Fermentation**	–	–	–	–	–	–
	Cattle						
1	Dairy Cattle	T2	CS				
	Non-dairy Cattle	T2	CS				
2	Sheep	T2	CS				
3	Swine	T1	CS				
4	Other Livestock (Buffalo, Camels, Deer, Goats, Horses, Mules and Asses, Poultry)	T1, T2	CS, D				
B	**Manure Management**						
	Cattle						
1	Dairy Cattle	T2	CS	T2	D		
	Non-dairy Cattle	T2	CS	NA	NA		
2	Sheep	T2	CS	NA	NA		
3	Swine	T1	CS	T1	CS		
4	Poultry	T1	D	T1	CS		
	Other Livestock (Buffalo, Camels, Deer, Goats, Horses, Mules and Asses)	T1, T2	CS,D	NA	NA		
C	**Rice Cultivation**	NA	NA				
D	**Agricultural Soils**						
	Direct Emissions						
	Inorganic Fertilisers			T2	CS		
	Animal Manure applied to Soils			T1, T2	CS		
	Sewage Sludge applied to Soils			NA	NA		
	Other Organic Fertilisers applied to Soils			NA	NA		
1	Urine and Dung Deposited by Grazing Animals			T1, T2	CS		
	Crop Residues			T2	CS		
	Mineralisation associated with Loss of Soil Organic Matter			T1	D		
	Cultivation of Organic Soils			T1	D		
	Indirect Emissions						
2	Atmospheric Deposition			T1, T2	D		
	Nitrogen Leaching and Runoff			T1, T2	CS		
E	**Prescribed Burning of Savannas**	NA	NA	NA	NA		
F	**Field Burning of Agricultural Residues**	T2	CS	T2	CS		
G	**Liming**					T1	D
H	**Urea Application**					T1	D
I	**Other Carbon-containing Fertilisers**					NA	NA

Note: CS = Country Specific; D = IPCC Guidelines (2006) Default; NA = not applicable; T1 = Tier 1; T2 = Tier 2.

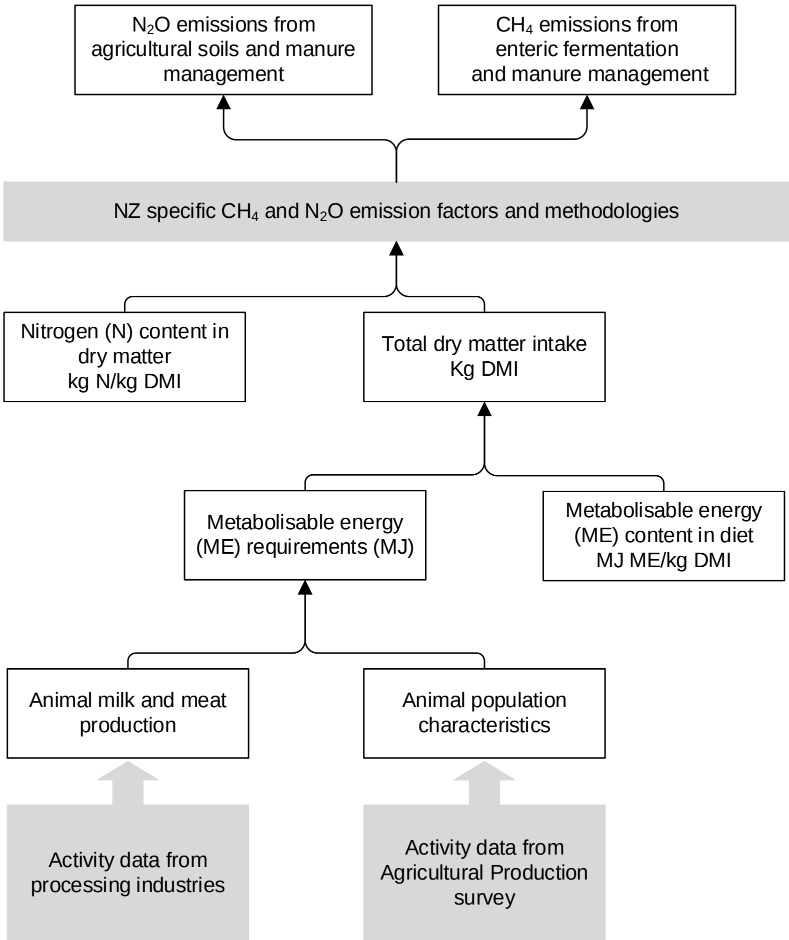
Further technical detail is provided in the inventory methodology document on the Ministry for Primary Industries (MPI) website (www.mpi.govt.nz/dmsdocument/13906-detailed-methodologies-for-agricultural-greenhouse-gas-emission-calculation) and in the methodological issues section for each category in this document. 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). This national 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 due to its use of thoroughly researched country-specific emission factors and the use of monthly data intervals for livestock populations, animal productivity and pasture quality. Figure 5.1.5 outlines the methodology used to estimate emissions for the four major livestock categories.

Agricultural production (meat, milk and wool) and livestock population data are combined with data on the total metabolisable energy (ME) content of the animal's diet. This is used to determine the level of feed intake required to meet total annual productivity levels of the livestock categories, 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 subsequent nitrogen excretion, and hence N_2O emissions.

Figure 5.1.5 Simplified methodology for calculating emissions for major ruminant livestock categories



Note: CH_4 = methane; DMI = dry-matter intake; kg = kilogram; MJ = megajoule; N_2O = nitrous oxide; NZ = New Zealand.

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 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 ruminants, 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, gender, breed and stage of maturity (ME_{BASAL})
- energy required for the given level of productivity (milk yield and liveweight gain for dairy and beef production respectively) and physiological state (e.g., pregnant or lactating)
- the additional amount of energy expended during grazing, compared with similar housed animals (ME_{GRAZE}).

$$ME_{TOTAL} = ME_{BASAL} + 1.1ME_P + ME_{GRAZE} + ME_c$$

Where: ME_{BASAL} is the energy requirement for maintenance

ME_P is the energy used directly for production (meat, milk, wool and so on)

ME_{GRAZE} is the additional energy required by grazing livestock, and

ME_c is the energy used for gestation or growth of the conceptus (MJ/d)

And:

$$ME_{TOTAL} = \frac{KSM(0.28W^{0.75}\exp(-0.03A))}{k_m} + 1.1ME_P + \frac{E_{GRAZE}}{k_m} + ME_c$$

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.

For the 2020 submission, minor improvements were made to the equation used to estimate k_m for beef cattle, sheep and deer (not dairy cattle), so that it is consistent with the CSIRO (1990) ruminant feeding standards methodology and the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines (IPCC, 2006). More information on this improvement is provided in section 10.1.3 (chapter 10).

The CSIRO algorithms take into account animal liveweight and production requirements based on the rate of liveweight gain, gender, milk yield and physiological state (CSIRO, 1990). For further details, see the inventory methodology document on the MPI 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. This diet may be supplemented with supplementary feeds of various types, such as pasture hay and silage, and brassica crops. These data are reported in the inventory methodology document (Pickering and Gibbs, 2019, appendices 3, 9 and 19) 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 data on livestock population and productivity to calculate livestock energy requirements. Animal population data are collected by Statistics New Zealand. Productivity data are available from the Livestock Improvement Corporation (LIC) 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 MPI and are used to derive liveweights.

A challenge for New Zealand activity data is that the inventory is calculated on a calendar year, while New Zealand uses a June year for animal statistics because this reflects the natural biological cycle for animals in the southern hemisphere. New Zealand developed a Tier 2 model that estimates 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 agricultural inventories of other countries.

Dairy cattle is the only livestock category where emissions are calculated on a regional council area basis (this allows the inventory to take into account regional differences in productivity for dairy livestock (Clark, 2008a)). A regional emissions assessment is not carried out for other livestock types because regional productivity data are not available.

Animal population data

Statistics New Zealand collects animal population data on a territorial authority basis. Animal population data are collected on an annual basis through the Agricultural Production Census and Agricultural Production Survey. The census occurs every five years (the most recent occurred in 2017) and the survey is conducted in the interim years. The only difference between these two processes is the sample size, a census attempts to gather information from the entire target population, and a survey attempts to gather information from a sample of that population. Further details about the scope and accuracy of Statistics New Zealand Agricultural Production data collection are provided in annex 3.1.

The timing of Statistics New Zealand data releases (June) and the inventory submission means provisional data (released in December) have been used in the 2020 (1990–2018) submission. These will be updated with final data from Statistics New Zealand in the 2021 (1990–2019) submission. This affects 2019 data, which are sourced from Statistics New Zealand only.

The New Zealand inventory uses a different population characterisation for pasture-based livestock, compared with that recommended by the 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 MPI website (http://mpi.govt.nz/news-and-resources/statistics-and-forecasting/greenhouse-gas-reporting).

Dairy cattle encompass all cattle that 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 goes 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). Populations within a given 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, their numbers therefore 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. Average national estimates of monthly birth and death rates are used, which are based on expert opinion. In reality, these vary across the country and between farms.

Animal productivity data

Productivity data are obtained from LIC and DairyNZ (2019), Beef + Lamb New Zealand Ltd (2019) and Deer Industry New Zealand. These are non-governmental, industry goods levy bodies providing services to the dairy cattle, non-dairy cattle, sheep and deer industries.

Slaughter statistics are collected by MPI (www.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).

The same data sources are used each year to ensure consistency. 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.

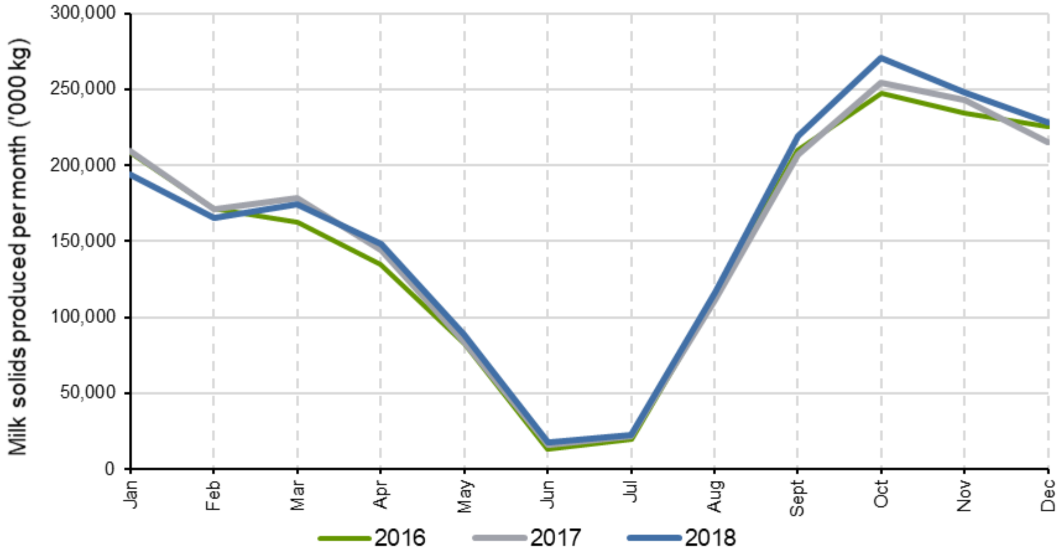
Dairy cattle – milk production: Regional data on milk production, proportions of dairy cattle breeds and animal liveweights are provided by LIC and published annually. These data are collectively compiled by LIC and DairyNZ.

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 total kilograms of milk solids (fat and protein) collected. 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 5.1.6).

From 2004, annual milk yields per animal have been obtained and reported as additional data in the 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 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 5.1.6 National monthly milk production in New Zealand from 2016 to 2018



Source: Dairy Companies Association of New Zealand (2019)

Before 1993, no productivity data were collected at a territorial authority level, so pre-1993 data have 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 have been collected by LIC at a similar territorial authority level as the livestock population data collected by Statistics New Zealand. MPI officials aggregate the territorial data up into the regional council boundaries used for the population data.

Approximately 72.4 per cent of all dairy cattle in milk were tested by LIC for milk production, along with the milk tested for milk fat and protein levels in the 2017/18 season (LIC and DairyNZ, 2018). 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 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 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 and applied nationally.

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.

LIC and DairyNZ (2019), reported a number of different breeds in the New Zealand dairy herd, these included:

- Holstein–Friesian/Jersey crossbreed (48.5 per cent of the national cow population in 2018)
- Holstein–Friesian (33.1 per cent)
- Jersey (8.6 per cent)
- Ayrshire (0.5 per cent)
- other breeds (9.3 per cent).

The Holstein–Friesian/Jersey crossbreed has been developed specifically for New Zealand's pasture-based systems. This breed is approximately 7.3 per cent lighter than a Holstein–Friesian (LIC and DairyNZ, 2019) and has lower 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 MPI. All growing beef animals are assumed to be slaughtered at two years of age[38], 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 period.

MPI slaughter statistics have only recently begun to separate carcass weights of adult dairy cows and adult beef cows. Therefore, a number of assumptions[39] 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 MPI are used to estimate the liveweights of adult sheep and lambs at slaughter, assuming killing-out percentages[40] 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 on average (Thomson et al., 2010). Growing breeding and non-breeding ewe hoggets are assumed to reach full adult size when subsequently mated at an age of 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 2018 from which the individual fleece weight is estimated (Beef + Lamb New Zealand Ltd, 2019).

***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).

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38 This assumption is from Clark et al., 2003. In reality, the age at slaughter will vary; however, not enough data are available to estimate using a model. For more information on this assumption, see www.mpi.govt.nz/dmsdocument/32863/direct.

39 The number of beef cows slaughtered is assumed to be 17 per 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).

40 Percentage of carcass weight in relation to liveweight.

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.

A small number of buffalo and donkeys are farmed in New Zealand. Statistics New Zealand advised that, in 2011, there were 192 buffalo and 141 donkeys. Because 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.

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.

Poultry is further classified into three sub-categories: broiler chicken, layer hens and other poultry. 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. Ostrich and emu farming in New Zealand is extremely rare and, in 2015, it was estimated only 739 ostriches were in the country. Other poultry manure management emissions are included and calculated, and enteric fermentation is negligible and therefore not estimated.

The average annual flock size of chickens is determined by the following equation:

$$Average\ annual\ flock\ size = \frac{days\ alive}{365} \times annual\ number\ of\ birds\ processed(1 - rate\ of\ mortality)$$

Rabbits are considered an agricultural pest, and only a very small number are farmed in the country (R Sanson, pers comm., 2019). Because of this, emissions from farmed rabbits are reported as ‘not estimated’ (NE) because their emissions are insignificant. There is no known farming of other fur-breeding animals.

5.1.5 Recalculations

Agriculture emissions research

New Zealand has set up a number of research organisations and reference groups to research novel methods and further build an evidence base to enable reductions in biological greenhouse gas emissions from agriculture. These include the following:

- The New Zealand Agricultural Greenhouse Gas Research Centre (NZAGRC) was set up in 2009. It’s aims are to contribute to agricultural greenhouse gas understanding and mitigation through research programmes and international collaboration, and to enhance New Zealand’s research capability and infrastructure in this area.

- The Pastoral Greenhouse Gas Research Consortium (PGGRC) was established in 2003 by New Zealand 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 PGGRC is funded in partnership between the Government, through the Ministry of Business, Innovation and Employment (MBIE), and the Agriculture sector.
- New Zealand is one of the founding members of the Global Research Alliance on Agricultural Greenhouse Gases (GRA), which uses international research collaboration to study means of increasing global food production while limiting agricultural greenhouse gas emissions. The GRA's global networks build emission research capability and facilitate transfer of mitigation technologies and knowledge. MPI has hosted the GRA Secretariat since its establishment in 2009 and coordinates New Zealand's contribution.
- MPI's Greenhouse Gas Inventory Research Fund aims to support continuous improvement of the Agricultural Greenhouse Gas Inventory, as required under the United Nations Framework Convention on Climate Change (UNFCCC) agreed processes, through using research to improve the accuracy of emissions reporting and forecasting.

Research and data from these sources feed into New Zealand's improvement of the Agriculture inventory, and these research activities allow New Zealand to share technical skills and expertise internationally.

Biological Emissions Reference Group

The Biological Emissions Reference Group (BERG) was established in 2016. Group members included representatives from agricultural sector organisations and government agencies. The BERG's purpose was to build a portfolio of published and reviewed scientific evidence covering the opportunities to reduce biological greenhouse gas emissions from New Zealand agriculture, and the costs and benefits of these opportunities and barriers to their use.

The BERG published its evidence base[41] in December 2018. This evidence has informed government agricultural emissions policy, as well as actions farmers can take to reduce their emissions. This group has now been disbanded.

He Waka Eke Noa

In October 2019, the Government announced the formation of a Joint Action Plan (He Waka Eke Noa) with the agri-food and fibre sector to address agricultural emissions. He Waka Eke Noa aims to deliver a world-first scheme for the Agriculture sector nationwide, measuring, managing and pricing of greenhouse gas emissions by 2025. It will do this by setting up milestones for the sector to achieve, including ensuring that all farms know their emissions. The Ministers of Climate Change and Agriculture are required to report back in 2022 on the design and feasibility of implementing a farm-level scheme.

He Waka Eke Noa will form part of New Zealand's actions towards its Climate Change Response (Zero Carbon) Amendment Act 2019 targets and Nationally Determined Contributions (NDCs) under the Paris Agreement.

[41] BERG reports can be found on the Ministry for Primary Industries website: www.mpi.govt.nz/protection-and-response/environment-and-natural-resources/biological-emissions-reference-group.

Recalculation and improvement approval process in the Agriculture inventory

The process for developing improvements and agreeing methodological changes to the Agriculture inventory is shown in figure 5.1.7.

Two national science and industry expert groups, Methanet and NzOnet,[42] have been running since the early 2000s. The groups were formed to identify the main direction of research needed to improve the CH_4 and N_2O inventory accounts 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 by MPI. The implementation of the Tier 2 approach for livestock, development of country-specific emission factors and parameters, improved activity data, model improvement and uncertainty analysis are all examples of research identified, conducted and peer reviewed by these expert groups.

Research findings are presented annually at the Greenhouse Gas Inventory Research Conference. New inventory research ideas raised by the two networks provide input into future research. Final decisions on research priorities are made by MPI, following discussions between the network leaders and Ministry for the Environment (MfE) staff. Research is contracted to address specific questions related to gaps in New Zealand's knowledge and to review, test and improve current model parameters used. Draft research reports are peer 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.

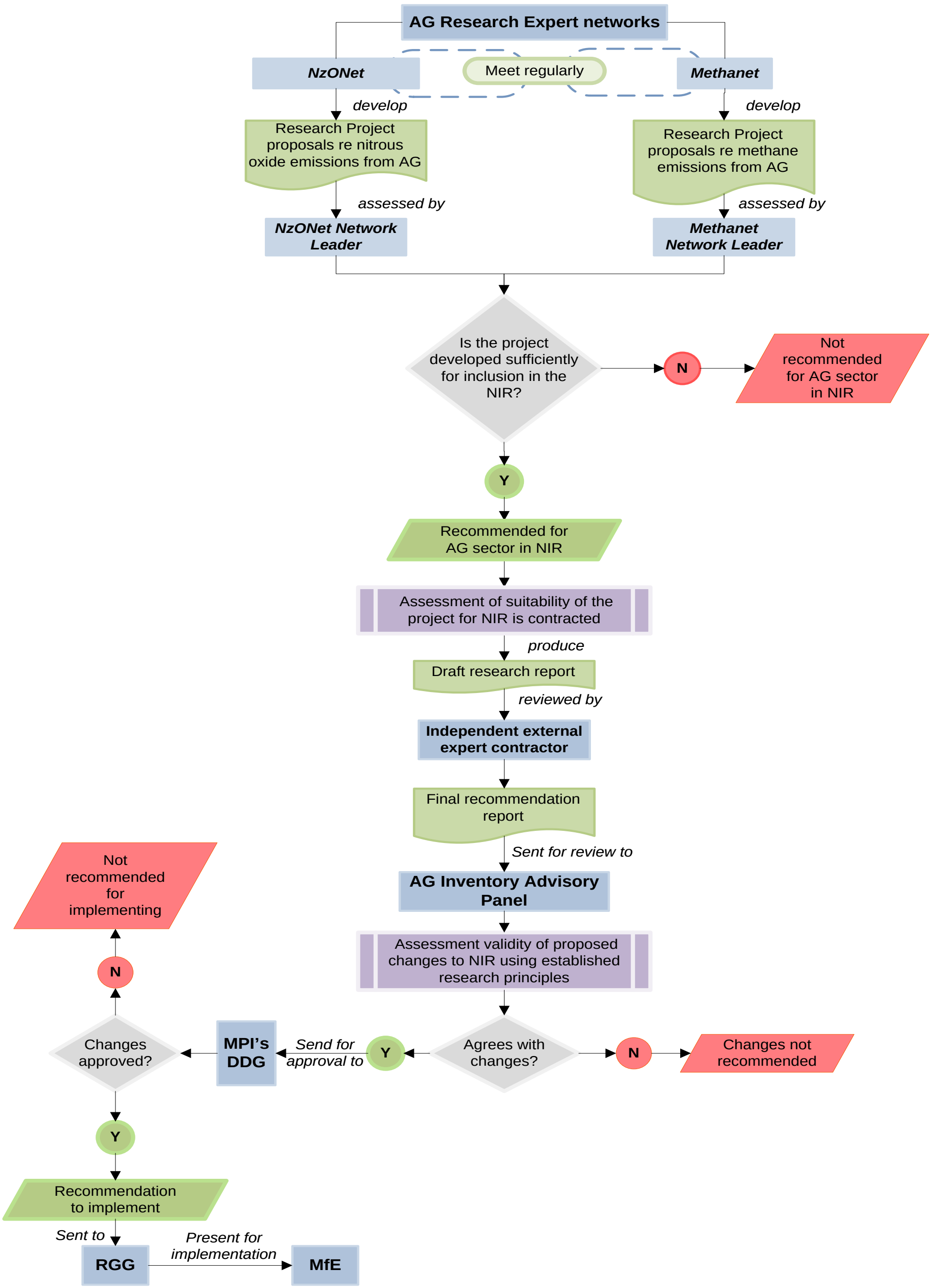
If the report is suitable for inclusion in the inventory, a briefing and the final report are sent to the Agriculture Inventory Advisory Panel, which meets annually to review proposed changes to the inventory. The Panel comprises expert representatives from MPI and MfE, nominated science representatives 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) at MPI. The Deputy Director-General approves the changes that will be presented to MfE for implementation into the annual national inventory.

During the course of the year, recalculations being considered by all greenhouse sectors in the annual submission to the UNFCCC are proposed to the Reporting Governance Group (RGG). This group is chaired by MfE and leads the reporting, modelling and projections of greenhouse gas emissions and removals across government. Further details of the RGG are provided in chapter 1, section 1.2.2.

[42] In 2017, the name of the Methanet and NzOnet annual meeting was changed to the New Zealand Greenhouse Gas Inventory Research Conference.

Figure 5.1.7 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 – 2019

The 2019 meeting of the Panel was held on 29 October, and considered the following proposed inventory changes:

- modifying the N_2O emission factors for livestock excreta ($EF_{3,PRP}$) for dung and urine based on hill slope and livestock type. This change is based on evidence from a meta-analysis of New Zealand-specific data collected over the past decade, and adopting a methodology to allocate dung and urine to low (of gradient between 0 degrees and 12 degrees), medium (of between 12 degrees and 24 degrees) and steep (greater than 24 degree) slopes

- revising the methodology for estimating emissions from farmed goats
- minor improvements to the equations used to estimate energy efficiency for maintenance (k_m) for cattle, sheep and deer.

The Panel recommended that the first and third proposed changes (modified N_2O emission factor values for $EF_{3,PRP}$ based on hill slope and livestock type, and minor improvements to the equations used to estimate k_m) be incorporated into the 2020 inventory submission, because the research and justification underpinning the change was robust and well documented.

For the second proposed change, the Panel recommended that new activity data on dairy goat population estimates from Burggraaf et al. (unpublished) be implemented with the existing methodology to estimate emissions from goats. The Panel accepted the use of the new dairy goat population estimates, after considerable scientific scrutiny.

More significant improvements were proposed for the goat sector but were rejected. The Panel considered the activity data were insufficient to develop a robust and accurate methodology. These improvements will be revisited with updated evidence and data in a future Panel meeting.

Further details on these changes are outlined in section 5.1.3 (minor improvements to the equations used to estimate k_m), section 5.5.5 (modified N_2O emission factor values for $EF_{3,PRP}$ based on hill slope and livestock type), chapter 10 (all recalculations) and annex 3 (which contains additional detail on the revised emission factors and methodologies used to estimate direct N_2O emissions from dairy cattle, beef cattle, sheep and deer).

The briefs, reports and minutes of the 2019 Panel meetings (as well as panel meetings for previous years) are all available on the MPI website (http://mpi.govt.nz/news-and-resources/statistics-and-forecasting/greenhouse-gas-reporting/agricultural-inventory-advisory-panel).

Recalculations approved for the 2020 National Inventory Report submission in the Agriculture sector

Following the recommendations from the Agriculture Inventory Advisory Panel and approval from the Deputy Director-General (Policy and Trade) at MPI and the RGG, New Zealand has made the following improvements and corrections to the Agriculture sector in its 2020 annual submission:

- use of new N_2O emission factors from animal excreta ($EF_{3,PRP}$) split by stock type and hill slope, applied using a new model to calculate the amount of livestock excreta deposited onto the different slopes: low (gradient between 0 degrees and 12 degrees), medium (between 12 degrees and 24 degrees) and steep (greater than 24 degrees gradient)
- use of revised activity data for the proportion of dairy goats in the overall farmed goat population
- minor improvements to the equations used to estimate energy efficiency for maintenance (k_m) for beef cattle, sheep and deer, including the specification of a constant to more significant figures and reverting to the IPCC default value of 18.45 megajoules per kilogram of dry matter (MJ/kg DM) for the gross energy content of feed (from the previous values of 18.40 MJ/kg DM for cattle and deer, and 18.50 MJ/kg DM for sheep).

The implementation of these improvements has resulted in the estimate of Agriculture sector emissions in 2017 being 3.8 per cent lower in the 2020 submission than the estimate for 2017 Agriculture sector emissions in the 2019 (1990–2019) submission. Further details of these improvements are provided in sections 5.2.6, 5.3.6, 5.5.6 and 10.1.3.

5.1.6 Quality assurance and quality control (QA/QC)

The team responsible for the Agriculture inventory preparation within MPI 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 agricultural 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 MPI 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 MfE that is responsible for coordinating the annual national inventory submission. MfE monitors MPI progress in implementing recommendations from previous expert review reports and on meeting timelines during the year.

MfE 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 UNFCCC and 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.

MPI participates in the annual inventory debrief coordinated by MfE, 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 in table 5.1.4.

Table 5.1.4 Agriculture sectoral approval process for inventory recalculations and improvements

QA/QC area	Details of QA/QC procedure
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 the 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 types are almost all kept outdoors on pasture in all seasons. Total emissions and key activity data from the common reporting format (CRF) tables 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. Examples of these reviews are below. 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 Crown research institute 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). In 2018, the population models in the inventory model were reviewed. Small errors in the implementation of the population equations in the inventory model were found and have been corrected for the 2019 (1990–2017) submission. For more information on this, see sections 5.1.5 and 10.1.3.
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

MPI is undertaking a number of research projects aimed at improving New Zealand's Agriculture inventory.

Short-term studies (one year) include:

- research identifying the amount and types of supplemental feed used in the dairy, sheep, beef and deer farming industries
- obtaining past scientifically robust and verifiable laboratory data on the energy content, nitrogen content and digestibility of different supplemented feeds
- updating national estimates of pasture quality for ME, nitrogen and dry matter digestibility
- reviewing the models used to estimate monthly population changes and liveweight for dairy cattle, beef cattle, sheep and deer
- reviewing the FracLeach parameter used to help calculate indirect N2O emissions from agricultural soils (see section 5.5.6)
- understanding emissions from potential N_2O 'hotspots' on dairy farms; areas with high animal treading (such as gateways and water troughs) could have higher N_2O emission factors (see section 5.5.6).

Long-term studies (more than one year) focused on improving the Agriculture inventory include:

- improving the relationship between DMI and CH_4 emissions from cattle (see section 5.2.6)
- researching how the use of manure management systems has changed in New Zealand over time, and the implications for emissions estimates (see section 5.3.6)
- using top down inverse modelling techniques to help verify New Zealand's estimates of CH_4 emissions
- researching the factors causing variability in N_2O emissions from livestock excreta on pasture to gain a better understanding of them (see section 5.5.6)
- continuing work to improve activity data, including through the annual collection of agricultural data by Statistics New Zealand.

Some of these potential improvements cover multiple categories of the Agriculture inventory and are described further below. The remaining improvements relate only to a single Agriculture inventory category and are discussed in further detail in the relevant 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)).

Use of supplemental feed

This project gathers robust activity data on the use of different feeds in the dairy, sheep, beef and deer farming industries from 1990 to the present day (such as palm kernel extract, maize grain and fodder beet). The completion of this research (in conjunction with the *Laboratory data on different feed types* and *Improvements to the pasture quality dataset* projects) will improve the accuracy of our feed intake calculations, which affect emissions estimates from *Enteric fermentation*, *Manure management* and *Agricultural soils* categories.

Laboratory data on different feed types

Currently, New Zealand's agriculture emissions reporting assumes that livestock are fully pasture-fed all year round, yet the use of non-pasture feeds, such as palm kernel expeller, brassicas and fodder beet, have increased in recent years. The aim of this research is to obtain authoritative laboratory data on the characteristics of different feeds in terms of energy and nitrogen content, and digestibility. The ability to use robust laboratory data on these different feeds will improve the accuracy of emissions estimates in the *Enteric fermentation*, *Manure management* and *Agricultural soils* categories.

Improvements to the pasture quality dataset

New Zealand is continuing research to improve its knowledge on national pasture quality, including energy, and nitrogen content that affects emissions from manure. A programme of pasture sample collection and analysis began in 2018. The aim of this work is to provide a more up-to-date and detailed pasture quality dataset that is nationally representative of the range of farming systems and that takes seasonal variations into account. 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 quality within specific uncertainty levels. Improvements to the pasture quality dataset will improve estimations of emissions in the *Enteric fermentation*, *Manure management* and *Agricultural soils* categories.

Improvements to population modelling

The purpose of this project is to improve the estimates of monthly animal populations used in the inventory model for dairy cattle, beef cattle, sheep and deer.

The Agriculture inventory relies heavily on animal population data from the Agricultural Production Survey and Census, which provide population estimates for June only of each year. This project will improve the population model used to estimate the populations of these animals (and how they change) for the other months of the year.

As part of this work, the methodology and data used to estimate liveweight for cattle, sheep and deer will also be reviewed and improved if necessary. The results from these modelling projects will affect emissions in the *Enteric fermentation*, *Manure management* and *Agricultural soils* categories, and will improve the accuracy and transparency of the inventory.

Inverse modelling to verify estimates of methane emissions

The aim of this project is to generate an independent top-down estimate of CH_4 emissions using inverse modelling techniques, field data and atmospheric models to 'back calculate' CH_4 sources on a spatial basis. The first set of results from this work is expected in 2020.

5.2 Enteric fermentation (CRF 3.A)

5.2.1 Description

Methane is produced predominantly by ruminants as a by-product of enteric fermentation. Enteric fermentation is a digestive process that breaks down consumed plant material in the gut under anaerobic conditions. A portion of the plant material is fermented in the rumen to simple fatty acids, CO_2 and CH_4. The gases from this process are released by eructation and exhalation by the animal. The amount of CH_4 released depends on the type and 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.

Methane emissions from the *Enteric fermentation* category from dairy cattle, non-dairy cattle and sheep were identified among the largest key categories for New Zealand in the 2018 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.

Enteric fermentation contributed an estimated 27,939.0 kt CO_2-e, representing 35.4 per cent of New Zealand's gross emissions and 74.1 per cent of agriculture emissions in 2018. The major livestock categories contributing to *Enteric fermentation* are:

- *Dairy cattle* (36.1 per cent of *Enteric fermentation*)
- *Sheep* (22.3 per cent of *Enteric fermentation*)
- *Non-dairy cattle* (14.3 per cent of *Enteric fermentation*)
- *Deer* (1.3 per cent of *Enteric fermentation*).

Trends

Emissions from *Enteric fermentation* increased 5.2 per cent (1,390.0 CO_2-e) between 1990 and 2018. 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 (129.2 per cent increase in *Enteric fermentation* emissions between 1990 and 2018). 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 (methane expressed in kt CO_2-e) from livestock categories between 1990 and 2018

	Emissions (kt CO_2-e)		Change from 1990		Share of Enteric fermentation category (%)		Share of total Agriculture sector (%)	
Livestock category	1990	2018	%	kt CO_2-e	1990	2018	1990	2018
Dairy cattle	5,940.0	13,611.6	129.2	7,671.6	22.4	48.7	18.5	36.1
Non-dairy cattle	5,754.7	5,402.2	–6.1	–352.6	21.7	19.3	17.9	14.3
Sheep	14,172.1	8,390.1	–40.8	–5,782.0	53.4	30.0	44.0	22.3
Deer	432.7	488.0	12.8	55.3	1.6	1.7	1.3	1.3
Minor livestock	249.5	47.2	–81.1	–202.3	0.9	0.2	0.8	0.1

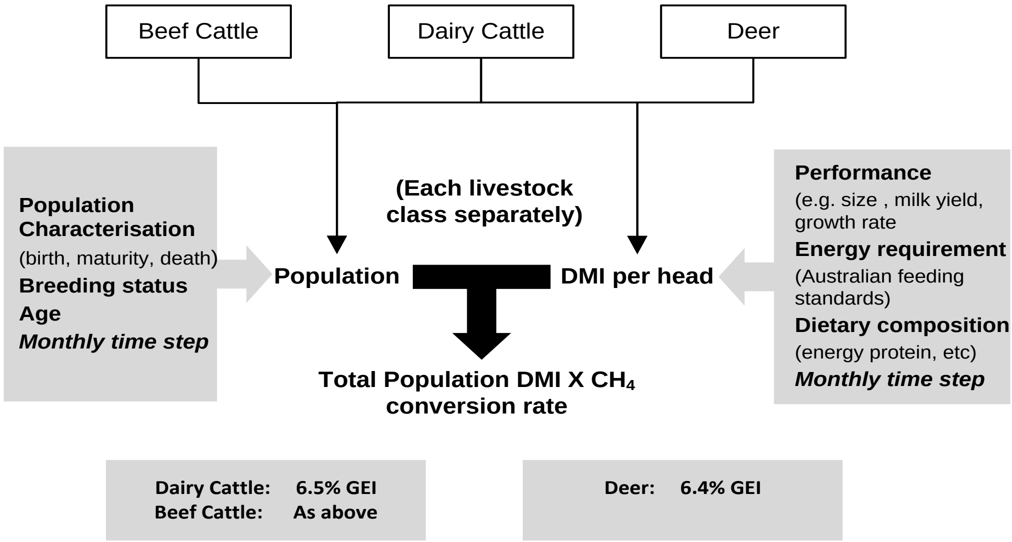
Note: Percentages presented are calculated from unrounded values.

5.2.2 Methodological issues

Emissions from cattle and deer

The total amount of enteric CH_4 emitted by cattle and deer is calculated using a CH_4 conversion factor for emissions per unit of feed intake in kilograms DMI per livestock category (see figure 5.2.1). Livestock population characterisation and DMI per head is calculated by New Zealand's Tier 2 inventory model (see section 5.1.3). A more complex algorithm has been used to calculate enteric CH_4 emissions from sheep and is 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 CH_4 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 experiments where CH_4 emissions from sheep, fed pasture of varying amounts and quality, were measured using respiration chambers, the gold standard for recording CH_4 emissions from livestock. The study confirmed that DMI has the largest influence on CH_4 emissions and that pasture quality (as measured by ME content) had only a small but statistically significant effect on emissions from sheep less than one year of age.

The paper concluded that two log-transformed linear regressions (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[43] for the total production of enteric CH_4 for sheep less than one year of age is:

$$CH_{4-enteric} = \sum_{class} \sum_{month} d_m \, Lamb_{cm} \frac{11.705}{1000} e^{0.05 \times ME} DMI^{0.734}$$

The equation[44] for the total production of enteric CH_4 for sheep greater than one year of age is:

$$CH_{4-enteric} = \sum_{class} \sum_{month} d_m \, Sheep_{cm} \frac{21.977}{1000} DMI^{0.765}$$

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

$Lamb_{cm}$ is the population of sheep in class c during month m (head), less than one year old (i.e. lambs)

$Sheep_{cm}$ is the population of sheep in class c during month m (head), greater than one year old

ME is the metabolisable energy concentration of pasture during month m (megajoules of metabolisable 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).

Methane measurement and modelling

New Zealand uses country-specific methodology and emission factors for estimating enteric fermentation CH_4 emissions per kilogram of feed (i.e., DMI) for a number of reasons. First, the data requirements for existing digestion models[45] are less relevant, given New Zealand's predominantly pasture-based systems. The relationships in these models have been mainly derived from animals fed indoors on diets unlike those consumed by New Zealand's grazing ruminants. Further, none of these methods had high predictive power when compared against empirical experimental data (Clark et al., 2003).

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 CH_4 emissions from livestock. New Zealand has

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43 The equation displayed here is a rearranged form of the equation displayed in Swainson et al. (2016): $Ln(CH_4) = 0.734 \times ln(DMI) + 0.05 \times ME + 2.46$.

44 The equation displayed here is a rearranged form of the equation displayed in Swainson et al. (2016): $Ln(CH_4) = 0.765 \times ln(DMI) + 3.09$.

45 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).

invested significantly in sufficient chamber facilities for respiration chamber based measurement of emissions, particularly for sheep.

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 are 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 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.

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 2018

Year	All dairy cattle (kg CH_4 per animal per annum)	Milking 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	69.1	74.1	50.1	9.8	17.7
1991	72.1	72.5	51.6	10.0	18.2
1992	72.6	77.2	52.3	9.9	19.0
1993	73.6	76.7	53.1	10.2	19.5
1994	72.1	77.8	53.6	10.3	19.1
1995	71.8	77.1	53.0	10.2	19.9
1996	74.2	77.3	54.8	10.6	20.1
1997	75.0	80.2	55.8	10.9	20.3
1998	73.0	81.1	55.9	11.0	20.5
1999	74.5	78.6	54.6	10.9	20.7
2000	76.1	80.6	56.5	11.3	21.1
2001	77.0	83.2	57.6	11.4	21.1
2002	76.5	84.7	57.3	11.4	21.2
2003	79.3	84.5	57.0	11.3	21.2

Year	All dairy cattle (kg CH_4 per animal per annum)	Milking 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)
2004	78.1	85.7	57.9	11.6	21.4
2005	78.6	83.5	58.6	11.7	21.8
2006	78.4	84.2	59.7	11.5	22.1
2007	77.4	85.3	59.0	11.4	22.3
2008	76.4	84.8	58.5	11.6	22.4
2009	76.9	84.3	58.0	11.8	22.6
2010	78.8	84.2	57.9	11.5	22.6
2011	79.8	86.1	58.7	11.7	22.8
2012	79.7	88.6	59.5	11.8	22.9
2013	81.7	88.3	58.6	11.8	22.6
2014	82.0	91.2	58.3	11.9	22.8
2015	84.2	91.8	58.9	11.9	22.9
2016	82.2	93.4	59.5	12.2	23.3
2017	83.2	90.7	59.1	12.2	23.2
2018	85.3	93.2	58.1	12.3	22.9

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 2018. 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 2018, the population of goats declined from 1,062,900 to 88,785. New Zealand uses a country-specific emission factor for goats 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 2018, the emission factor is calculated based on goat population, with the assumption that the dairy goat population has remained relatively consistent over time while the rest of the goat population has declined. The emission factor in 2018 was calculated to be 9.0 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, IPCC, 2006) 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,[46] 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 (2006) default value 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 annex 3.1.

Methane emissions from enteric fermentation

In 2009, MPI (formerly the Ministry of Agriculture and Forestry) commissioned a report that calculated 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 using 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, was ±16 per cent (Kelliher et al., 2009); see table 5.2.4.

46 The IPCC (2006) default emission factor for swine is identical to the IPCC (1996) emission factor.

Table 5.2.4 **New Zealand's uncertainty in the annual estimate of enteric fermentation emissions for 1990 and 2018, 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	1062.0	892.0	1231.9
2018	1117.6	938.7	892.0

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 due to genetic, management and environmental factors. Uncertainties in the estimates of livestock energy requirements, forage quality and animal 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, non-dairy cattle and sheep was identified as a key category (level and trend assessment). Methane from *Enteric fermentation* from deer is a key category in the 2018 level assessment and CH_4 from *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.

Enteric CH_4 emission rates have been verified using micrometeorological techniques. Laubach and Kelliher (2004) used the integrated horizontal flux technique and the flux gradient technique to measure CH_4 emission 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 for CH_4 measurement.

Enteric methane emissions from lactating dairy cows have also been measured using the New Zealand SF_6 tracer method compared with the 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) but the uncertainty of the SF_6 technique measurements was greater.

The calculations in New Zealand's model for cattle, sheep and deer are Tier 2 and are based on the IPCC Guidelines (IPCC, 2006). Table 5.2.5 shows a comparison of the New Zealand-specific 2018 IEFs for enteric fermentation with the IPCC Tier 1 Oceania default value, the IPCC Tier 2 net energy-based value and the Australian-specific 2017 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, 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 (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 2017 value[47]	92.0	51.2 (pasture) 67.6 (feedlot)	6.7
New Zealand-specific IEF 2018 value	85.3 (all dairy cattle, including calves) 93.2 (mature milking cattle only)	58.1	12.3

Note: The IPCC (2006) value for sheep is for developed countries.

Dairy cattle: New Zealand's 2018 IEF for all dairy cattle, excluding mature milking cattle, is lower than the IPCC Tier 1 Oceania default value and the Australian-specific IEF. New Zealand's 2018 IEF for mature milking cattle is higher than the IPCC Tier 1 Oceania default value and the 2017 Australian-specific IEF.

Although the predominantly pasture-based system in New Zealand is similar to Australian dairy cattle management, the lower IEF value could be explained by New Zealand's higher proportion of lighter (by liveweight) cattle breeds. The 2017 Australian dairy herd comprised 70 per cent Holstein–Friesian; other breeds include Jersey, Brown Swiss, Ayrshire, the Australian Red and the Illawarra (AUSTREX, 2020). In 2018, 48 per cent of New Zealand's cow population comprised a Holstein–Friesian/Jersey crossbreed, 33 per cent are Holstein–Friesian and 9 per cent are Jersey (LIC and DairyNZ, 2019).

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.

New Zealand's dairy 2018 IEF is higher than the IPCC Tier 2 net energy-based value 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 2018 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 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 energy 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 New Zealand's pastoral-based farming systems.

47 As reported in Australia's *National Inventory Report 2017 Volume 1* on Greenhouse Gas Accounts (Commonwealth of Australia, 2019). 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.

Sheep: New Zealand's 2018 IEF for sheep is higher than the IPCC Tier 1 default value and higher than the 2017 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 excludes the majority of the lamb population, 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 annual enteric CH_4 emissions because emissions are calculated on a monthly basis, but it does not include the lamb population when estimating the IEF. This results in the 2018 calculated sheep IEF being higher than the IPCC default IEF. The IPCC Tier 2 net energy-based sheep IEF is lower than New Zealand's-specific 2018 sheep IEF. The difference can be explained by the same rationale as put forward for cattle.

5.2.5 Source-specific recalculations

Emissions estimates in the *Enteric fermentation* category have been affected by the following methodological improvements and corrections.

- Minor improvements were made to the equations used to estimate energy efficiency for maintenance (k_m) for beef cattle, sheep and deer, which are used to help calculate energy requirements and intake and, subsequently, have an effect on manure management emissions from cattle, sheep and deer. This change had a small effect on estimated emissions and included the specification of a constant to more significant figures and reverting to the IPCC default value for the gross energy content of feed of 18.45 MJ/kg dry matter.

All activity data were updated with the latest available data: Statistics New Zealand table builder and Infoshare database (Statistics New Zealand, 2020) and LIC statistics (LIC and DairyNZ, 2019).

Table 5.2.6 Comparison of current and previous methane emissions estimates before and after changes to energy efficiency for maintenance (k_m) equation, for enteric fermentation

Emissions (kt CO_2-e)		1990	2018	Change in emissions outputs between 1990 and 2018 (kt CO_2-e)	Percentage change in emissions outputs between 1990 and 2018
Total emissions from Enteric fermentation (kt CO_2-e)	2020 (1990–2018) emissions estimate using previous k_m equation specification	26,569.8	27,950.3	1,380.5	5.2
	2020 (1990–2018) emissions estimate using new k_m equation specification	26,548.9	27,939.0	1,390.0	5.2
	Difference in emission estimates compared with current inventory	–20.9	–11.3	9.6	
	Percentage difference in emission estimates	–0.1	0.0		

Table 5.2.7 Effect of revised dairy goat population estimates on methane emissions estimates, 1990 to 2018, for enteric fermentation

Emissions ($kt\ CO_2$-e)		1990	2018	Change in emissions outputs between 1990 and 2018 ($kt\ CO_2$-e)	Percentage change in emissions outputs between 1990 and 2018
Total emissions from Enteric fermentation ($kt\ CO_2$-e)	2020 (1990–2018) emissions estimate using previous dairy goat population estimates	26,548.9	27,937.4	1,388.5	5.2
	2020 (1990–2018) emissions estimate using new dairy goat population estimates	26,548.9	27,939.0	1,390.0	5.2
	Difference in emission estimates compared with current inventory	0.0	1.6	1.6	
	Percentage difference in emission estimates	0.0	0.0		

5.2.6 Source-specific planned improvements

Clarification of cattle methane yields

New Zealand is continuing research to improve its understanding of CH_4 emissions from enteric fermentation of cattle and develop a more robust relationship between CH_4 yields and extreme DMI (very low or very high levels of consumption). Research will clarify whether the CH_4 yield relationship currently in use in the inventory accurately calculates enteric CH_4 emissions at DMI extremes. Research is being carried out at the NZAGRC ruminant CH_4 measurement facility in purpose-built calorimeter chambers. The results of the study will be added to past cattle research to help develop a more robust country-specific equation describing the relationship between DMI and CH_4 yields in New Zealand.

5.3 Manure management (CRF 3.B)

5.3.1 Description

The majority of the emissions from the *Manure management* category are from CH_4 produced during the storage and treatment of manure, and 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 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.

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. In New Zealand, most manure falls on pasture, with little going into manure management systems mainly from dairy cattle. Therefore, this is only a very small source (0.3 per cent in 2018) of agricultural emissions.

Pastoral farming is the principal farming system in New Zealand, which means that the share of agricultural emissions from *Manure management* is lower than in other countries with high use of more intensive farming practices (such as animal housing and feedlots).

Methane from *Manure management* from dairy cattle was identified as a key category for New Zealand in the 2018 level and 1990–2018 trend assessment.

Manure management contributed an estimated 1,609.7 kt CO_2-e, representing 4.3 per cent of *agriculture* emissions in 2018. Estimated emissions from this category consist of:

- CH_4 emissions (92.4 per cent of *Manure management* emissions)
- N_2O emissions (7.6 per cent of *Manure management* emissions).

In 2018, N_2O emissions were 122.5 kt CO_2-e (0.3 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 5,015.4 kt CO_2-e in 2018 (13.3 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 2018

Manure management category	Emissions (kt CO_2-e) 1990	Emissions (kt CO_2-e) 2018	Change from 1990 %	Change from 1990 Difference (kt CO_2-e)	Share of Manure management category (%) 1990	Share of Manure management category (%) 2018	Share of total Agriculture sector (%) 1990	Share of total Agriculture sector (%) 2018
Methane (CRF 3.B.(a))	670.7	1,487.2	121.7	816.4	92.8	92.4	2.1	3.9
Nitrous oxide (CRF 3.B.(b))	51.9	122.5	135.9	70.6	7.2	7.6	0.2	0.3

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 (7.3 per cent in 2018) stored in anaerobic lagoon waste systems (Rollo et al., unpublished). This is based on 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[48] (%)	Pasture, range and paddock[49] (%)	Solid storage and dry lot (%)	Other (%)
Dairy cattle[50]	7.3	–	92.7	–	–
Non-dairy cattle	–	–	100.0	–	–
Sheep	–	–	100.0	–	–
Deer	–	–	100.0	–	–
Goats	–	–	100.0	–	–
Horses	–	–	100.0	–	–
Swine[51]	20.5	25.7	8.9	42.5	2.4
Poultry – broilers[52]	–	–	4.9	–	95.1
Poultry – layers[53]	–	–	5.8	–	94.2
Poultry – other[54]	–	–	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.(a))

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)

(3) New Zealand-specific emission factors for the quantity of CH_4 produced per unit of faecal dry-matter (FDM) output.

48 Reported under *Agricultural soils*, under *Organic nitrogen fertilisers* (CRF 3.D.1.2).

49 Reported under *Agricultural soils*, under *Urine and dung deposited by grazing animals* (CRF 3.D.1.3).

50 Calculated using 2018 data.

51 Hill (2012).

52 Fick et al. (2011) and pers. comm. (2010).

53 Fick et al. (2011) and pers. comm. (2010).

54 IPCC (1996) default waste management proportions for Oceania.

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 dry-matter digestibility 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

Each year, a proportion of manure from dairy cows is stored in anaerobic lagoons (Rollo et al., unpublished). A Tier 2 methodology derived from the IPCC Guidelines (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 CH_4-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 CH_4 conversion factor, 0.74 (IPCC, 2006, table 10.17, default for uncovered anaerobic lagoon, average annual temperature 15 degrees Celsius, verified by Pratt et al., unpublished)

MS is the fraction of total dairy manure excreted in anaerobic lagoons.

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 CH_4 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 deposited 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. Further information on the calculation of the manure CH_4 emissions factor for deer is contained on page 123 (section 7.1.4) of the inventory methodology (Pickering and Gibbs, 2019).

Methane emissions from minor livestock categories

Manure CH_4 emissions from the minor livestock categories are calculated per head, using country-specific and IPCC 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 1996 IPCC 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 category 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 poultry 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 IPCC 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 had the productivity increases seen in sheep.

Nitrous oxide from manure management systems (CRF 3.B.(b))

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 manure 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 eaten. 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, is taken from New Zealand research (Bown et al., 2013).

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. Nitrogen excretion 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 MPI 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 2018

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	103.9	64.47	12.97	26.31
1991	107.9	66.35	13.26	26.96
1992	108.6	67.37	13.21	28.07
1993	109.8	68.49	13.58	28.66
1994	107.8	69.14	13.82	27.98
1995	107.4	68.47	13.67	29.17
1996	110.5	70.98	14.19	29.39
1997	111.5	72.27	14.83	29.66
1998	108.9	72.36	14.89	29.84
1999	110.9	70.53	14.82	30.17
2000	112.5	73.06	15.48	30.77
2001	113.7	74.33	15.63	30.77
2002	112.9	73.93	15.60	30.86
2003	117.0	73.48	15.54	30.60
2004	115.5	74.75	15.94	30.75
2005	116.1	75.67	16.13	30.95
2006	115.3	77.16	15.94	31.11
2007	114.0	76.14	15.73	31.11
2008	112.3	75.48	16.02	30.98
2009	113.0	74.83	16.31	30.96
2010	115.7	74.75	15.82	30.91
2011	116.7	75.76	16.15	31.21
2012	116.7	76.86	16.40	31.27
2013	119.2	75.59	16.38	30.96
2014	119.2	75.26	16.63	31.23
2015	122.1	76.12	16.64	31.30
2016	119.4	76.78	16.94	31.93
2017	120.9	76.20	17.01	31.62
2018	123.6	74.92	17.29	31.23

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 carcass weights are collected by MPI.

Goats: New Zealand uses country-specific N_{ex} rates for goats to estimate N_2O 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 2006 IPCC Guidelines (IPCC, 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 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 2018

Year	Goat N_{ex} (kg/head/year)	Swine N_{ex} (kg/head/year)	Year	Goat N_{ex} (kg/head/year)	Swine N_{ex} (kg/head/year)
1990	10.6	9.0	2005	11.8	10.6
1991	10.7	9.2	2006	11.9	10.7
1992	10.8	9.3	2007	11.9	10.8
1993	10.8	9.5	2008	12.0	10.8
1994	10.9	9.5	2009	12.1	10.8
1995	11.0	9.6	2010	12.2	10.8
1996	11.1	9.8	2011	12.3	11.0
1997	11.2	9.9	2012	12.3	11.0
1998	11.2	9.9	2013	12.4	11.1
1999	11.3	9.9	2014	12.5	11.3
2000	11.4	10.2	2015	12.6	11.4
2001	11.5	10.5	2016	12.7	11.3
2002	11.5	10.2	2017	12.7	11.3
2003	11.6	10.1	2018	12.7	11.4
2004	11.7	10.5			

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 2006 IPCC 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 2006 IPCC Guidelines (table 10.21, IPCC, 2006) 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 dry lot and other manure management systems are estimated using the IPCC (2006) default emission factors for direct N_2O emissions from manure management ($EF_{3,PRP}$) 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 $EF_{3,PRP}$ 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:

$$N_{vol-MMS} = \sum_S \left[\sum_T \left[\left(N_T \cdot Nex_T \cdot MS_{T,S} \right) \cdot \left(\frac{Frac_{GasMS}}{100} \right)_{T,S} \right] \right]$$

Where: $N_{vol\text{-}MMS}$ 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 available data is usually extremely limited (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 for the livestock population and the classification and 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 per cent for Tier 1 methodologies and ±20 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 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 for manure and manure management systems, activity data on the livestock populations and the classification and use of the various manure management systems (IPCC, 2006).

Uncertainty ranges for the default N_{ex} values are estimated at about ±50 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 $EF_{3,PRP}$ for direct N_2O emissions from the manure management of swine and poultry, which have uncertainties ranging from –50 per cent to +100 per cent. An uncertainty value range of ±100 per cent has been used for the *Manure management* N_2O emission factor uncertainty.

As above, uncertainties for the livestock characterisation are discussed in section 5.1.4 and annex A3.1.1.

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 2018 level and 1990–2018 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 2017 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 2016 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 2006 IPCC Guidelines (i.e., equations 10.16, 10.24 and 10.23 respectively).

New Zealand has lower IEFs for CH_4 from *Manure management* for non-dairy cattle and sheep 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 2016 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. The New Zealand-specific IEF from *Manure management* for dairy cattle also reflects the activity data on the use of dairy effluent management systems in New Zealand (see section 5.3.2).

Table 5.3.6 Comparison of IPCC (2006) table 10A-4 default emission factors and country-specific implied emission factors (IEFs) for methane from manure management

	kg CH_4/head/year		
	Dairy cattle	Non-dairy cattle	Sheep
IPCC Tier 1 Oceania default value (average temperature 15ºC (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 2017 value[55]	14.79	0.02 (pasture) 3.54 (feedlot)	0.002
New Zealand-specific IEF 2018 value	7.91 (all dairy cattle, including calves) 9.88 (mature milking cows only)	0.78	0.13

5.3.5 Source-specific recalculations

The following methodological improvement has implications for emissions estimates in the *Manure management* category.

- Minor improvements were made to the equations used to estimate energy efficiency for maintenance (k_m) for beef cattle, sheep and deer, which is used to help calculate energy requirements, intake, and, subsequently, has an effect on manure management emissions from cattle, sheep and deer. This change had a small effect on estimated emissions and included the specification of a constant to more significant figures and reverting to the IPCC default value for the gross energy content of feed of 18.45 MJ/kg dry matter (IPCC, 2006).

Emissions estimates have also been updated using the latest available activity data from the sources described in section 5.1.4. Provisional data entered for the reporting year 2018 have been replaced with final data.

Minor improvements to the equations used to estimate energy efficiency for maintenance (k_m)

The variable k_m estimates the efficiency of energy used for maintenance activities for cattle, sheep and deer, which is used to help calculate energy requirements, intake and nitrogen excretion. For the 2020 submission, minor improvements were made to this equation for beef cattle, sheep and deer (not dairy cattle), so that it is consistent with the CSIRO (1990) and 2006 IPCC Guidelines. More details on this change are in section 10.1.3 (chapter 10).

This change had a small effect on estimated emissions from *Manure management*, as shown in table 5.3.7.

55 As reported in Australia's *National Inventory Report 2017* (Commonwealth of Australia, 2019). Retrieved from https://unfccc.int/documents/195779 (20 December 2019). 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.

Table 5.3.7 **Comparison of current and previous emissions estimates before and after changes to the energy efficiency for maintenance (k_m) equation**

Emissions ($kt\ CO_2$-e)		1990	2018	Change in emission outputs between 1990 and 2018 ($kt\ CO_2$-e)	Percentage change in emission outputs between 1990 and 2018
Total emissions from Manure management ($kt\ CO_2$-e)	2020 (1990–2018) emissions estimate *using previous* k_m equation specification	722.6	1,608.8	886.1	122.6
	2020 (1990–2018) emissions estimate *using new* k_m equation specification	722.6	1,609.7	887.0	122.7
	Difference in emission estimates compared with current inventory	0.0	0.9	0.9	
	Percentage difference in emission estimates	0.0	0.1		

5.3.6 Source-specific planned improvements

The following section covers the planned improvements being undertaken for *Manure management*. These findings may be incorporated in future annual inventory submissions.

Improvement of the manure management inventory

A research project is currently under way that aims to improve the manure management component of the inventory. This project will undertake new emissions research on different manure management systems in New Zealand and will recommend changes to the current methodology.

5.4 Rice cultivation (CRF 3.C)

5.4.1 Description

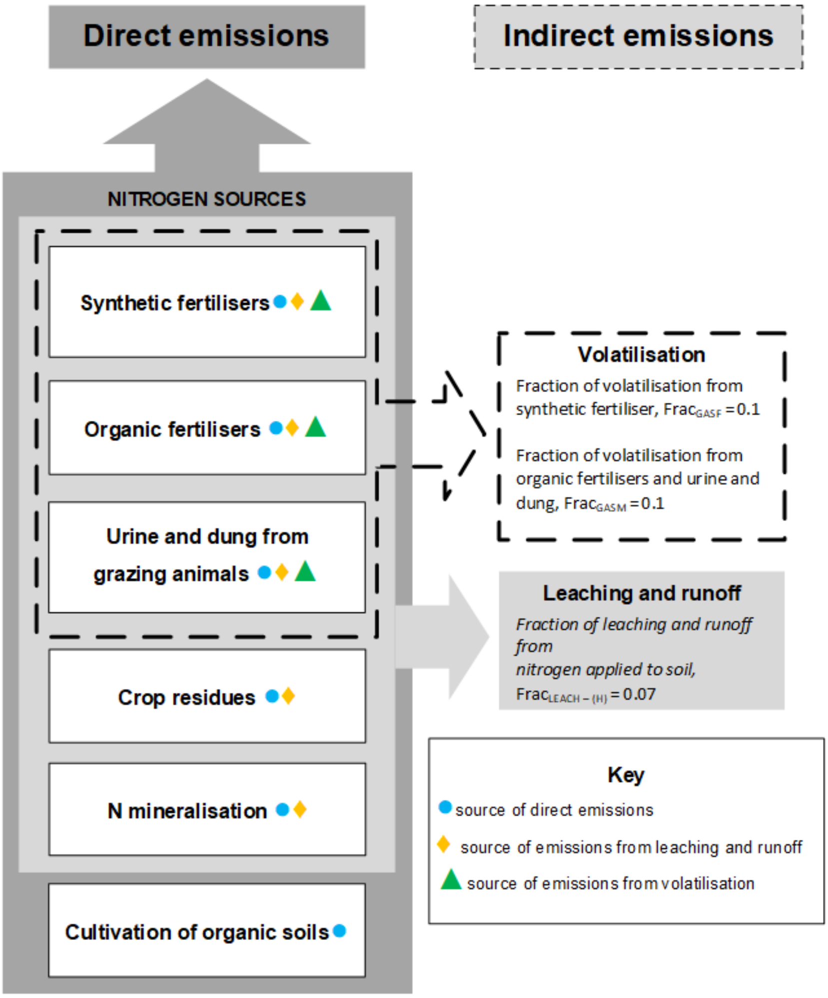
At present, no commercial rice cultivation is carried out in New Zealand. This has been confirmed with experts from Plant and Food Research, a New Zealand Crown research institute. The 'NO' (not occurring) notation is reported in the CRF tables.

5.5 Agricultural soils (CRF 3.D)

5.5.1 Description

Several categories contribute to N_2O emissions from agricultural soils from both direct and indirect pathways, these are summarised in figure 5.5.1.

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**



Direct N_2O emissions come directly from the soils to which nitrogen has been applied in either organic (animal excreta) or inorganic (synthetic fertiliser) form. 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) and from further nitrification and denitrification from waterways.

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*).

Agricultural soils contributed an estimated 7,026.3 kt CO_2-e, representing 8.9 per cent of New Zealand's gross emissions and 18.6 per cent of agriculture emissions in 2018. The *Agricultural soils* category was also the source of 92.5 per cent of New Zealand's total 2018 N_2O emissions.

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 (pasture, range and paddock manure) (level and trend assessment): 54.4 per cent of emissions from *Agricultural soils*.
- Synthetic nitrogen fertiliser (level and trend assessment): 20.1 per cent of emissions from *Agricultural soils*.

- Volatilisation (level assessment): 13.1 per cent of emissions from *Agricultural soils*.
- Leaching and runoff (level assessment): 7.2 per cent of emissions from *Agricultural soils*.
- Crop residues (level assessment): 3.6 per cent of emissions from *Agricultural soils*.

Trends

Emissions from *Agricultural soils* increased 56.7 per cent (2,542.5 kt CO_2-e) between 1990 and 2018. Increases in the use of synthetic nitrogen fertiliser and the dairy cattle population are the predominant drivers of increasing emissions from *Agricultural soils*, which have been partially offset by decreases in the sheep and beef cattle populations.

Trends across the key categories in *Agricultural soils* are detailed below.

- Urine and dung deposited by grazing animals (pasture, range and paddock manure) (level and trend assessment): 30.7 per cent (897.4 kt CO_2-e) increase between 1990 and 2018.
- Synthetic nitrogen fertiliser (level and trend assessment): 512.8 per cent (1,181.0 kt CO_2-e) increase between 1990 and 2018.
- Volatilisation (level assessment): 30.5 per cent (214.7 kt CO_2-e) increase between 1990 and 2018.
- Leaching and runoff (level assessment): 34.1 per cent (129.4 kt CO_2-e) increase between 1990 and 2018.
- Crop residues (level assessment): 44.3 per cent (77.7 kt CO_2-e) increase between 1990 and 2018.

Table 5.5.1 shows the trends and relative contribution of N_2O emissions from these categories between 1990 and 2018.

Table 5.5.1 Trends and relative contribution of nitrous oxide emissions from Agricultural soils categories between 1990 and 2018

Agricultural soils category		Emissions (kt CO_2-e) 1990	Emissions (kt CO_2-e) 2018	Change from 1990–2018 kt CO_2-e	Change from 1990–2018 %	Share of Agricultural soils category (%) 2018	Share of total Agriculture sector (%) 2018
Direct	Synthetic nitrogen fertilisers	230.3	1411.3	1181.0	512.8	20.1	3.7
	Organic fertilisers (animal manure spread on pasture)	36.8	79.1	42.2	114.6	1.1	0.2
	Pasture, range and paddock manure	2,926.9	38,24.2	897.4	30.7	54.4	10.1
	Crop residue	175.5	253.2	77.7	44.3	3.6	0.7
	Cropland nitrogen mineralisation from soil organic matter loss	0.03	0.1	0.1	390.1	0.0	0.0
	Cultivation of organic soils	30.0	30.0	0.0	0.0	0.4	0.1
Indirect	Volatilisation	704.9	919.6	214.7	30.5	13.1	2.4
	Leaching and runoff	379.3	508.7	129.4	34.1	7.2	1.3
Total Agricultural soils		4,483.8	7,026.3	2,542.5	56.7		18.6

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

5.5.2 Methodological issues

New Zealand uses methodologies based on the IPCC Guidelines (IPCC, 2006), outputs of the Tier 2 livestock population characterisation, 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 is 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, A3.1.6 and A3.1.7 (annex 3); and in table 5.5.5 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 around 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)). Direct N_2O emission factors for urine have been disaggregated based on livestock type (for *Dairy cattle*, *Non-dairy cattle*, *Sheep*, and *Deer*) and hill slope category based on recent research by van der Weerden et.al (2019). A 'nutrient transfer model' developed by Saggar et al. (2015) is used to calculate the amount of dung and urine deposited onto different hill slope categories. Approximately 80 per cent of land on sheep, beef and deer farms is classed as medium (12–24 degrees) or steep (greater than 24 degrees) sloped land (see figure A3.1.3).

For minor livestock categories, such as *Horses*, *Llamas and alpacas*, *Poultry*, *Swine*, *Goats*, and *Mules and asses*, New Zealand uses IPCC default emission factors and methodology. Research conducted in New Zealand confirmed that the IPCC default emission factors and methodology for direct N_2O emissions from manure deposited onto soil ($EF_{3,PRP\text{-}MINOR}$) are appropriate for New Zealand conditions (Carran et al., 1995; de Klein et al., 2003; Muller et al., 1995).

New Zealand uses country-specific emission factors for urea fertiliser (0.0059) and dairy cattle effluent manure (0.0025) applied to soils (van der Weerden et.al., 2016a and 2016b). The IPCC default value of 0.01 is used for other nitrogen inputs including synthetic nitrogen fertiliser (excluding urea), animal manure from minor livestock species 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 is required to develop a country-specific value, and that the IPCC (2006) default emission factor (0.0075) is appropriate for New Zealand in the meantime.

In addition to these country-specific emission factors, New Zealand has developed country-specific parameters for volatilisation, leaching, and nitrogen input from crop residue burning and pasture renewal (see table 5.5.4). New Zealand has also incorporated country-specific emission factors and country-specific parameters for calculating emissions from the use of the following mitigation technologies (see table 5.5.5):

- urease inhibitors such as N-butyl thiophosphoric triamide
- dicyandiamide (DCD), a nitrification inhibitor.

Table 5.5.2 Nitrous oxide (N_2O) emission factors for Agricultural soils in New Zealand, excluding $EF_{3,PRP-URINE}$ for cattle, sheep and deer

Category		Emission factor		Source
3.D.1 Direct N_2O emissions				
Synthetic nitrogen fertiliser (urea)	EF_{1-UREA}	0.0059	kg N_2O-N/kg N	van der Weerden et al. (2016a, 2016b)
Organic fertiliser (dairy cattle manure)	$EF_{1-DAIRY}$	0.0025	kg N_2O-N/kg N	van der Weerden et al. (2016a, 2016b)
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 (dung and urine) from minor grazing animals (i.e., *excluding* cattle, sheep and deer) in pasture, range and paddock systems	$EF_{3,PRP-MINOR}$	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	$EF_{3,PRP-DUNG}$	0.0012	kg N_2O-N/kg N	van der Weerden et al. (2019)
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 Direct nitrous oxide (N_2O) emission factors for urine deposited by cattle, sheep and deer, by livestock type and slope, using values calculated by van der Weerden et al. (2019)

	Emission factor by slope	
Livestock type	Flat and low sloped land (less than 12° gradient) $EF_{3,PRP-FLAT}$	Medium and steep sloped land (greater than 12° gradient) $EF_{3,PRP-STEEP}$
All cattle (includes dairy and non-dairy)	0.0098	0.0033
Deer	0.0074	0.0020
Sheep	0.0050	0.0008

Table 5.5.4 Parameters for indirect nitrous oxide (N_2O) emissions from agricultural soils in New Zealand

Category		Parameter		Source
3.D.2 Indirect N_2O emissions				
Fraction of volatilisation from synthetic fertiliser	$Frac_{GASF}$	0.1	kg NH_3-N + NO_x-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 NH_3-N + NO_x-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 5.5.5 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 coated with 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 N_2O 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 N_2O emissions from indirect pathways as well, and these calculations are described in detail in the section on indirect N_2O emissions from *Agricultural soils*.

Emissions from the non-manure components of organic fertilisers (F_{ON}) are not estimated in New Zealand's inventory because they have been found to be insignificant. 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 of significant volume in 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 MPI website (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 they have grown significantly since 1990. Most synthetic nitrogen fertiliser used in New Zealand is urea fertiliser applied to dairy pasture land to increase pasture growth during spring (September to November) and autumn (March to May).

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:

$$N_2O\ emissions = \frac{44}{28} \cdot \left[\left(F_{SN(UREA)} \cdot EF_{1(UREA)} \right) + \left(F_{SN(OTHER)} \cdot EF_1 \right) \right]$$

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

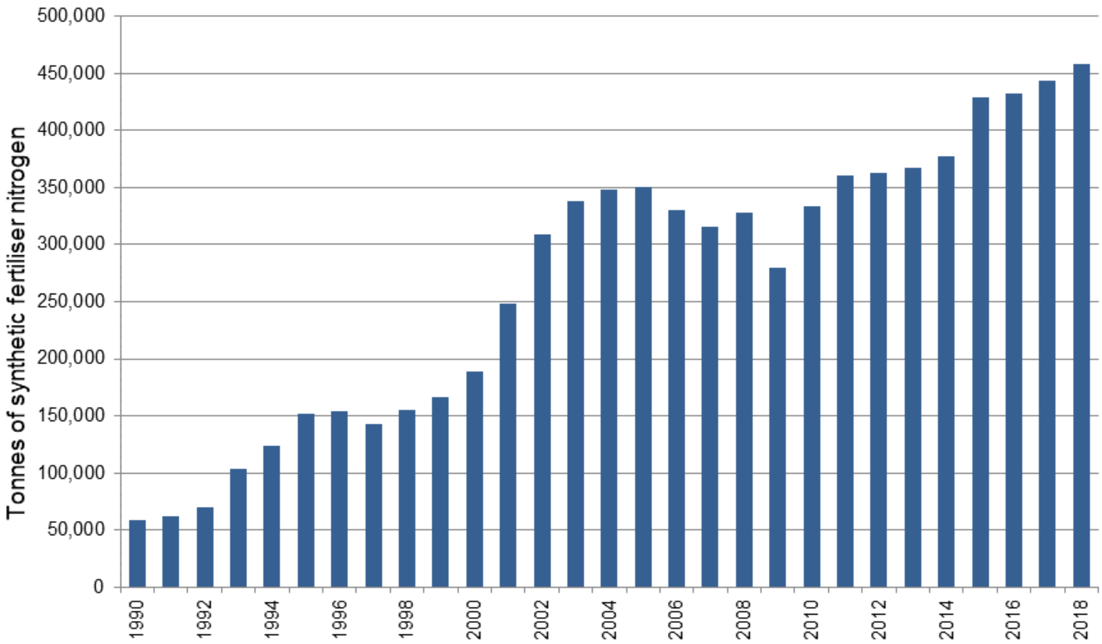
EF_1 is the proportion of direct N_2O emissions from nitrogen input to the soil (0.01; table 5.5.2).

Data on synthetic fertiliser use are provided by the Fertiliser Association of New Zealand from sales records for 1990 to 2018.

The $EF_{1(UREA)}$ value was changed to 0.0059 in 2017, following a meeting of the Agriculture Inventory Advisory Panel in 2016. The Panel agreed that the value of 0.0059, based on the research by van der Weerden et al. (2016a), was more representative of New Zealand farming practices and conditions, where only small (30–50 kg N/ha/application) urea dressings are applied but on several occasions during a year. The lower value of $EF_{1(UREA)}$, compared with the IPCC default of 1 per cent, is comparable with studies conducted in Australia (Chen et al., 2010; Galbally et al., 2005) and the Netherlands (Kuikman et al., 2006), which have found EF_1 urea fertiliser values of approximately 0.5 per cent.

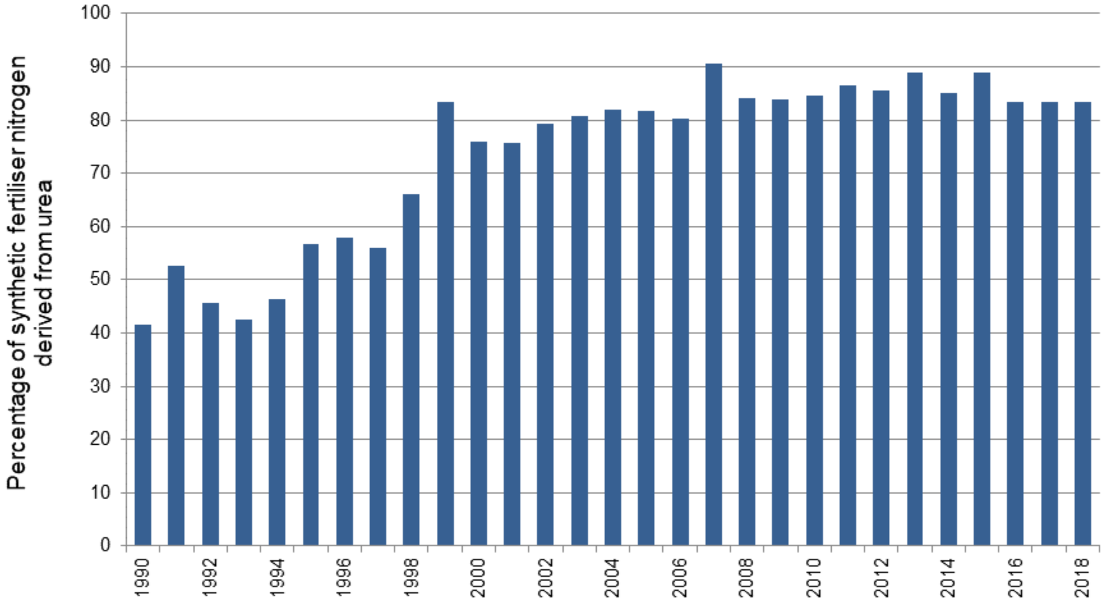
Since 1990, there has been a large increase in nitrogen applied through synthetic fertiliser, from 59,265 tonnes in 1990 to 457,800 tonnes in 2018 (see figure 5.5.2). At the same time, the proportion of urea fertiliser applied has increased from just over 40 per cent to more than 80 per cent of all synthetic nitrogen fertiliser (see figure 5.5.3).

Figure 5.5.2 Synthetic nitrogen fertiliser use in New Zealand from 1990 to 2018



Source: Fertiliser Association of New Zealand

Figure 5.5.3 Percentage of synthetic nitrogen fertiliser derived from urea from 1990 to 2018



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 total agricultural emissions) to 1,411.3 kt CO_2-e in 2018 (3.7 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 collected 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 emissions calculation in this sub-category (organic nitrogen fertilisers) 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, 2016b). 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. This emission factor was changed to 0.0025 in 2017, following a meeting of the Agriculture Inventory Advisory Panel in 2016. The Panel agreed that the new value was more representative of New Zealand farming practices and conditions. Given that dairy cattle manure is a mixture of urine and dung (combined with water), the value of 0.0025 is consistent with the EF_3 emission factor values used in New Zealand for dairy cattle urine (0.0098) and dung (0.0012) (van der Weerden et al., 2016a). Direct N_2O emissions from organic fertiliser (dairy cattle manure) in 2018 (using the EF of 0.0025) were 0.147 kilotonnes of N_2O. If the IPCC emission factor was used, estimated direct N_2O emissions from organic fertiliser (dairy cattle manure) would be 0.589 kilotonnes of N_2O.

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 (swine and poultry) 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_2O emissions from animal manure (swine and poultry) applied to soils (0.01; table 5.5.2)

$F_{AM(DAIRY)}$ is the total amount of animal manure nitrogen (dairy) applied to soils from manure management systems (other than pasture, range and paddock), which is derived as a fraction of the nitrogen excretion rates, Nex, described in section 5.3.2, and

$EF_{1(DAIRY)}$ is the proportion of direct N_2O emissions from animal manure (dairy cattle) applied to soils (0.0025; table 5.5.2).

The IPCC Guidelines (IPCC, 2006) 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.

Because most livestock manure in New Zealand is excreted directly onto pasture, emissions from the organic nitrogen fertilisers category are relatively small. In 2018, N_2O emissions from this source contributed 79.1 kt CO_2-e (1.1 per cent of emissions from *Agricultural soils*, and 0.2 per cent of total agricultural emissions). This is an increase of 42.2 kt CO_2-e (114.6 per cent) from the 1990 level of 36.8 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 around 92.7 per cent of dairy cattle excreta and 100 per cent of non-dairy cattle, sheep, deer and other livestock excreta deposited on pasture (see table 5.3.2).

The following equations are used to determine direct N_2O emissions from grazing livestock manure.

For urine deposited on flatland and low slopes by sheep, cattle and deer only:

$$N_2O\ emissions = \frac{44}{28}(N_2O - N)$$
$$= \frac{44}{28}\left(\sum_T N_T \cdot (Nex_{URINE,FLAT} + Nex_{URINE,LOW}) \cdot MS_T\right) \cdot EF_{3(PRP-FLAT)}$$

For urine deposited on medium and steep slopes by sheep, cattle and deer only:

$$N_2O\ emissions = \frac{44}{28}(N_2O - N)$$
$$= \frac{44}{28}\left(\sum_T N_T \cdot \left(Nex_{URINE,MED} + Nex_{URINE,STEEP}\right) \cdot MS_T\right) \cdot EF_{3(PRP-STEEP)}$$

For all dung from sheep, cattle and deer:

$$N_2O\ emissions = \frac{44}{28}(N_2O - N) = \frac{44}{28}\left(\sum_T N_T \cdot Nex_{DUNG,T} \cdot MS_T\right) \cdot EF_{3(PRP-DUNG)}$$

For urine and dung from other livestock categories (swine, goats, horses, alpaca, mules, asses and poultry):

$$N_2O\ emissions = \frac{44}{28}(N_2O - N) = \frac{44}{28}\left(\sum_T N_T \cdot Nex_T \cdot MS_T\right) \cdot EF_{3(PRP-MINOR)}$$

Where: N_T is the population of the livestock category (sheep, cattle, deer or other); T (population as calculated in section 5.1.3)

$Nex_{URINE,FLAT}$ is the annual urinary N excretion per head deposited on flatland[56] (kg N/head/year)

$Nex_{URINE,LOW}$ is the annual urinary N excretion per head deposited on low slopes[57] (kg N/head/year)

$Nex_{URINE,MED}$ is the annual urinary N excretion per head deposited on medium slopes[58] (kg N/head/year)

$Nex_{URINE,STEEP}$ is the annual urinary N excretion per head deposited on steep slopes[59] (kg N/head/year)

$Nex_{DUNG,T}$ is the annual average excretion per head (kg N/head/year)

Nex_T is the annual average N excretion per head (kg N/head/year) (see section 5.3)

MS_T is the proportion of manure excreted directly onto pasture, range and paddock (see table 5.3.2)

$EF_{3(PRP-FLAT)}$ is the emission factor for urinary N deposited on flatland and low slopes by sheep, deer and cattle (note that emission factors vary by animal category, see table 5.5.2)

$EF_{3(PRP-STEEP)}$ is the emission factor for urinary N deposited on medium and steep slopes, for sheep, deer and cattle (note emission factors vary by animal category, see table 5.5.2)

$EF_{3(PRP-DUNG)}$ is the emission factor for dung N excreta deposited by sheep, deer and cattle on pasture, range and paddock (0.0012, see table 5.5.2)

$EF_{3(PRP-MINOR)}$ is the emission factor for dung from minor animal categories deposited on pasture, range and paddock (see table 5.5.2).

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56 Flatland is classified as flat pastoral land or plains with a gradient lower than 12 degrees.

57 Low slopes are classified as hill country pastoral land with a gradient lower than 12 degrees.

58 Medium slopes are classified as hill country pastoral land with a gradient between 12 degrees and 24 degrees.

59 Steep slopes are classified as hill country pastoral land with a gradient greater than 24 degrees.

For cattle, sheep and deer, the estimated nitrogen excretion (N_{ex}) values are separated into urine and dung components using the methodology outlined by Pacheco et al. (unpublished).

The inventory assumes that all dairy cattle graze on flatland, due to New Zealand farming practices, therefore, all dairy urinary N is allocated to $Nex_{URINE,FLAT}$.

Urinary N from beef cattle, sheep and deer is allocated to the different slope types, $Nex_{URINE,LOW}$, $Nex_{URINE,MED}$ and $Nex_{URINE,STEEP}$, however, there is zero land allocated to flatland, $Nex_{URINE,FLAT}$, due to New Zealand farming practices (flatland is used for dairy systems).

New EF_3 emission factors for excreta deposited by cattle, sheep and deer on sloped land

New EF_3 emission factors have been incorporated in the 2020 inventory and are detailed in table 5.5.2 ($EF_{3(PRP\text{-}DUNG)}$) and table 5.5.3. The new EF_3 emission factors used to calculate N_2O emissions from cattle (dairy and beef), sheep and deer are based on a meta-analysis undertaken by van der Weerden et al. (2019) based on field studies undertaken in the past decade (de Klein et al., 2014; Hoogendoorn et al., 2013; Luo et al., 2013, 2016, 2019; and Saggar et al., 2015). The research collectively shows:

- a statistically significant difference in urine emission factors between cattle and sheep
- that emissions from sheep, beef cattle and dairy cattle excreta deposited on low (between 0 degrees and 12 degrees), medium (between 12 degrees and 24 degrees) and steep (greater than 24 degrees) sloped land are significantly lower than corresponding emissions on land that is flat or of a low gradient.

Evidence and meta-analysis for new EF_3 emission factors for excreta deposited on sloped land

The meta-analysis (2019) built on a previous study by Kelliher et al. (2014), calculated new emission factors based on animal type, season and slope from an expanded dataset of 1,218 replicate-level emission factors from 236 field experiments conducted over the past decade.

The meta-analysis included results of studies from dung and urine deposited onto flatland and steep sloped land published in scientific journals (Hoogendoorn et al., 2008; Ledgard et al., 2014; Luo et al., 2013; van der Weerden et al., 2011) and reported to MPI's inventory reporting team (Hoogendoorn et al., 2013; Luo et al., 2016, 2019). These data were compiled to contribute to existing data on emissions from dung and urine deposited on low and medium sloped land from the Kelliher et al. (2014) study.

Additional evidence conducted overseas supporting the use of emission factors that vary by slope has been provided in a study in the United Kingdom by Marsden et al. (2018), who found that sheep EF_3 values are lower on upland and hill areas compared with intensively managed lowlands.

Table 5.5.6 Number of replicate-level EF_3 values collated for van der Weerden et al. (2019) analysis, for each nitrogen source and topography (number of individual trials shown in brackets)

Nitrogen source	Flatland (0–12°)	Low sloped land (0–12°)	Medium sloped land (12–24°)	Steep sloped land (>24°)	Total
Dairy cattle urine	341 (57)	108 (22)	20 (4)		469 (83)
Dairy cattle dung	84 (19)	46 (9)	20 (4)		150 (32)
Non-dairy cattle urine	8 (1)	40 (8)	60 (12)	20 (4)	128 (25)
Non-dairy cattle dung		76 (16)	60 (12)	20 (4)	156 (32)
Sheep urine	40 (7)	64 (12)	60 (12)	20 (4)	184 (35)
Sheep dung	54 (13)	36 (8)	20 (4)	20 (4)	130 (29)
Total urine	**389 (65)**	**212 (42)**	**140 (28)**	**40 (8)**	**781 (143)**
Total dung	**138 (32)**	**158 (33)**	**100 (20)**	**40 (8)**	**436 (93)**
Total excreta	**527 (97)**	**370 (75)**	**240 (48)**	**80 (16)**	**1,217 (236)**

Table 5.5.7 Number of replicate-level EF_3 values collated for van der Weerden et al. (2019) analysis, for each nitrogen source, season that trial was undertaken, and topography

Nitrogen source	Topography class	Autumn	Winter	Spring	Summer	Total
Dairy cattle urine	Flatland (0°)	128	105	88	12	333
	Low slope (0–12°)	34	34	28	20	116
	Medium slope (12–24°)		20			20
	Steep slope (>24°)					
Dairy cattle dung	Flatland (0°)	14	34	36		84
	Low slope (0–12°)		26		20	46
	Medium slope (12–24°)		20			20
	Steep slope (>24°)					
Non-dairy cattle urine	Flatland (0°)		8			8
	Low slope (0–12°)		20		20	40
	Medium slope (12–24°)	10	30		20	60
	Steep slope (>24°)	10	10			20
Non-dairy cattle dung	Flatland (0°)					
	Low slope (0–12°)	20	28	8	20	76
	Medium slope (12–24°)	10	30		20	60
	Steep slope (>24°)	10	10			20
Sheep urine	Flatland (0°)	8	8	20		36
	Low slope (0–12°)	24		44		68
	Medium slope (12–24°)	30	10	20		60
	Steep slope (>24°)	10	10			20
Sheep dung	Flatland (0°)	10	16	28		54
	Low slope (0–12o)	20	8	8		36
	Medium slope (12–24o)	10	10			20
	Steep slope (>24o)	10	10			20
Total urine		**254**	**255**	**200**	**72**	**781**
Total dung		**104**	**192**	**80**	**60**	**436**
Total excreta		**358**	**447**	**280**	**132**	**1,217**

The meta-analysis used arithmetic means to calculate new average EF_3 values (categorised by animal, slope and excreta type). Because the differences between some of these values were not statistically significant, it was recommended that some of the arithmetic means be pooled. This resulted in the dung EF_3 averages being combined into a single value (0.0012). The urine EF_3 values were pooled into four categories:

- cattle urine on flatland/low slopes (0.0098)
- cattle urine on medium/steep slopes (0.0033)
- sheep urine on flatland/low slopes (0.0020)
- sheep urine on medium/steep slopes (0.0008).

The lower emission factors observed for urine on steeper slopes are thought to be due to these soils having lower soil fertility and moisture content compared with less steep slopes (Luo et al., 2013).

The new urine emission factor values for each livestock type by slope are lower than the current IPCC default EF_3 value, which is based on common international farming systems where, on average, farmed land is on less hilly terrain than common farm land in New Zealand. In addition to the large proportion of farmed hill country, New Zealand's climate and soil characteristics contribute to differences between international default emission factors and New Zealand's country-specific emission factor. When using these emission factors, the IEF for direct N_2O from dung and urine was 0.0054 in 2018. This value is comparable with that calculated for the United Kingdom (0.0047) and Australia (0.004) in their respective inventory submissions in 2019.

Nitrous oxide measurements have not been taken for deer excreta, therefore, deer EF_3 values were calculated using average EF_3 values from cattle and sheep. Based on animal liveweight, deer excreta characteristics (in terms of total deposition volume and weight) are assumed to be between the excreta characteristics of cattle and sheep (van der Weerden et al., 2019).

To apply these emission factors, estimates on the amount of urine and dung deposited onto separate slopes are needed. A nutrient transfer model developed by Saggar et al. (2015) is used to allocate total excreta (N_{ex}, calculated using the methods described in section 5.3) by livestock type to the different slope categories. The nutrient transfer model uses data on the area of farm land for each slope type, and accounts for animal behaviour where livestock spend relatively more time on lower slopes, and hence deposit more excreta on these lower slopes. For more information on this model, please refer to annex 3.1.3.

The revised EF_3 emission factors and nutrient transfer model were discussed by the Agriculture Inventory Advisory Panel in late 2019, which recommended that they be included in the 2020 inventory submission.

Direct nitrous oxide emission factors for minor livestock types

Minor livestock types including swine, goats, horses, alpaca, mules, asses, lions and poultry, make up a small proportion of total agricultural emissions. New Zealand will therefore continue to use the previous emission factor for minor livestock types ($EF_{3(PRP\text{-}MINOR)}$) of 0.001, which is the IPCC default. Research conducted in New Zealand has confirmed this value is appropriate for New Zealand's conditions (Carran et al., 1995; de Klein et al., 2003; Muller et al., 1995).

In 2018, N_2O emissions from *Urine and dung deposited by grazing animals* (pasture, range and paddock manure) contributed 54.4 per cent (3,824.2 kt CO_2-e) of emissions from *Agricultural soils*, or 10.1 per cent of total agricultural emissions). This is an increase of 30.7 per cent since 1990. Emissions for each livestock category are given in table 5.5.8. Emissions from *Urine and dung deposited by grazing animals* were identified as a key category (level and trend assessment).

Table 5.5.8 Trends and relative contribution of direct nitrous oxide emissions from urine and dung deposited by grazing animals per livestock category between 1990 and 2018

	Emissions (kt CO_2-e)		Change from 1990–2018		Share of Agricultural soils category (%)		Share of total Agriculture sector (%)	
Livestock category	**1990**	**2018**	**kt CO_2-e**	**%**	**1990**	**2018**	**1990**	**2018**
Dairy cattle	1,198.5	2,529.8	1,331.2	111.1	26.7	36.0	3.7	6.7
Non-dairy cattle	711.8	683.8	–28.0	–3.9	15.9	9.7	2.2	1.8
Sheep	887.7	542.9	–344.8	–38.8	19.8	7.7	2.8	1.4
Deer	47.9	47.5	–0.5	–1.0	1.1	0.7	0.1	0.1
Minor livestock	80.8	20.2	–60.6	–75.0	1.8	0.3	0.3	0.1

Note: Percentages presented are calculated from unrounded values.

Nitrous oxide from crop residue returned to soil (CRF 3.D.1.4)

This emission 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 method to increase farm productivity. The direct emissions from agricultural residue burning are reported under section 5.7.

New Zealand does not include an adjustment for crop residue removed for feed and bedding, as recommended by Thomas et al. (2008), who recommended that this be ignored until appropriate 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 A3.1.8, 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 A3.1.8).

$$AG_{DM} = \left(\frac{Crop_T}{HI}\right) - Crop_T \cdot Frac_{BURN} \cdot C_f$$

Where: HI is the crop-specific harvest index or fraction of the crop that is harvested (see annex 3, table A3.1.8)

$Frac_{BURN}$ is the fraction of residue burned in the field (see table 5.5.4), 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 1990–2018. 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. This means that 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 253.2 kt CO_2-e (0.7 per cent of agricultural emissions) in 2018.

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 from 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 0.14 kt CO_2-e in 2018.

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 being 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 overall agricultural emissions is small and has been assumed to remain constant at 30.0 kt CO_2-e since 1990 to the present (0.1 per cent of agricultural emissions in 2018).

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 (see 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:

$$N_2O_{ATD}\ emissions = \frac{44}{28}(N_2O_{ATD} - N) = \frac{44}{28}\left[(F_{SN} \cdot Frac_{GASF}) + \left((F_{ON} + F_{PRP}) \cdot Frac_{GASM}\right)\right] \cdot EF_4$$

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 5.5.4)

$Frac_{GASM}$ is the fraction of nitrogen from manure spreading and pasture, range and paddock manure that volatilises as NH_3 and NO_x (see table 5.5.4), 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 pasture, range and paddock 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 2018, N_2O emissions from volatilisation contributed 2.4 per cent (919.6 kt CO_2-e) to total agricultural emissions, an increase of 30.5 per cent from the 1990 value of 704.9 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 (see 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 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 5.5.4), 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.[60] 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 $Frac_{LEACH}$ value of 0.15[61]).

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 (from nitrogen-based fertilisers, dung and urine applied as dairy farm effluent or directly excreted by grazing animals). Dung and urine from animals is calculated from the difference between nitrogen intake by grazing animals and nitrogen retained in animal products – such as milk, meat, velvet. This is based on user inputs of stocking rates or production and an internal database with information on the nitrogen content of pasture and animal products, and is calibrated against field measurements.

In 2018, N_2O emissions from leaching and runoff made up 1.3 per cent (508.7 kt CO_2-e) of total agricultural emissions, an increase of 34.1 per cent from the 1990 value of 379.3 kt CO_2-e.

Incorporation of nitrous oxide mitigation technologies into the Agriculture inventory

Urease inhibitors

The N_2O emissions reported under the *Agricultural soils* category 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 urease enzyme. 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 product. Saggar et al. (2013) showed that the presently recommended country-specific value of $Frac_{GASF}$ of 0.1 should be reduced to 0.055. This finding was based on field and laboratory studies conducted both in New Zealand and worldwide.

60 For reporting under the 1996 IPCC Guidelines, this parameter was defined as $Frac_{LEACH}$; under the 2006 IPCC Guidelines, it is defined as $Frac_{LEACH-(H)}$.

61 A New Zealand parameter for $Frac_{LEACH}$ of 0.15 was used in inventories submitted before 2003.

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 dung and 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.[62] 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 non-nitrogen fertiliser products.

Estimates of the mitigation impact of urease inhibitors on N_2O emissions from volatilisation for the calendar years 2001 to 2018 are shown in table 5.5.9. In 2014 and 2016, there were large increases in the use of urease inhibitors.

Table 5.5.9 Mitigation impact of urease inhibitors on nitrous oxide emissions from volatilisation, from 2001 to 2018

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
2007	5.0	3.0
2008	5.2	3.0

62 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
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
2017	27.8	21.6
2018	29.9	24.0

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 5.5.5). 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 DCD on dung ($EF_{3(PRP\text{-}DUNG)}$); however, this research was non-conclusive and further work needs 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 5.5.10) 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 DCD 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 (March to May) and early spring (September) 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 the calendar years 2007 to 2012 are shown in table 5.5.10.

Table 5.5.10 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)	0.00972	0.00970	0.00973	0.00975	0.00973	0.00974
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)	15.5	21.0	15.2	11.2	16.0	16.0

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 (pasture, range and paddock 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 ±55.3 per cent for 2018.

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 Monte Carlo method used for previous years 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(b)) (see table 5.5.11). 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 5.5.11 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 (2018)

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
2018	23.6	16.9	30.2

Note: The N_2O emissions listed in this table 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 in the trend from 1990. The uncertainty between years was assumed to be correlated, and therefore the uncertainty is mostly associated with the emission factors. The uncertainty associated with the trend is 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(b)).

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, MPI 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 sold 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.

Comparison of New Zealand emission factors and parameters with IPCC default values

Table 5.5.12 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 from trials summarised by van der Weerden et al. (2019) (see section 5.5.2).

Table 5.5.12 Comparison of New Zealand's implied emission factors (IEFs) for EF_1 (synthetic nitrogen fertiliser) and $EF_{3(PRP)}$ (pasture, range and paddock manure) with the IPCC default and the Australian-specific value

	EF_1 (kg N_2O-N/kg N)	EF_3 (kg N_2O-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 2017 value	0.0038	0.0040
New Zealand-specific IEF 2018 value	0.0066	0.0054

Source: UNFCCC (https://unfccc.int/documents/65705)

Table 5.5.13 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).

This research also showed that the default value of 0.2 for $Frac_{GASM}$ was too high and a lower value of 0.1 was adopted after an extensive review of scientific literature (Sherlock et al., 2008), which 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, over 95 per cent of animal excreta is deposited onto pasture and only a small proportion 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 application rate, which can be typical in other developed countries.

Table 5.5.13 Comparison of New Zealand's country-specific factors for volatilisation ($Frac_{GASF}$, $Frac_{GASM}$) and leaching and runoff ($Frac_{LEACH-(H)}$) 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 2017 value	0.1	0.2	0.3
New Zealand-specific IEF 2018 value	0.1	0.1	0.07

Source: UNFCCC (https://unfccc.int/documents/195780)

5.5.5 Source-specific recalculations

Emissions estimates in the *Agricultural soils* category have been affected by the following methodological improvements and corrections:

- the use of new EF_3 emission factors for N_2O emissions from excreta deposited on hill country (low, medium or steep); split by livestock type, excreta type and slope, applied using new methodology from the nutrient transfer model described in section 5.5.2 and annex 3.1.3
- revised activity data on the proportion of dairy goats in the overall farmed goat population, which reflects the findings of recent research. This change affected N_2O emissions from goats
- minor improvements to the equations used to estimate energy efficiency for maintenance (k_m) for beef cattle, sheep and deer, which is used to help calculate energy requirements, intake and nitrogen excretion. This change had a small effect on estimated emissions and included the specification of a constant to more significant figures and reverting to the IPCC default value for the gross energy content of feed of 18.45 MJ/kg dry matter.

Emissions estimates have also been updated using the latest available activity data from the sources described in section 5.1.4.

New EF_3 emission factor values for cattle, sheep and deer, and new methodology to allocate nitrogen excretion to different hill slopes

For the 2020 inventory submission, a new set of emission factors to calculate N_2O emissions from sheep, deer, beef cattle and dairy cattle from dung and urine deposited directly onto pasture ($EF_{3,PRP}$) has been adopted, based on research from van der Weerden et al. (2019). More information on this research and the new emission factors is in section 5.5.2, pages 208–213.

As part of this change, a nutrient transfer model developed by Saggar et al. (2015) is used to allocate total urine and dung N_{ex} (calculated using the methods described in section 5.5.2) to the different hill slope categories. The nutrient transfer model uses data on the area of farm land under different slope types, and accounts for animal behaviour which spend relatively more time on lower slopes. For more information on this model, please refer to annex 3.1.3.

In previous inventory submissions, an $EF_{3,PRP}$ value of 0.01 was used for urine from cattle, sheep and deer, while an $EF_{3,PRP}$ value of 0.0025 was used for urine from cattle, sheep and deer. These emission factors overestimated N_2O emissions on sloping hill land, as shown by the extensive research conducted on these slopes by van der Weerden et al. (2019).

The implementation of this change in methodology caused estimated emissions from *Agricultural soils* to decrease by 33.3 per cent in 1990 and 19.2 per cent in 2018 (see table 5.5.14). The difference in emission factors between sheep and cattle, the large fall in the sheep population and large increase in the dairy population since 1990 are the main causes of the difference between the 1990 change and the 2018 change.

Table 5.5.14 Comparison of current and previous emissions estimates before and after change to $EF_{3,PRP}$ values for cattle, sheep and deer, and new methodology to allocate N_{ex} to different hill slopes

Emissions (kt CO_2-e)		1990	2018	Change in emission outputs between 1990 and 2018 (kt CO_2-e)	Percentage change in emission outputs between 1990 and 2018
Total emissions from Agricultural soils (kt CO_2-e)	2020 (1990–2018) emissions estimate *using previous* EF_3 values	6,727.2	8,699.8	1,972.6	29.3
	2020 (1990–2018) emissions estimate *using new* EF_3 values	4,483.8	7,026.3	2,542.5	56.7
	Difference in emission estimates compared with current inventory	−2,243.4	−1,673.5	569.9	
	Percentage difference in emission estimates	−33.3	−19.2		

Revised activity data on dairy goats

A revised set of estimates on the dairy goat population from 1990 to 2018 has been implemented for the 2020 submission. This change has a small effect on estimated emissions from *Agricultural soils*, as detailed in table 5.5.15. More information on the revision is provided in section 10.1.3 (chapter 10).

Table 5.5.15 Comparison of current and previous emissions estimates before and after change to estimated dairy goat population

Emissions (kt CO_2-e)		1990	2018	Change in emission outputs between 1990 and 2018 (kt CO_2-e)	Percentage change in emission outputs between 1990 and 2018
Total emissions from Agricultural soils (kt CO_2-e)	2020 (1990–2018) emissions estimate *using previous* dairy goat population estimates	4,483.8	7,025.8	2,542.1	56.7
	2020 (1990–2018) emissions estimate *using new* dairy goat population estimates	4,483.8	7,026.3	2,542.5	56.7
	Difference in emission estimates compared with current inventory	0.0	0.5	0.5	
	Percentage difference in emission estimates	0.0	0.0		

Minor improvements to the equations used to estimate energy efficiency for maintenance (k_m)

The variable k_m estimates the efficiency of energy used for maintenance activities for cattle, sheep and deer, which is used to help calculate energy requirements, intake, and nitrogen excretion. For the 2020 submission, minor improvements were made to this equation for beef cattle, sheep and deer (not dairy cattle), so that it is consistent with the CSIRO (1990) and 2006 IPCC Guidelines. More details on this change are in section 10.1.3 (chapter 10).

This change had a small effect on estimated emissions from *Agricultural soils*, as shown in table 5.5.16.

Table 5.5.16 Comparison of current and previous emissions estimates before and after changes to energy efficiency for maintenance (k_m) equation

Emissions ($kt\ CO_2$-e)		1990	2018	Change in emission outputs between 1990 and 2018 ($kt\ CO_2$-e)	Percentage change in emission outputs between 1990 and 2018
Total emissions from Agricultural soils ($kt\ CO_2$-e)	2020 (1990–2018) emissions estimate *using previous* k_m equation specification	4,486.9	7,027.6	2,540.7	56.6
	2020 (1990–2018) emissions estimate *using new* k_m equation specification	4,483.8	7,026.3	2,542.5	56.7
	Difference in emission estimates compared with current inventory	–3.1	–1.3	1.8	
	Percentage difference in emission estimates	–0.1	0.0		

5.5.6 Source-specific planned improvements

New Zealand is carrying out ongoing research to improve estimates of emissions from the *Agricultural soils* category.

Understanding the factors causing variability in N_2O emissions from livestock excreta on pasture

This research will study the causes of variability in N_2O emissions from excreta on New Zealand pasture in a controlled environment. A combination of laboratory experiments and process-based modelling and data analysis will be used to determine the influence of key variables including soil water content, temperature, soil organic carbon, cation exchange capacity and nitrogen load on N_2O emissions.

The research will result in an improved understanding of the influence of key variables on N_2O emissions from dairy urine and produce recommendations for further research aimed at improving the accuracy of New Zealand's agricultural N_2O inventory.

Understanding potential N_2O emissions from hotspots

The aim of this research is to determine N_2O emission factors from physical hot-spot areas within a dairy grazed farm (i.e., water troughs, gateways and laneways) in New Zealand, by gathering and analysing experimental trial data. These results will be used to determine whether the inventory should account for these areas when estimating emissions.

Review and update $Frac_{Leach}$ parameter

This project will review the $Frac_{Leach}$ parameter and provide recommendations as to whether it should be changed to improve the accuracy of our N_2O emissions estimates. The project will provide recommendations as to whether the inventory should use a single $Frac_{Leach}$ value or a set of disaggregated values.

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

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, fire risk restrictions 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).

Field burning of agricultural residues contributed an estimated 19.0 kt CO_2-e, this is 0.1 per cent of Agriculture emissions in 2018. Emissions from *Field burning of agricultural residues* decreased 30.7 per cent (8.4 kt CO_2-e) between 1990 and 2018.

Burning of agricultural residues was not identified as a key category in 2018.

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 1990 to 2004 and 2005 to 2018, to account for changes in the availability of activity data over these periods. 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}) was 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:

$$AG_{BURN} = AG_{DM} \cdot Frac_{AREA-BURN} \cdot Frac_{RESIDUE} \cdot Frac_{BURN} \cdot 10$$

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 2018, calculation of the amount of biomass residue burned was based on information about the area of crop residue burning from the Statistics New Zealand Agricultural Production Census and Surveys. 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 largest contributor to uncertainty in the estimated emissions is considered to be the fraction of agricultural residue burned in the field. 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 2018 were 27.1 per cent (calculated as a percentage of total crop area) and have ranged from a high in 2006 of 61.5 per cent to a low in 2018 of 27.1 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 per cent. Given that emissions from field burning are low, compared with emissions from 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

All activity data were updated with the latest available Statistics New Zealand data.

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).

Liming was identified as a key category for the Agriculture sector in 2018 (level assessment).

Emissions from the application of lime contributed an estimated 494.9 kt CO_2, representing 0.6 per cent of New Zealand's gross emissions and 1.3 per cent of Agriculture emissions in 2018.

Emissions from *Liming* increased 37.4 per cent (134.8 kt CO_2) between 1990 and 2018.

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 annual surveys in the intervening years. 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

Limestone is more commonly applied than dolomite 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). The quality of the lime applied is assumed to be 100 per cent limestone.

Figure 5.8.1 Limestone usage on agricultural land in New Zealand from 1990 to 2018

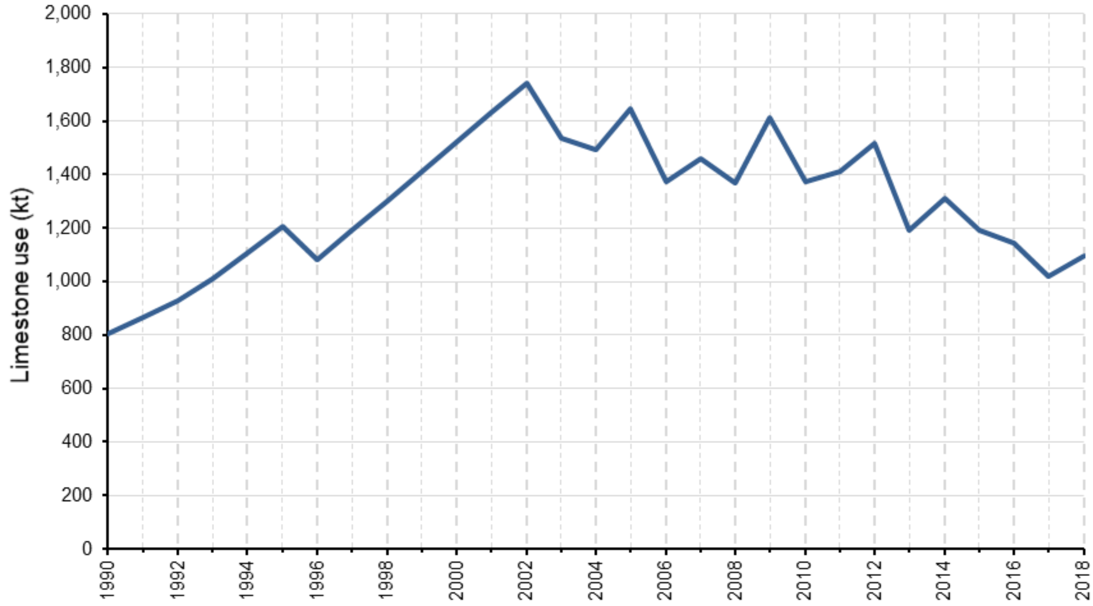
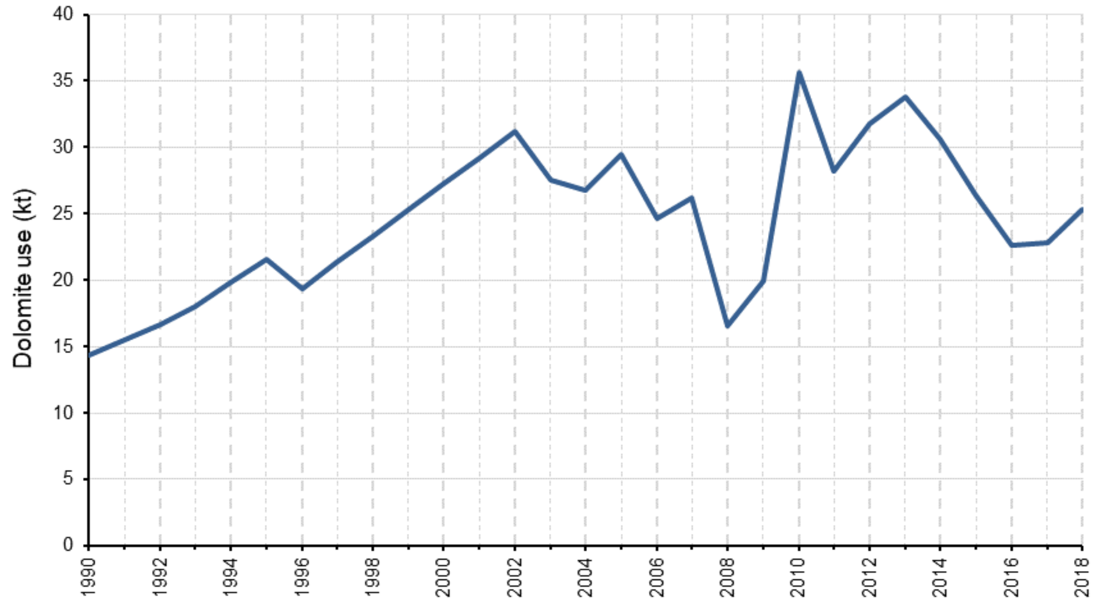


Figure 5.8.2 Dolomite usage on agricultural land in New Zealand from 1990 to 2018



5.8.4 Uncertainties and time-series consistency

Using the IPCC (2006) Tier 1 methodology, default emission factors are used, which are based on the chemical formulae of lime and assume all carbon in lime is emitted as CO_2 into the atmosphere. However, the 2006 IPCC Guidelines state that the maximum available C is not necessarily lost and that the emissions could be up to 50 per cent lower. This gives a lower uncertainty estimate of –50 per cent and an upper uncertainty estimate of 0 per cent.

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 the 2020 (1990 to 2018) submission.

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.

Urea application was identified as a key category for the Agriculture sector in 2018 (level and trend assessment).

Urea application contributed an estimated 608.2 kt CO_2, representing 0.8 per cent of New Zealand's gross emissions and 1.6 per cent of Agriculture emissions in 2018.

Emissions from *Urea application* increased 1,451.7 per cent between 1990 and 2018. The increase in emissions from *Urea application* is driven by the increase in urea fertiliser applied. Since 1990, the proportion of urea fertiliser applied (relative to total synthetic nitrogen fertiliser use) has increased from 41.5 per cent to 83.3 per cent.

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 2018. From 1990 to 2013, data on the percentage of synthetic nitrogen fertiliser derived from urea were sourced from the International Fertilizer Industry Association online database and are used to calculate the amount of applied urea fertiliser. Since 2014, data for total nitrogen from synthetic nitrogen fertiliser derived from urea have been provided by the Fertiliser Association of New Zealand.

There has been a substantial increase in elemental nitrogen applied to agricultural land as urea fertiliser, from 24,586 tonnes in 1990 to 381,500 tonnes in 2018. This is consistent with the increase in the total amount of synthetic nitrogen fertiliser, which is about 672.5 per cent greater than that used in 1990 (see reporting on *Agricultural soils* category and figure 5.5.2).

5.9.4 Uncertainties and time-series consistency

Under the IPCC (2006) Tier 1 methodology, the default emission factors are used, which are based on the chemical formulae of urea and assume all carbon in urea is emitted as CO_2 into the atmosphere. However, the 2006 IPCC Guidelines state that the maximum available C is not necessarily lost and that the emissions could be up to 50 per cent lower. This gives a lower uncertainty estimate of –50 per cent and an upper uncertainty estimate of 0 per cent.

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. In general, it is difficult to obtain information on the actual timing of application of fertiliser on farm. As outlined above (section 5.9.3), sales data on synthetic nitrogen fertiliser derived from urea was not available before 2014.

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 2020 (1990 to 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

Net emissions summary

2018

In 2018, net emissions by the Land Use, Land-Use Change and Forestry (LULUCF) sector were –23,394.1 kilotonnes carbon dioxide equivalent (kt CO_2-e). This comprises net removals of 23,568.6 kt CO_2, emissions of 75.3 kt CO_2-e of methane (CH_4) and 99.2 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.

1990–2018

Net emissions in 2018 have increased by 4,903.0 kt CO_2-e (17.3 per cent) from the 1990 level of –28,297.0 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 because a larger proportion of the estate is at harvest age when compared with 1990. Increased emissions in the *Grassland* category are primarily due to the conversion of plantation forests to grassland that has been occurring since 2000. 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 from land-use change are estimated as occurring over a 20-year period.

Table 6.1.1 New Zealand's greenhouse gas net emissions for the LULUCF sector by land use category in 1990 and 2018

	Net emissions (kt CO_2-e)		Difference (kt CO_2-e)	Change (%)
Land use category	**1990**	**2018**	**1990–2018**	**1990–2018**
Forest land	–26,961.3	–16,907.2	10,054.1	37.3
Cropland	476.2	391.3	–84.9	–17.8
Grassland	186.3	3,699.9	3,513.6	1,885.9
Wetlands	–10.7	13.6	24.2	227.2
Settlements	72.4	103.4	30.9	42.7
Other land	12.9	51.6	38.7	299.7
Harvested wood products	–2,072.9	–10,746.7	–8,673.8	–418.4
Total LULUCF	**–28,297.0**	**–23,394.1**	**4,903.0**	**17.3**

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).

2017–2018

Net emissions from the LULUCF sector decreased between 2017 and 2018 (by 684.0 kt CO_2-e; 3.0 per cent).

The largest change in emissions in the LULUCF sector occurred in the *Harvested wood products* category, with a decrease in emissions of 2,366.8 kt (CO_2-e) due to an increase in the production of harvested wood products. The increase in the production of harvested wood products was driven by an increase in the rate of harvesting of planted forests between 2017 and 2018. This increase in harvesting contributed to an increase in emissions from *Forest land* by 2,150.9 kt CO_2-e over this period, the second-largest change in emissions for the LULUCF sector.

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 2018.

Figure 6.1.1 New Zealand's annual emissions from the LULUCF sector from 1990 to 2018

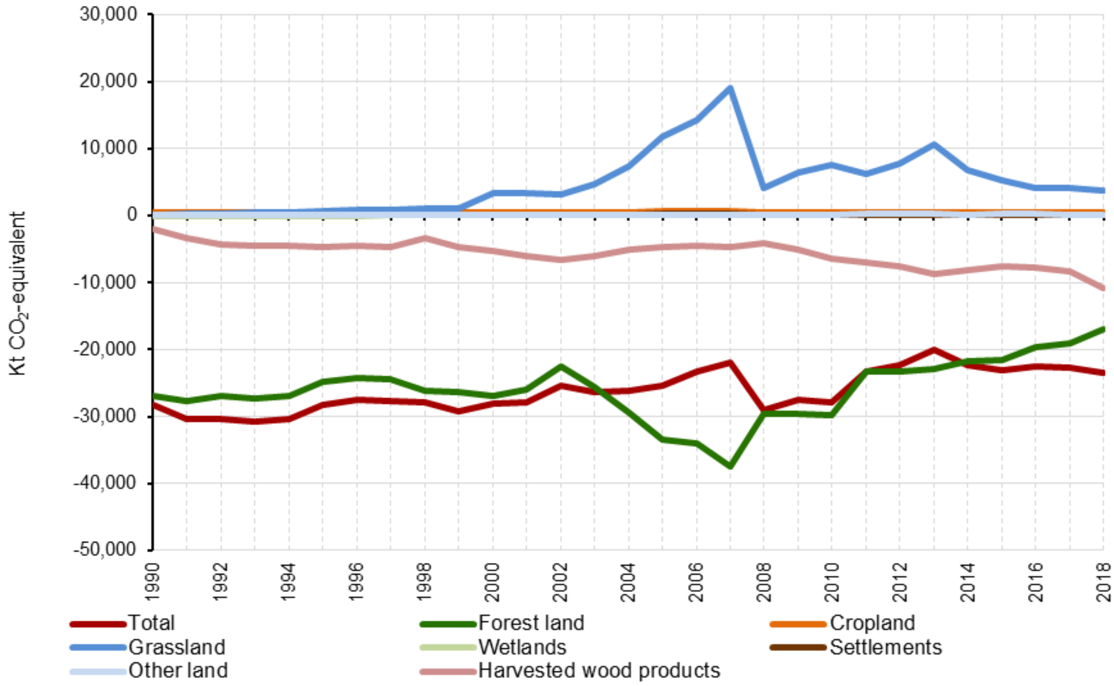
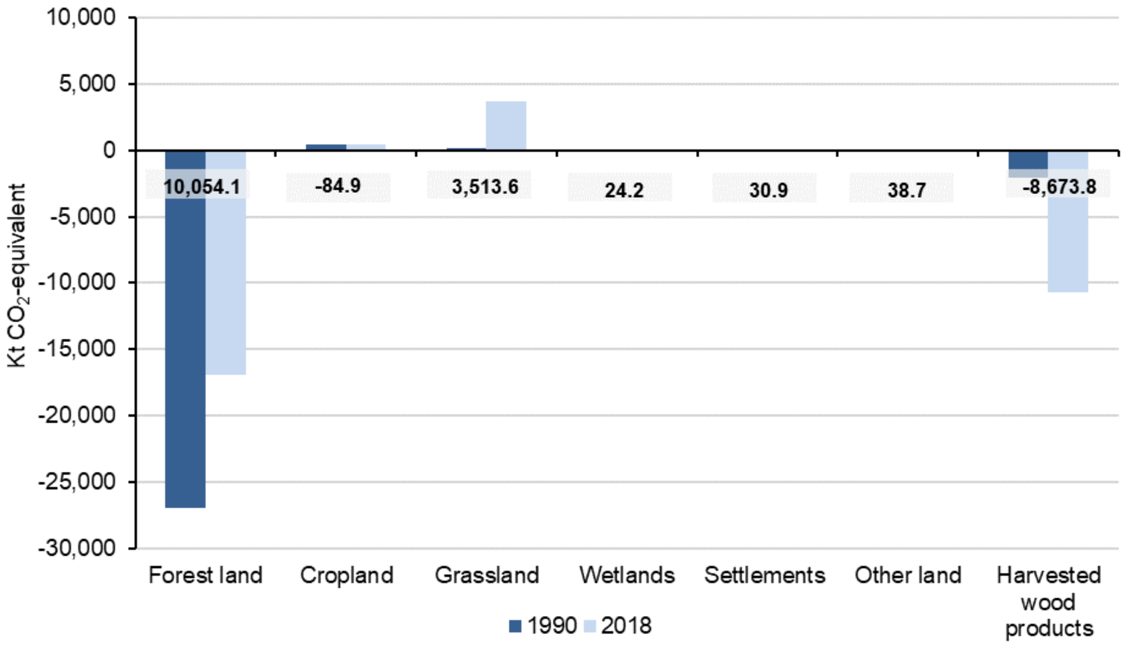


Figure 6.1.2 Change in New Zealand's emissions from the LULUCF sector from 1990 to 2018



Recalculations since the 2019 submission

Since the 2019 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 (approximately 19,800 kilometres). New Zealand has a temperate climate, highly influenced by the surrounding ocean. Around 60 per cent of the land is hilly or mountainous, with many lakes and fast-flowing rivers and streams.

Since 1990, approximately 8.8 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 2018, pre-1990 natural forest covers around 28.8 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 2018

Category	Land use	Area (kha)	Proportion of total area (%)
Forest land	Pre-1990 natural forest	7,756.584	28.8
	Pre-1990 planted forest	1,445.989	5.4
	Post-1989 forest	702.590	2.6
	Subtotal	9,905.163	36.8

Category	Land use	Area (kha)	Proportion of total area (%)
Cropland	Annual	371.357	1.4
	Perennial	104.696	0.4
	Subtotal	476.053	1.8
Grassland	High producing	6,872.829	25.5
	Low producing	6,400.945	23.8
	With woody biomass	1,376.035	5.1
	Subtotal	14,649.809	54.4
Wetlands	Open water	534.688	2.0
	Vegetated	226.933	0.8
	Subtotal	761.621	2.8
Settlements		236.357	0.9
Other land		896.164	3.3
Total		**26,925.168**	**100.0**

Note: Areas as at 31 December 2018. 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 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 2018, plantation forests covered approximately 2.10 million hectares – around 7.8 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 net 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 are used to estimate carbon stock changes in organic soils, and a Tier 2 modelling approach is applied to estimate soil organic carbon changes from mineral soils.

Different methods are used to obtain emission factors when estimating emissions and removals from post-1989 natural forest and post-1989 planted forest, to ensure 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: regenerating*	Based on an annual carbon stock yield table	All biomass pools	Paul et al. (unpublished(b))
	Pre-1990 natural forest: tall forest*	251.0	All biomass pools	Derived from Paul et al. (unpublished(b))
	Pre-1990 planted forest	Based on an age-based carbon yield table	All biomass pools	Paul et al. (unpublished(a))
	Post-1989 natural forest	Based on an age-based carbon yield table	All biomass pools	Beets et al. (2014b)
	Post-1989 planted forest	Based on an age-based carbon yield table	All biomass pools	Paul et al. (unpublished(d))
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 regenerating) 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: regenerating	0.62	NA	All biomass pools	Paul et al. (unpublished(b))
	Pre-1990 natural forest: tall forest	0	NA	All biomass pools	Paul et al. (unpublished (b))
	Pre-1990 planted forest	Based on an age-based carbon yield table	NA	All biomass pools	Paul et al. (unpublished(a))
	Post-1989 natural forest	Based on an age-based carbon yield table	NA	All biomass pools	Beets et al. (2014b)
	Post-1989 planted forest	Based on an age-based carbon yield table	NA	All biomass pools	Paul et al. (unpublished(d))
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	
						Soil organic matter	
Kyoto Protocol reporting pool		Above-ground biomass	Below-ground biomass	Dead wood	Litter	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 regenerating) 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; LUCAS = Land Use Carbon Analysis System; 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).

Pre-1990 natural forest

As described in table 6.1.3, the methods for calculating emissions from *Forest land* biomass 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 regenerating). The area of pre-1990 natural forest deforestation is sub-classified as tall forest or regenerating using spatial data on land cover, sourced from the national land cover database (LCDB).

Tall forest deforestation emissions are determined from the average carbon stock per hectare in biomass for tall forests. Regenerating forest deforestation emissions are determined from the average carbon stock per hectare in biomass for regenerating forests. All carbon in biomass, for both tall and regenerating forest, is assumed to be an instantaneous emission at the time of deforestation (see the Deforestation section in 6.4, for further information on this assumption).

Table 6.1.6 shows the areas of pre-1990 natural forest deforestation split by these two types (tall forest and regenerating).

Table 6.1.6 New Zealand's areas of pre-1990 natural forest deforestation estimated by type from 1990 to 2018

	Area of natural forest deforestation (ha)							
Natural forest type	**1990–2007**	**2008–12**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Tall forest	9,024	2,488	405	283	357	259	367	367
Regenerating	24,929	4,856	715	188	255	116	373	373
Total	**33,953**	**7,344**	**1,120**	**471**	**612**	**375**	**740**	**740**

Note: Columns may not total due to rounding.

Pre-1990 planted forest

Deforestation emissions for pre-1990 planted forest are calculated based, where possible, on the planting date from Ministry for Primary Industries' Emissions Trading Scheme data and/or estimated from historical imagery. In the absence of date information, the deforestation age is based on the average age at which the forests are harvested, which is derived from the National Exotic Forest Description (NEFD) (Ministry for Primary Industries, 2018b).

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. New Zealand assumes a baseline harvest of 500 hectares a year at age 12. Longer rotation crops are assumed to be harvested at the oldest possible age in a given year (e.g., the age of 28 years in 2018). 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 2018 (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)
- estimates of planted forest harvest area and harvest age class distribution (see section 6.2)
- 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:

$$\left(\textit{Loss of biomass present in previous crop} \times \textit{Activity data (Area)} \right) + \left(\textit{Annual growth in biomass carbon stocks in new land use} \times \textit{Activity data (Area)} \right) \quad (1)$$

The formula used to calculate emissions from mineral soil changes on land-use conversion is:

$$\frac{\textit{Mineral soil carbon at steady state in the new land use} - \textit{Mineral soil carbon at steady state in the previous land use}}{\textit{20 years (transition period)}} \times \left(\textit{Activity data (Area)} \right) \quad (2)$$

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 × 100) + (0.67 × 100) = –219.7 tonnes C *(1)*

Mineral soil change = (((88.44 – 105.98) / 20) × 100) = –87.7 tonnes C *(2)*

Total carbon stock change = –307.4 tonnes C

Total emissions = (carbon stock change / 1,000 × –1) × (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 LUCAS. 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 48.4 per cent. Given this uncertainty, net emissions from the LULUCF sector could range from –12,070.0 kt CO_2-e to –34,718.2 kt CO_2-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 CO_2)	Uncertainty introduced into emissions for LULUCF (%)
Pre-1990 planted forest remaining pre-1990 planted forest	1,379.8	±34.9
Harvested wood products	10,746.7	±31.3
Low producing grassland converted to post-1989 forest	7,963.6	±9.3

The greatest contribution of uncertainty to the LULUCF sector arises from pre-1990 planted forest remaining pre-1990 planted forest in the *Forest land* category. 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 second-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).

The third-largest contribution to uncertainty in the LULUCF sector comes from low producing grassland converted to post-1989 forest. The uncertainty for this category is derived from emissions from harvesting and relatively large removals from forest growth, which overall contribute to large net removals. This results in high uncertainty introduced into emissions for LULUCF, despite relatively low uncertainty in carbon stocks (±12.2 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 2020 submission, New Zealand has recalculated its emission estimates for the LULUCF sector from 1990 to 2017, to incorporate new activity data from the creation of a new land use map and updated emission factors. These recalculations have improved the accuracy, consistency and completeness of the LULUCF estimates.

As a result of the recalculations, estimates of net emissions in 1990 have increased by 9.2 per cent, and net emissions in 2017 have increased by 4.4 per cent (see table 6.1.8).

Table 6.1.8 **Recalculations to New Zealand's total net LULUCF emissions for 1990 and 2017**

	Reported net emissions		Change in estimate	
Year	2019 submission (kt CO_2-e)	2020 submission (kt CO_2-e)	(kt CO_2-e)	(%)
1990	−31,161.8	−28,297.0	2,864.7	9.2
2017	−23,958.4	−22,710.1	1,248.3	5.2

The main differences between this submission and previous estimates of New Zealand's LULUCF emissions reported in the 2019 submission are the result of the following changes (in decreasing order of magnitude).

A revised analysis of the pre-1990 natural forest plot data was undertaken for the 2020 submission (Paul et al., unpublished (b)). This resulted in a 55.4 per cent reduction in the estimate for carbon stock change in the regenerating component of pre-1990 natural forest, compared with the previous submission. Details of the revised analysis and the drivers of this reduction can be found in section 6.4.5 under *Forest land*.

The post-1989 planted forest yield table has been revised for the 2020 submission. The revised yield table uses data from the annual national forest inventories of 2016, 2017 and 2018 and previous periodic national forest inventories between 2007 and 2015. The analysis of the data collected has provided a plot-based estimate of carbon stock and mean carbon density within this forest type, which leads to more accurate estimates.

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 2017 by category

	Net emissions (kt CO_2-e)					
Land use category	2019 submission: 1990 estimate	2020 submission: 1990 estimate	2019 submission: 2017 estimate	2020 submission: 2017 estimate	Change in 1990 estimate (%)	Change in 2017 estimate (%)
Forest land	–29,891.0	–26,961.3	–21,760.7	–19,058.0	+9.8	+12.4
Cropland	476.9	476.2	396.3	395.7	–0.2	–0.1
Grassland	249.0	186.3	3,760.6	4,164.3	–25.17	+10.7
Wetlands	–10.0	–10.7	13.9	13.7	–7.1	–1.7
Settlements	72.7	72.4	100.7	101.9	–0.3	+1.2
Other land	13.6	12.9	49.2	52.2	–5.05	+6.0
Harvested wood products	–2,072.9	–2,072.9	–6,518.5	–8,379.9	+0.0	–28.6
Total	**–31,161.8**	**–28,297.0**	**–23,958.4**	**–22,710.1**	**9.2**	**+5.2**

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 carbon stock change estimates in natural forests
- revisit the assumption that controlled burning of post-harvest residues on land converted to forest land does not occur, due to the increasing harvest rate in these forests as they reach maturity
- analyse the data collected from re-measurement of the post-1989 natural forest ground plot network to develop new emissions factors for this forest type
- continue to re-measure the pre-1990 natural forest ground plot inventory on a continuous basis (on a 10-year cycle). These data will be analysed and incorporated into the National Inventory Report on a periodic basis

- continue to re-measure the complete planted forest plot network (pre-1990 and post-1989) on a continuous basis (on a five-year cycle). These data will be incorporated into the National Inventory Report as they become available and on a regular basis
- continue to improve mapping land use by using information collected through the New Zealand Emissions Trading Scheme (NZ ETS). 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, 2012 and 2016 land use maps
- develop a methodology for mapping age cohorts for forest planted after 1990
- revisit the justification for New Zealand's chosen 28-year transition period. New Zealand is planning to move back to the 2006 IPCC Guidelines default transition period of 20 years (IPCC, 2006a).

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 Subantarctic 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 2018 (section 3.1.1, IPCC, 2006a). The total land use areas as at 1 January 1990, 1 January 2008, 31 December 2012 and 31 December 2016 are based on wall-to-wall mapping of satellite and aircraft remotely sensed imagery taken in, or close to the start of, 1990, 2008, 2013 and 2017 respectively, as described in section 6.2.2. The mapping of forest areas in these four maps includes improvements made up to August 2019 using aerial photography and data from the NZ ETS. Deforestation occurring between 2008 and 2016 has been mapped by year using ancillary satellite imagery and aerial photography. All other land-use changes occurring between the four major mapping years 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.

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

IPCC category	New Zealand land use
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, 2006).

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 (where managed as forest) • broadleaved hardwood shrubland, mānuka–kānuka (*Leptospermum scoparium–Kunzea* spp.) 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)

Land use	Definition
	• 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.(where managed as forest) 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.
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, including trees of any stature, in a wetland context (periodically or permanently flooded) • areas under peat extraction • estuarine–tidal areas including mangroves.

Land use	Definition
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 2018 are based on four wall-to-wall land use maps derived from satellite imagery at nominal mapping dates of 1 January 1990, 1 January 2008, 31 December 2012 and 31 December 2016. Area information from these maps is interpolated and extrapolated to obtain a complete time series of land-use change occurring between 1990 and 2018 (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, SPOT or Sentinel-2 satellite imagery acquired over the summer periods (October to March) as described in table 6.2.3. Acquisition is limited to 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
2016	Sentinel-2	10	October 2016 – March 2017

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 generated 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.

Creating the first two land use maps: 1990 and 2008

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[63] 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.

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. By using this approach, it was possible to obtain a consistent resolution of change detection even though there was a significant difference between the resolutions of the source imagery at the two mapping dates – 30 metres at 1990 versus 10 metres at 2008.

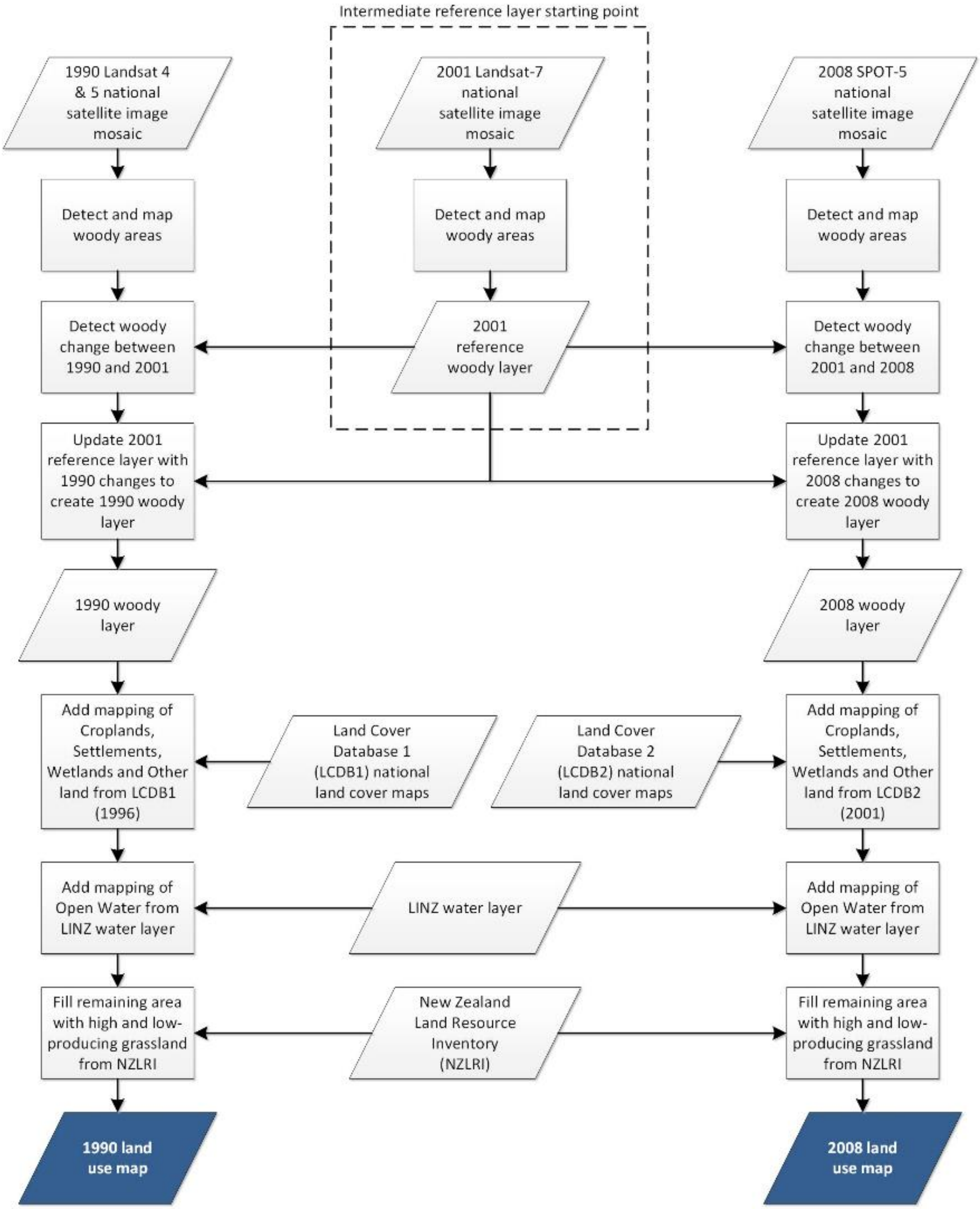
Area and proximity rules were used to convert these layers from woody land cover to woody land use, making allowances for unstocked areas within forest extents and areas of regenerating vegetation in a forest context. This process is described in Shepherd and Newsome (unpublished(b)).

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.

[63] Land cover consistent with pre-1990 natural forest, pre-1990 planted forest, post-1989 forest and grassland with woody biomass land uses.

Figure 6.2.1 New Zealand's land use mapping process for 1990 and 2008 land use maps

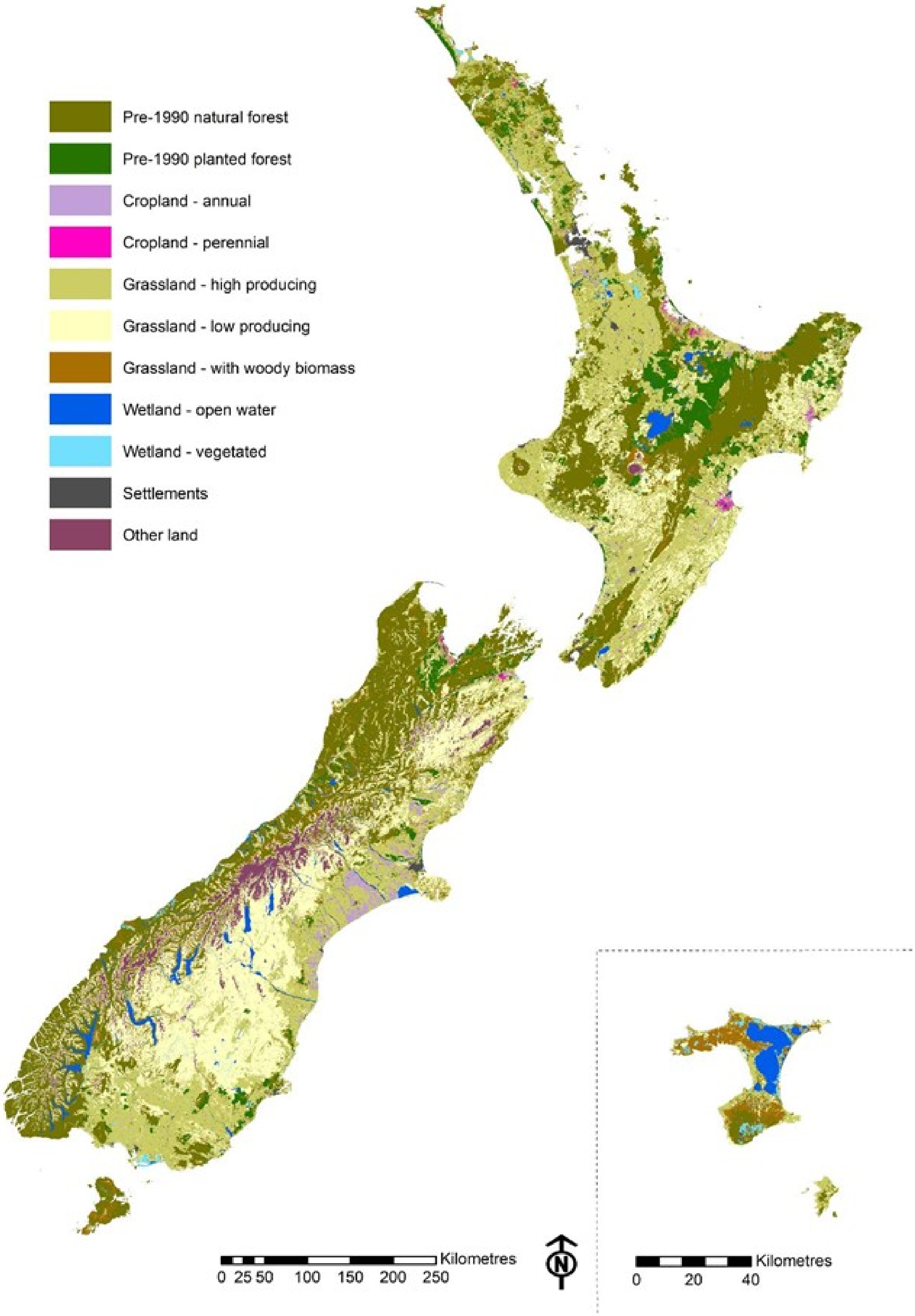


Note: LINZ = Land Information New Zealand.

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). During the mapping process, independent quality control checks were performed to ensure consistent image interpretation. 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).

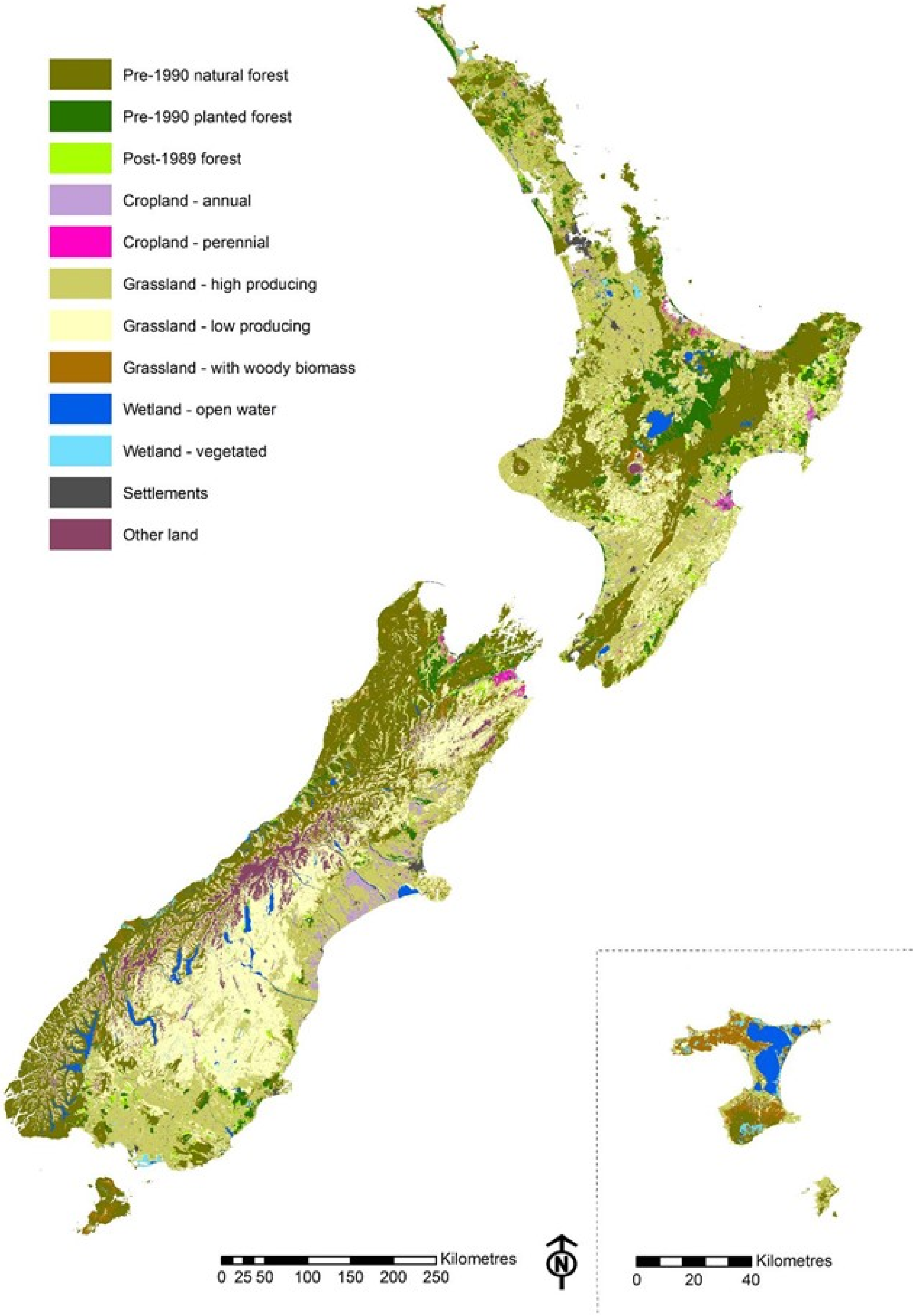
Figure 6.2.2 and figure 6.2.3 show the land use map of New Zealand as at 1 January 1990 and 1 January 2008 respectively.

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



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.

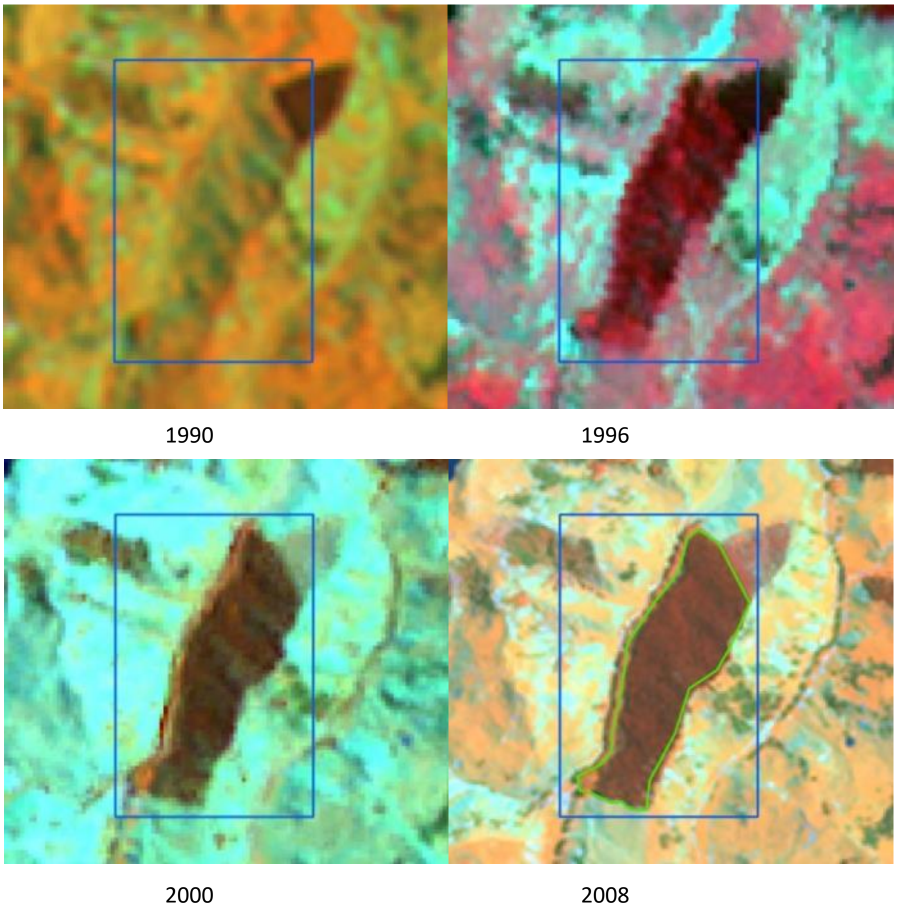
Owners of post-1989 forest are able to lodge their forests with the NZ ETS to obtain credit for increases in carbon stock since 1 January 2008. Mapping received by the Ministry for Primary Industries for these applications is used to improve LUCAS land use maps.

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, 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 help 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 shows 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

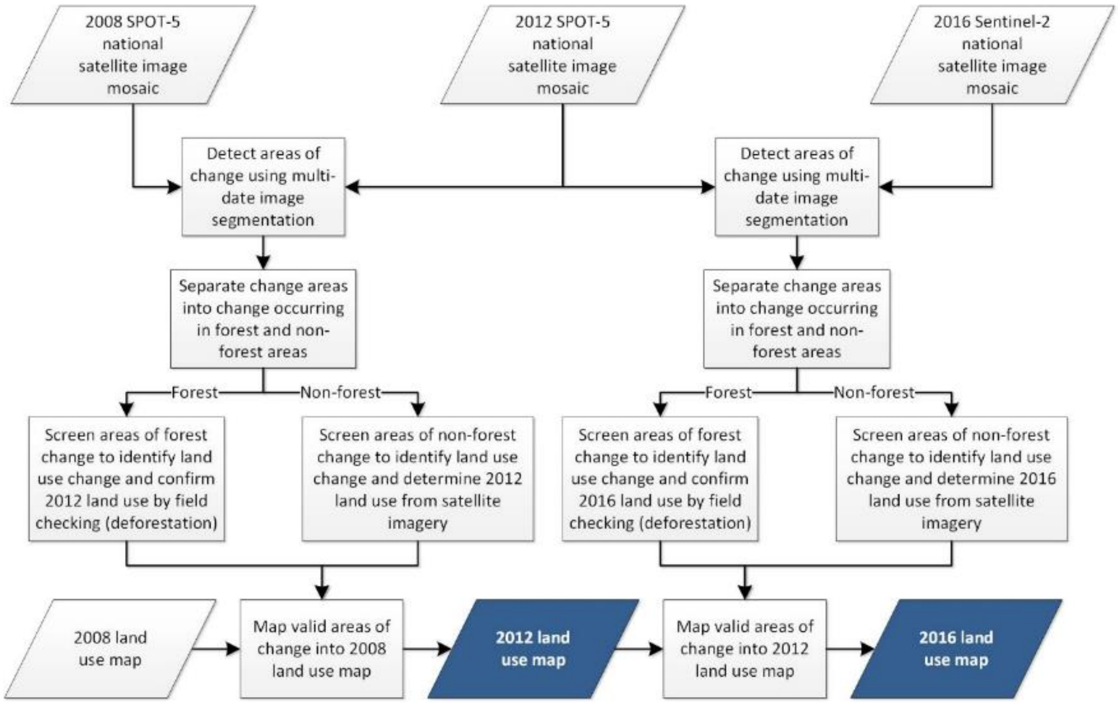


Images:	1990 Landsat 4 (top left) 1996 SPOT 2 (top right) 2000 Landsat 7 ETM+ (bottom left) 2008 SPOT 5 (bottom right)
Location:	2,017,800, 5,730,677 (NZTM)
1990 land use:	Low producing grassland
2008 land use:	Post-1989 forest
Explanation:	In the Landsat 1990 imagery acquired on 2 December 1990, there 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.

Adding land use maps to the time series: 2012 and 2016 land use maps

The 2012 and 2016 land use maps were created by detecting change between satellite imagery acquired for each mapping year (2008, 2012 and 2016) (Newsome et al., 2013; 2018). The 2012 map was created by using the 2008 map as a starting point and mapping in all the change detected between 2008 and 2012. Similarly, the 2012 map was used as a starting point for the 2016 map, with all areas of change detected between 2012 and 2016 mapped in to the 2012 map to create a snapshot of land use as at 2016. Figure 6.2.5 illustrates this mapping process.

Figure 6.2.5 New Zealand's land use mapping process for 2012 and 2016 land use maps



A multi-date image segmentation process was used to identify areas of potential change. 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 the start of the period and one for areas mapped as forest at the start of the period.

Mapping approach: non-forest areas

Potential changes in areas mapped as non-forest were manually checked in the satellite imagery to determine whether a land-use change had occurred since the previous land use map. Operators used the 2008 and 2012 SPOT imagery and 2016 Sentinel-2 imagery, along with other imagery data sets as listed in table 6.2.4, to establish whether land-use change had occurred. Once change was confirmed, the area of change was delineated in the land use map.

Table 6.2.4 Ancillary mosaicked imagery data sets used in land use mapping

Satellite imagery	Resolution (m)	Coverage	Acquisition period
Landsat 7	30	North Island, South Island and Stewart Island	September 1999 – February 2003 October 2011 – February 2012 October 2012 – March 2013
SPOT maps products	2.5 and 1.5	North Island, South Island and Stewart Island	January 2008 – June 2009 October 2012 – April 2014
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
Landsat 8	30	North Island, South Island and Stewart Island	November 2013 – February 2014 October 2014 – March 2015 October 2015 – March 2016
Sentinel-2	10	North Island, South Island and Stewart Island	November 2015 – March 2016
Aerial photography	Variable	All of North Island and Stewart Island and most of South Island	Various

As part of the 2016 mapping process, high and low producing grassland classes were mapped at 2008, 2012 and 2016 using a data fusion technique described in Manderson et al. (2018). This technique brought together a range of biophysical and land use data sets to create a probability map for high producing grassland at each mapping date. This map was used to classify grassland into high and low producing areas in the 2016 land use map and back-correct the 2012 and 2008 maps to maintain time-series consistency. (The 1990 land use map was assumed to contain a fair representation of the split between high and low producing grassland, based on the original mapping of this data set using the NZLRI as described in section 6.2.2.)

Mapping approach: forest areas

Areas of potential change within the forest extent were considered to be potential destocking.[64] These areas were first screened, to ensure they represented actual change as opposed to false change due to cloud contamination or image misregistration.

The next step was to determine which areas of destocking represented land-use change (deforestation) as opposed to temporary forest loss (e.g., harvesting activity occurring as part of ongoing forestry land use).

Where possible, areas of destocking were first checked in available aerial photography to determine whether replanting had occurred. Cases of replanting were then removed from the destocking layer.

Because it is not possible to determine whether deforestation has occurred using currently available satellite imagery alone, vertical or oblique aerial photography is obtained to provide a high-resolution view of land use activity occurring on the ground.

All remaining areas were field checked, with vertical or aerial photography acquired over each site, to determine the current land use for each area.

Based on the 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[65] 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.[66]
- No change: the area has not been destocked and was incorrectly identified as change.

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[64] '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.

[65] 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.

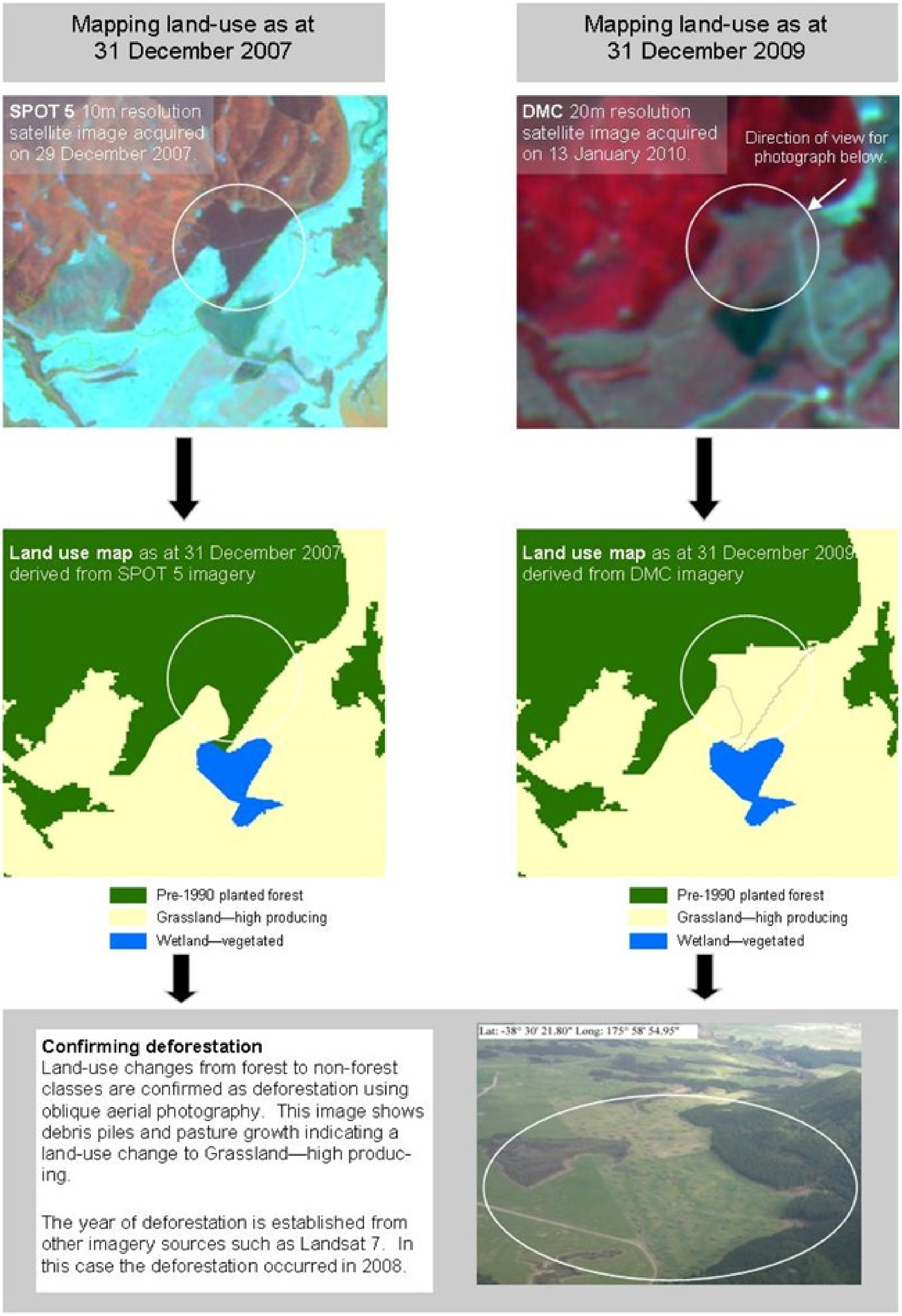
[66] Often regenerating shrubland areas are sprayed but land-use conversion is not completed by clearing the area. In these instances, the vegetation regenerates and recovers, therefore land-use change has not occurred.

- 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 land use map from the beginning of the change period.
- Non-anthropogenic change: destocking was not human induced – for example, erosion – and there has been no land-use change.

For each deforested area, further information was then recorded, 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. Figure 6.2.6 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 (2018).

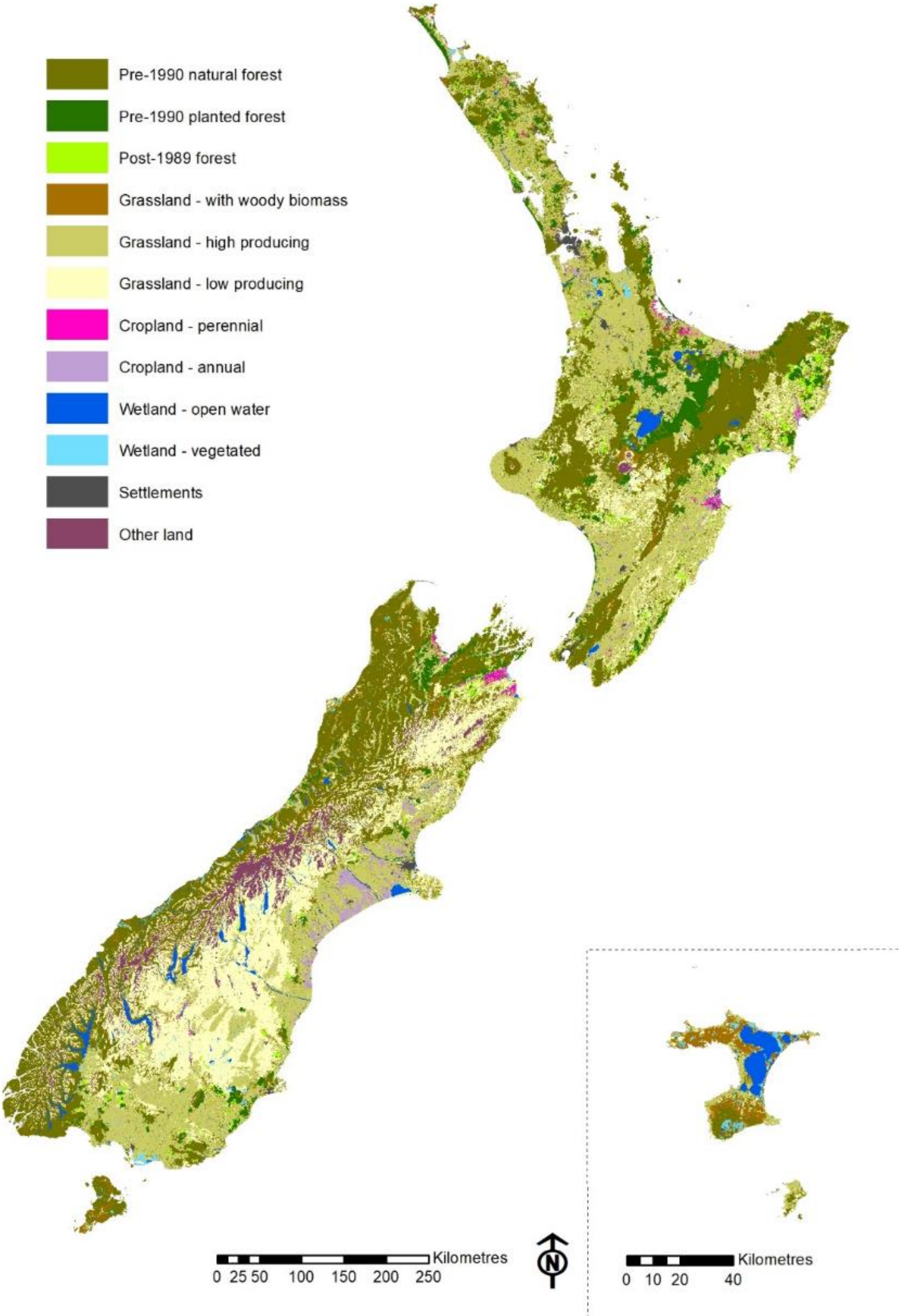
The final step in the 2012 and 2016 land use mapping process was to add the confirmed areas of deforestation into the land use map. Figure 6.2.7 shows the land use map of New Zealand as at 31 December 2016.

Figure 6.2.6 New Zealand's identification of deforestation



Note: DMC = Disaster Monitoring Constellation.

Figure 6.2.7 Land use map of New Zealand as at 31 December 2016



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 Annual land-use change

Annual land-use change areas are interpolated and extrapolated from the four national land use maps using a number of supporting data sets to inform the trends occurring between the wall-to-wall mapping dates of 1990, 2008, 2012 and 2016.

Land-use change prior to 1990

Data from a variety of sources were used to determine land areas prior to 1990. Data sources suitable for determining land use at a national level typically comprise one of the following:

- maps or scaled images depicting land use or proxies for land use (e.g., a 'map of forest areas')
- tabulated land use area data collected for an administrative area (e.g., county, district or region)
- production sector (e.g., the area of orchard crops).

This methodology was peer reviewed by Hunter and McNeill (unpublished), who provided independent subject-matter expertise.

Annual land-use changes from 1990 to 2007

Annual land-use changes from 1990 to 2007 are interpolated between the 1990 and 2008 land use maps, which provide the total area of change over that period. 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 this period. 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(c)).
- Afforestation trends for post-1989 planted forest are based on estimates from the NEFD (Ministry for Primary Industries, 2018b).
- Afforestation trends for post-1989 natural forest are based on plot analysis as described in Beets et al. (unpublished).

Annual land-use changes from 2008 to 2016

Annual land-use changes from 2008 to 2016 are generally linearly interpolated between the 2008, 2012 and 2016 land use maps. The only exceptions to this are:

- deforestation occurring between 2008 and 2016, which is mapped annually (see section 6.2.2 for a description of annual deforestation mapping)
- afforestation, which uses a mixture of mapped and surveyed data as detailed in table 6.2.5. This is because not all new planting will have been detected in satellite imagery and mapped into the 2016 map yet. New planting can take up to four years to be visible in satellite imagery, therefore, afforestation mapping up to 2016 will not be finalised until 2020.

Table 6.2.5 Methods used to estimate Afforestation total area and trends between 2008 and 2016

	Reporting years: 2008 to 2012		Reporting years: 2013 to 2016	
Afforestation type	Estimate of total afforestation for the period	Trend in afforestation within the period	Estimate of total afforestation for the period	Trend in afforestation within the period
Post-1989 planted forest	Based on mapped change between 2008 and 2012	Based on trend in afforestation reported in 2018 National Exotic Forest Description (NEFD) (Ministry for Primary Industries, 2018b)	Based on annual afforestation areas reported in the 2018 NEFD scaled up from net to gross area as described in section 6.4.1	From NEFD 2018 since using annual area totals from that data set
Post-1989 natural forest	Based on mapped change between 2008 and 2012	Linear interpolation	Based on Ministry for Primary Industries Forestry Scheme applications for funding to support planting and regeneration of indigenous forest	Based on actual planting dates supplied in Ministry for Primary Industries Forestry Scheme data

Estimating land-use change in 2017 and 2018

Activity data for the two most recent years of this inventory, 2017 and 2018, have been estimated from surveys for deforestation (Manley, 2019) and afforestation (Ministry for Primary Industries, 2018b) and extrapolated from the most recent mapped period of 2012–16 for all other land-use changes.

Deforestation

Deforestation of pre-1990 planted forest and post-1989 forest occurring during 2017 and 2018 has been estimated based on the Deforestation Intentions Surveys for 2018 (Manley, 2019). This report does not distinguish between pre-1990 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 (2012–16). 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 the period 2012–16.

Deforestation of pre-1990 natural forest for 2017 and 2018 has been estimated as occurring at the same annual rate as the most recently mapped five-year period (2012–16). 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 2017 and 2018 is based on estimates from the NEFD (Ministry for Primary Industries, 2018b).

The land use prior to afforestation has been pro-rated across all non-forest land uses in the same proportions as for post-1989 afforestation that has been mapped between 2012 and 2016.

Other land-use changes

All other land-use changes for 2017 and 2018 have been linearly extrapolated from the changes mapped between 2012 and 2016.

Prominent land-use changes from 1990 to 2018

Prominent land-use changes between 1 January 1990 and 31 December 2018 include:

- forest establishment of 733,862 hectares (classified as post-1989 forest) that has occurred mostly on land that was previously grassland, primarily low producing grassland. Of this area, 31,272 hectares has since been deforested
- deforestation of 204,628 hectares. This includes the 31,272 hectares of post-1989 forest that was planted and then deforested between 1990 and 2018. 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.

6.2.4 Methodological change

For this submission, improvements have been made to the 1990, 2008, 2012 and 2016 land use maps. This year, improvements have focused on:

- better delineation of the extent of vegetated wetland and wetland loss
- identification of tree weed areas. These areas should be mapped as pre-1990 natural forest or post-1989 natural forest, if the infestation occurred after 1990. In some cases, they were incorrectly mapped as pre-1990 planted forest because they have a similar spectral signature to New Zealand plantation forest species and sometimes *are* the same species; for example, *Pseudotsuga menziesii* (Douglas fir) is grown in plantations in the South Island but has also become a tree weed, spreading into nearby tussock high-country.

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.[67]

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

[67] 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.

is because vegetated wetland and grassland with woody biomass, are sometimes difficult to distinguish in imagery where the extent of flooding varies seasonally. Grassland with woody biomass 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, 2012 and 2016 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 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.

Quality-control checking for the 2016 land use map was carried out region by region looking at all areas of expected change (based on mapping targets sent to the mapping supplier) and actual change supplied in the map. Checks were also made for invalid change, for example, a pre-1990 planted forest cannot change to a post-1989 forest. Spatial checks were performed to ensure that the integrity of the map had been maintained. These included checking for gaps and overlaps as well as that the total area of the map had not changed.

Each mapping improvement activity carried out on the 1990, 2008, 2012 and 2016 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.

The approach used to implement quality-assurance processes is documented in the LUCAS Data Quality Framework (PricewaterhouseCoopers, unpublished).

6.2.7 Planned improvements

During 2020, the following mapping improvements will be undertaken:

- improvement to the accuracy of the mapping of pre-1990 planted forest through scrutiny of the areas not included in the Forestry Allocation Plan
- determining planting or establishment cohorts geospatially for post-1989 forests, which will improve the accuracy of post-1989 forest reporting and support future reporting requirements post 2020
- during the 2020 summer, an aerial deforestation survey will be undertaken to complete mapping of deforestation for forest loss events occurring in 2017 and 2018. This mapped area will replace the deforestation estimates for those years that are included in this inventory.

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:

$$\Delta C = [(\mathrm{SOC}_0 - \mathrm{SOC}_{(0\text{-}T)})/20] \times A \qquad (3)$$

Where: ΔC = change in carbon stocks (tonnes)

SOC_0 = stable SOC stock in the inventory year (tonnes C ha^{-1})

$\mathrm{SOC}_{(0\text{-}T)}$ = 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 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:

$$C_{i,j}^{0-30\mathrm{cm}} = M + L_i + S_j + b.SR + \varepsilon \qquad (4)$$

Where: M = the mean soil carbon in the 0–30-centimetre 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, www.soils.landcareresearch.co.nz/soil-data/national-soils-data-repository-and-the-national-soils-database), with a small number of samples from various supplementary data sets; data from all sources 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).

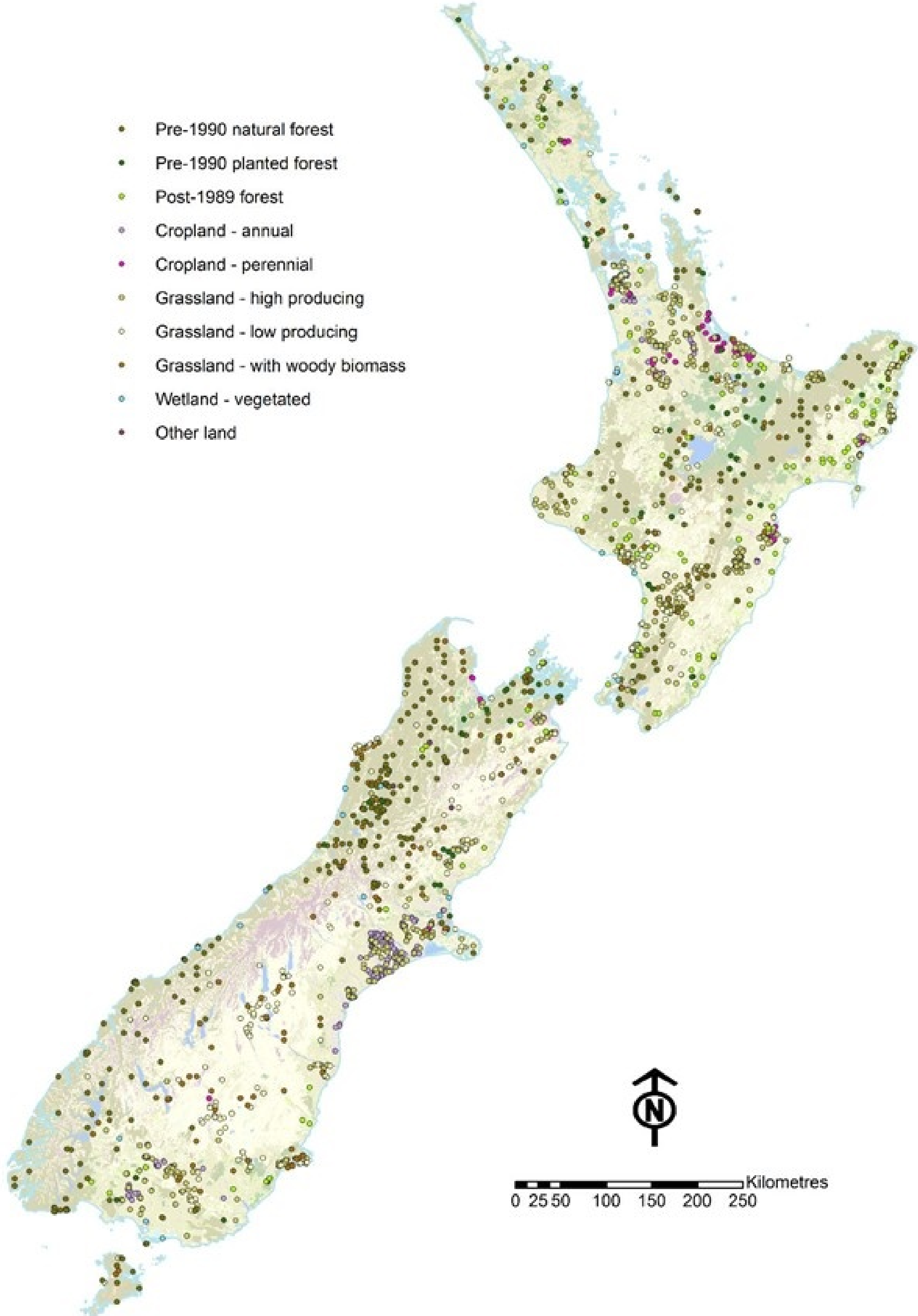
Post-1989 forest data: This data set was added to the analysis in 2014. It contains data collected specifically for Convention reporting from 90 post-1989 forest sites across New Zealand (Basher et al., unpublished; Interpine Forestry Limited, unpublished).

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.

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).

The number of records associated with the different land use categories and soil orders varies widely, with the largest land use category *Grassland* having 1,216 samples and the smallest (*Other land*) only three samples. While efforts to collect or obtain additional data in under-sampled land use categories have been made since LUCAS was established, helping to reduce uncertainties, the effect on uncertainty due to the considerable variability of sampling points among the different land use types still remains.

Figure 6.3.1 Soil samples in the Soil CMS model calibration data set



Settlements and the open water component of *Wetlands* were not used in the model due to lack of soil carbon data. 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 0.9 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 (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 $SOC_{(0\text{-}T)}$) 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})	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)

An Akaike information criterion (AIC) model selection procedure was used for the Soil CMS model. AIC is used to select the model that is the best trade-off between the complexity of the model and the goodness of fit. The use of the AIC value as a model selection and comparison mechanism is widely supported in the literature in soil modelling (Burnham and Anderson, 2002; Elsgaard et al., 2012; Ogle et al., 2007).

The selected model residual standard error is 41.3 tonnes per hectare. 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 distributed evenly throughout New Zealand). These values are consistent with earlier analyses (McNeill, unpublished(a), (b)).

Measures of statistical validity: Assessing significant differences among SOC stocks

The uncertainty of the LUE (the change in soil carbon, assuming the transition is stable) between two land use categories in isolation is conceptually straightforward: two estimates of LUE 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

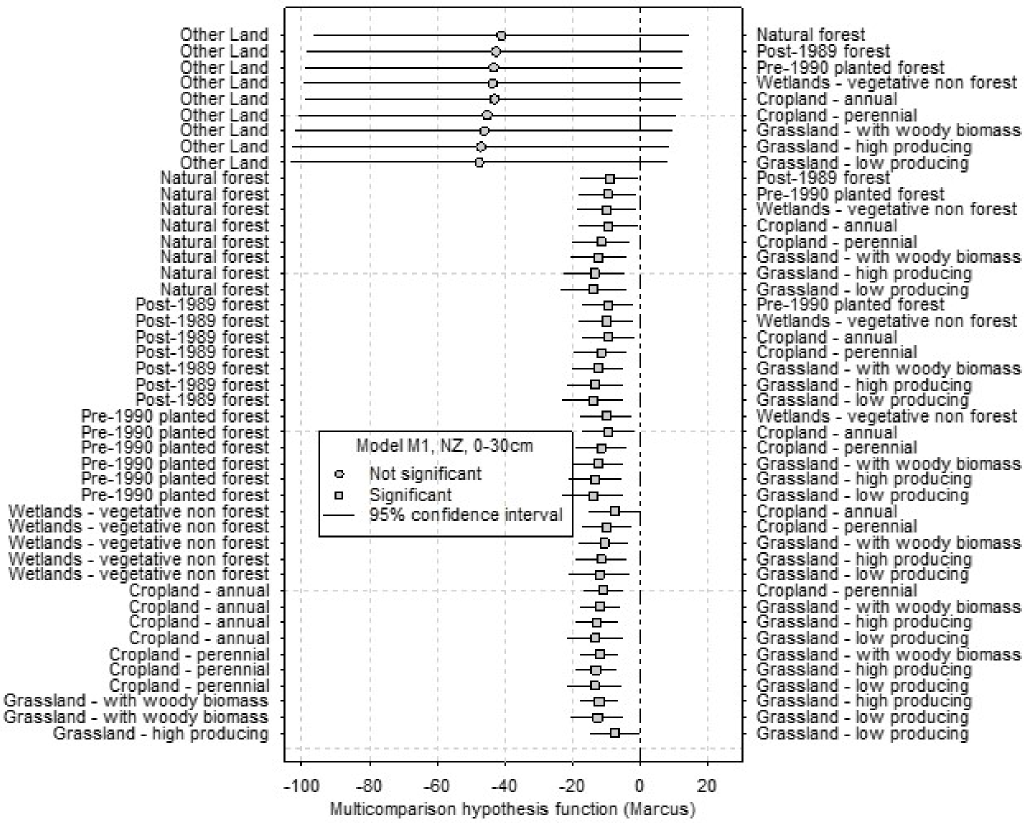
$Cov(L_i, L_j)$ = the covariance between land use effects L_i and L_j (McNeill and Barringer, unpublished; McNeill et al., unpublished).

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 LUE 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



Source: McNeill and Barringer (unpublished)

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 0.7 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 Warm temperate	5.0 ± 90% 10.0 ± 90%	IPCC (2006a, section 5.2.3.2, table 5.6)
Grassland	Cold temperate Warm temperate	0.25 ± 90% 2.5 ± 90%	IPCC (2006a, section 6.2.3.2, table 6.3)
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 Warm temperate	5.0 ± 90% 10.0 ± 90%	Cropland emission factors used (IPCC, 2006a, section 8.2.3.2)
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. 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 model include: the assumption that soil carbon reaches steady state in all land uses and that there is a 20-year linear transition period to reach steady state; lack of soil carbon data and soil carbon change 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 model 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 model 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 × 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 model 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

Following the 2019 in-country review of the 2019 submission, significant changes were found to be required in order for New Zealand's inventory to more closely align with the 2006 IPCC Guidelines (IPCC, 2006a). New Zealand is currently identifying a strategy for addressing the expert review team's concerns and this will be included in the improvement plan in the 2021 submission. Part of this strategy will include the ongoing sourcing of empirical SOC data for under-represented land use categories and activity data. A longitudinal study of soil carbon in *Grasslands* and *Croplands* is due to start in the 2020 calendar year. Results from this study will not be available for several years.

6.4 Forest land (CRF 4A)

6.4.1 Description

In *New Zealand's Initial Report under the Kyoto Protocol* (Ministry for the Environment, 2006), 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, the potential to reach a minimum 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. Furthermore, 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.

Between 1990 and 2018, *Forest land* is the most significant contributor to carbon stock changes in the LULUCF sector. In 2018, forests covered 36.8 per cent (just under 10 million hectares) of New Zealand's total land area. In 2018, *Forest land* contributed –16,907.2 kt CO_2-e of net emissions. This does not include emissions for the *Harvested wood products* category, which are reported separately within the CRF Reporter. The *Harvested wood products* category and calculation of emissions are reported in section 6.10.

Net emissions from *Forest land* have increased by 10,054.1 kt CO_2-e (37.3 per cent) from the 1990 level of –26,961.3 kt CO_2-e (see table 6.4.1).

In 2018, *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 2018

Land use category	Net area as at 1990 (ha)	Net area as at 2018 (ha)	Net emissions (kt CO_2-e) 1990	Net emissions (kt CO_2-e) 2018	Change from 1990 (%)
Forest land remaining forest land	8,538,328	9,216,142	–7,487.5	–1,368.6	+81.7
Land converted to forest land	836,446	689,021	–19,473.7	–15,538.6	+20.2
Total	**9,374,774**	**9,905,163**	**–26,961.3**	**–16,907.2**	**+37.3**

Note: Net area in 1990 is as at 1 January 1990; net area in 2018 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, and percentages presented are calculated from unrounded values.

When 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 2018 is relatively small (5.7 per cent increase in area), the change in net emissions for this land is large. This is due to the disproportionate influence that plantation forests have on the emissions profile for this category. Key factors include the timing of afforestation that has occurred since 1990 and the increased level of harvesting in 2018, compared with 1990, due to existing planted forests reaching 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 (note: non-CO_2 emissions are reported elsewhere). 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 2018 because, in 1990, only one year's worth of planting was contributing to the emissions figures whereas, by 2018, there is much more land included 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 2018 for New Zealand's Forest land

Land use	Net area (ha) 1990	Net area (ha) 2018	Change from 1990 (%)	Net emissions (kt CO_2 only) 1990	Net emissions (kt CO_2 only) 2018	Change from 1990 (%)
Pre-1990 natural forest	7,826,472	7,756,584	–0.9	–2,753.1	–2,684.6	+2.5
Pre-1990 planted forest	1,548,302	1,445,989	–6.6	–24,450.1	+562.5	+102.3
Post-1989 forest	0	702,590	NA	31.0	–14,854.8	–48,052.7
Total	**9,374,774**	**9,905,163**	**+5.7**	**–27,172.2**	**–16,976.9**	**+37.5**

Note: NA = not applicable. Net area in 1990 is as at 1 January 1990; net area in 2018 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 emissions 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 2018. Over this period, the total carbon stock stored in *Forest land* has increased by 207,182.2 kt C, equivalent to emissions of –759,668.0 tonnes 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 2018

	Net carbon stock change 1990–2018 (kt C)				Emissions 1990–2018
Land use	Living biomass	Dead organic matter	Soils	Total	(kt CO_2)
Pre-1990 natural forest	18,856.4	2,505.4	–134.7	21,226.8	–77,831.5
Pre-1990 planted forest	86,042.3	19,814.4	–4,244.2	101,612.6	–372,579.5
Post-1989 forest	81,199.8	10,767.7	–7,624.7	84,342.8	–309,257.0
Total	**186,098.1**	**33,087.6**	**–12,003.6**	**207,182.2**	**–759,668.0**

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. This land use includes mature forest as well as areas of regenerating vegetation that has the potential to return to forest under the management regime that existed prior to 1990. Pre-1990 natural forest ecosystems comprise of a range of indigenous and some naturalised exotic species. In New Zealand, two principal types of natural forest exist: beech forests (*Fuscospora* and *Lophozonia* species) and mixed 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 under 7.8 million hectares of pre-1990 natural forest (including these seral plant communities). Pre-1990 natural forest equates to 28.8 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 2018, pre-1990 planted forests covered an estimated 1.45 million hectares of New Zealand (5.4 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. The supply of a renewable timber resource has allowed New Zealand to protect and sustainably manage its pre-1990 natural forests. *Pinus radiata* is the dominant planted forest 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

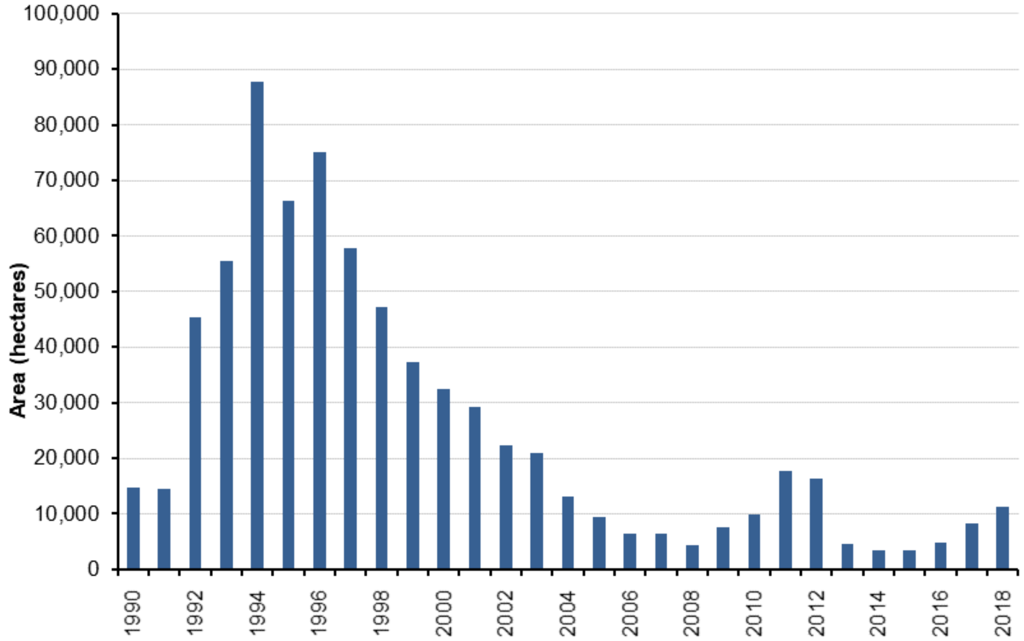
Between 1 January 1990 and 31 December 2018, the net area of forest established as a result of reforestation activities was 702,590 hectares (accounting for deforestation of post-1989 forests). It is estimated that 93 per cent of this forest type is planted forest, with the remaining area comprising 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 the majority of the remainder (Paul et al., unpublished(d)). The natural forest component of post-1989 forest comprises 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 2018 was, on average, 25,306 hectares per year. New planting rates were high from 1992 to 1998, averaging 62,152 hectares per year (see figure 6.4.1). 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 all contributed to high planting rates in the mid-1990s. 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 3,447 hectares in 2014. Afforestation has remained relatively low since then. The increase in planting between 2008 and 2012 is largely attributable to the NZ ETS (Ministry for Primary Industries, 2015b) and the Afforestation Grant Scheme (Ministry for Primary Industries, 2015a), both of which were introduced by the New Zealand Government to encourage new planting and regeneration of natural ecosystems. A total of 11,238 hectares of new forest was planted in 2018. The reduction in planting rates since the 1990s has likely been caused by the relative profitability of other forms of land use, high rural land prices and a lack of confidence in the carbon market. However, the exclusion of international units from the NZ ETS on 31 May 2015, the recent NZ ETS review, and implementation of some of its findings have all contributed to higher carbon prices, which are expected to encourage larger areas of afforestation in the future. The One Billion Trees Fund is also expected to increase afforestation rates in future. The fund was established in 2018 to work in partnership with landowners and organisations to achieve the goal of planting 1 billion trees by 2028 (Te Uru Rākau, 2018).

The area defined and reported as planted forest under the Convention differs from the area captured by the NEFD from which the new planting (post-1989 planted forest) statistics are sourced for 2013 onwards. Convention reporting uses a land use classification based on the gross stocked area standard, which includes forest tracks, skid sites and unstocked areas. This is the standard used for all mapped areas of new planting reported in the period of 1990 to 2012. The NEFD reports to a net stocked area standard. To account for these area differences, the net productive forest area has been identified and modelled separately. This ensures harvesting data used for Convention reporting are consistent with those reported by the Ministry for Primary Industries. Furthermore, an unstocked area component was added to the new planting statistics between 2013 and 2018 to maintain consistency with the mapped area used up to 2012. This ensures the planted forest areas used for Convention reporting are consistent with those reported by the Ministry for Primary Industries and that 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 forest plot network, as described in section 6.4.2.

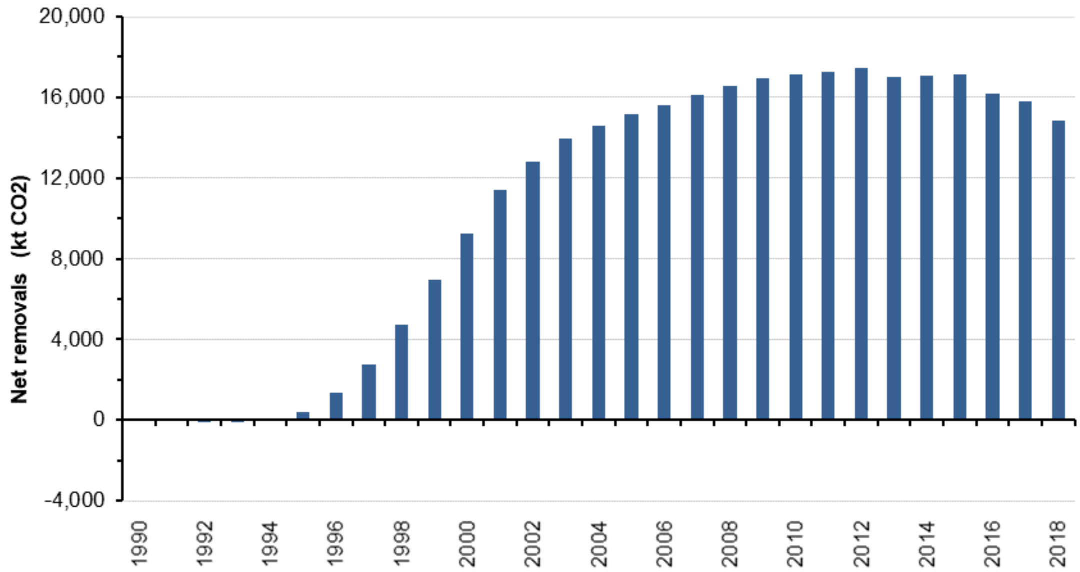
Figure 6.4.1 Annual areas of afforestation/reforestation in New Zealand from 1990 to 2018



Note: Annual planting estimates are derived from annual surveys of forest nurseries, as published in the NEFD (Ministry for Primary Industries, 2018b), 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 1996 (see figure 6.4.2) when net removals from forest growth surpassed net emissions. This was due to the loss of biomass in carbon stocks associated with the previous land use, in addition to the loss of soil carbon associated with a land-use change to forestry.

Figure 6.4.2 New Zealand's net carbon dioxide removals by post-1989 forests from 1990 to 2018



Deforestation

In 2018, an estimated 4,061 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 2018 and since 1990.

Table 6.4.4 New Zealand's Forest land subject to deforestation, 1990 and 2018

		Deforestation since 1990		Deforestation in 2018	
Land use	Area of forest in 1990 (ha)	Area (ha)	Proportion of 1990 area (%)	Area (ha)	Proportion of 1990 area (%)
Pre-1990 natural forest	7,826,472	45,355	0.58	740	0.01
Pre-1990 planted forest	1,548,302	128,001	8.27	2,629	0.17
Post-1989 forest	0	31,272	NA	692	NA
Total	**9,374,774**	**204,628**	**2.18**	**4,061**	**0.04**

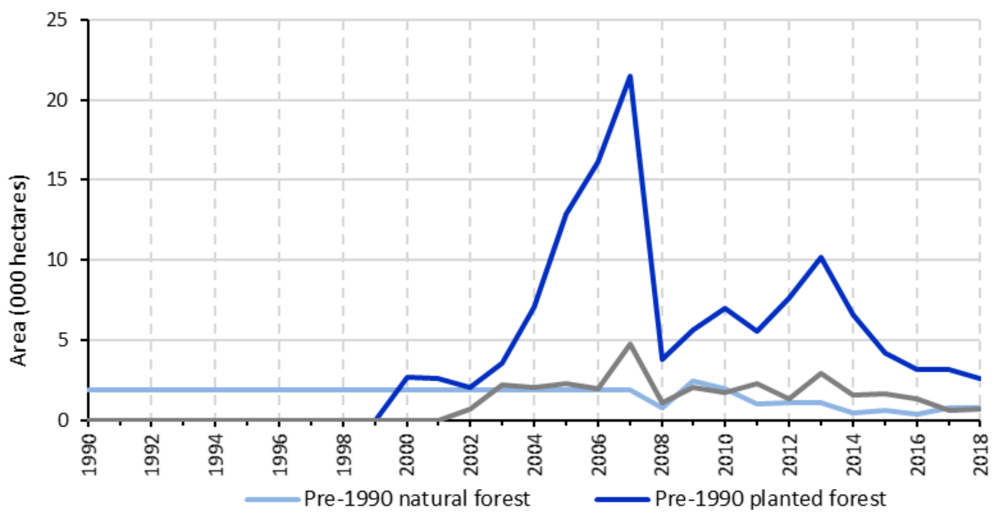
Note: NA = not applicable. The 2018 areas are as at 31 December 2018; 1990 areas are as at 1 January 1990 and, therefore, differ from 1990 area values in the CRF tables, which are as at 31 December 1990. Columns may not total due to rounding.

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. More recently, the exclusion of international units from the NZ ETS on 31 May 2015, the recent NZ ETS review, and implementation of some of its findings have all contributed to higher carbon prices. These higher carbon prices have contributed to a reduction in 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



No data are available on the deforestation profile of pre-1990 natural forests between 1990 and 2007 and, as a result, 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 between 2008 and 2012 through satellite image mapping of deforestation (see figure 6.2.6).

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 emissions from residues following deforestation activity given the rapid conversion from one land use to another and the multiple methods of removing residues. Furthermore, estimating biomass residue and decay rates for multiple disposal methods is difficult and costly.

Estimates of biomass burning emissions associated with deforestation are provided in the National Inventory Report (see section 6.11.5).

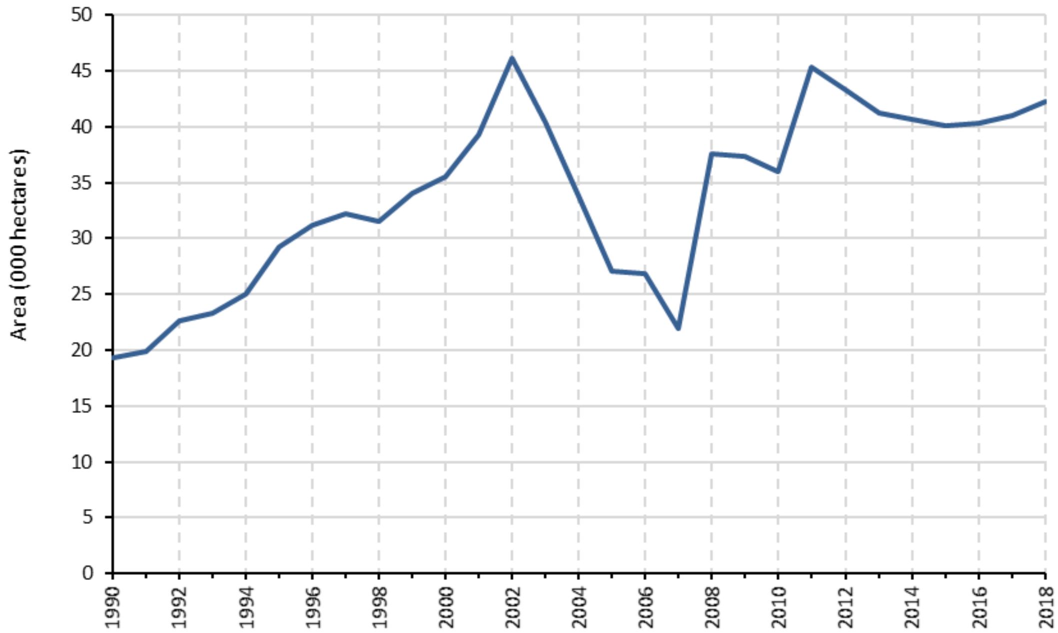
Soil carbon changes associated with deforestation are modelled over a 20-year period using a linear change profile (see section 6.3).

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

The estimated area across all planted forest (both pre-1990 and post-1989 planted forest) harvested each year between 1990 and 2018 is shown in figure 6.4.4. The estimated area between 1990 and 2009 is based on the harvested area reported in the NEFD, adjusted to calendar years. From 2011 onwards, roundwood harvesting statistics, sourced annually from the Ministry for Primary Industries (2018), were used to estimate the harvest area. This adjustment is made due to an inconsistency in which an increased harvesting volume did not correspond to the harvesting area reported in the NEFD, and so that an estimate of harvesting area in calendar years could be created for the most recent reporting year. Using this approach, the harvest area for a given year is estimated by multiplying the roundwood volume by the average ratio of roundwood volume to the NEFD area harvested over the previous four years.

Figure 6.4.4 New Zealand's area of planted forest harvest (inclusive of deforestation) from 1990 to 2018



The total area harvested is then split by forest type into:

- pre-1990 planted forest harvesting
- post-1989 forest harvesting.

Pre-1990 planted forest harvesting is 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 is estimated from the harvested area mapped between 2008 and 2018.

The harvest area in pre-1990 planted forests is profiled to accurately reflect the actual ages at which harvesting takes place. The harvest profile is derived from the NEFD (Ministry for Primary Industries, 2018b). 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 2018, 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, 2018a).

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, 2015d) other than in exceptional circumstances where legislation allows. For example, 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 a significant 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 (Forests Act 1949).

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)

This section describes pre-1990 natural forest, pre-1990 planted forest, post-1989 natural forest and post-1989 planted forest. Post-1989 forest makes up only a minor component (0.2 per cent) of *Forest land remaining forest land*; however, this proportion will increase over time as these forests mature and transition from *Land converted to forest land.* New Zealand uses a 28-year transition period for conversion to *Forest land remaining forest land*. This is the average age at which the majority of planted radiata pine forests are harvested (Ministry for Primary Industries, 2018a). The 2018 year is, therefore, the first year in which some post-1989 forest has fallen in the *Forest land remaining forest land* category. The majority of post-1989 forest is included in the *Land converted to forest land* category. 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 (8-kilometres north–south by 8-kilometres east–west). 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. Figures 6.4.5 and 6.4.6 show the distribution of the pre-1990 natural and planted forest, post-1989 natural and planted forest, and the carbon monitoring plots throughout New Zealand.

Figure 6.4.5 Location of New Zealand's pre-1990 forest carbon monitoring plots

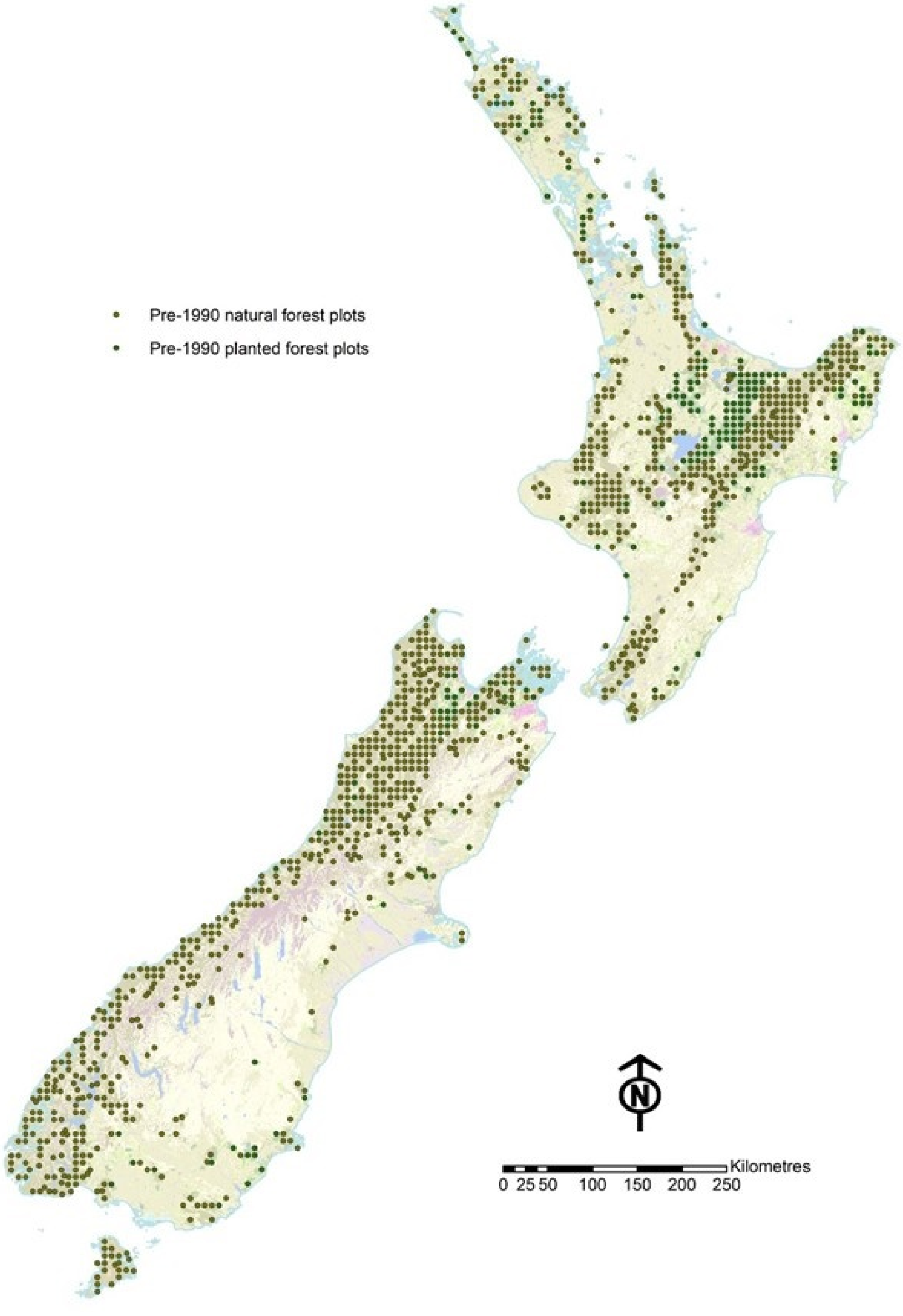


Figure 6.4.6 Location of New Zealand's post-1989 forest plots

Pre-1990 natural forest

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 (t_1) 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 (t_2) following a revised methodology for re-measurement purposes (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	Paul et al. (unpublished(b))
	Below-ground biomass	Estimated as the ratio of below-ground biomass to above-ground biomass	Paul et al. (unpublished(b)); Easdale et al. (2019)
Dead organic matter	Dead wood	Modelled from plot measurements; allometric equations	Garrett et al. (2019); Paul et al. (unpublished(b)); Kimberley et al. (2019)
	Litter	Plot samples; laboratory analysis of samples collected at plots	Paul et al. (unpublished(b)); 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; Paul et al., unpublished(b)). 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. The below-ground biomass was estimated for each individual tree based on an estimate of the root:shoot ratio for that species (the ratio of the below-ground biomass to above-ground biomass). Tree and shrub species in different taxonomic groups were assigned different root:shoot ratios, as outlined in (Easdale et al., 2019). Applying the root:shoot ratios as published in Easdale et al., 2019 has been included to address the expert review team recommendation L.5, 2017 (FCCC/ARR/2017/NZL).

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. The dead wood pool is very difficult to measure in the field (particularly wood that is in an advanced state of decay) and is currently being underestimated by the monitoring programme (Beets et al., 2019). An adjustment factor, derived by an approach developed by Beets et al. (2019), was applied to correct for this (Paul et al unpublished(b)).

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 the living biomass pool is calculated using a 'stem-following' method described in Paul et al. (unpublished(b)). In this method, carbon stock change for each plot is calculated by summing the stock change for each individual live stem and subtracting the summed carbon at t_1 for individual stems that died in the period between t_1 and t_2. To account for ingrowth and missing measurements, the diameter of trees measured at t_2 that were not measured at t_1 were predicted and used in the calculation of stock change, provided that the diameter at t_2 was above the threshold for field measurement (e.g., 2.5 centimetres for the embedded 0.04 hectare square plot, and 60 centimetres for the 0.13 hectare circular plot). The total summed carbon 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 third round of measurements is under way and due for completion in 2024). 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 0.62 ± 0.25 tonnes C ha^{-1} yr^{-1} (Paul et al., unpublished(b)). 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 (+0.04 ± 0.21 tonnes C ha^{-1} yr^{-1}; Paul et al., unpublished(b)). Carbon stock change in regenerating forest was driven primarily by an increase in live above-ground biomass of 0.48 ± 0.21 tonnes C ha^{-1} yr^{-1} (Paul et al., unpublished(b)).

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-CO_2 emissions for pre-1990 natural forest

Direct N_2O 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_2O emissions from nitrogen fertilisation of *Forest land* and *Other land* are reported in the Agriculture sector under the category *Direct N_2O emissions from managed soils*.

Post-1989 natural forest

Post-1989 natural forest consists of forest land established since 1 January 1990 and has resulted from direct human-induced changes in land-management practice. The resulting vegetation is a seral plant community, generally comprising a mix of native and introduced species, which is in the early successional stages of reversion to mature forest. As the vegetation matures, it generally becomes increasingly dominated by native species and in most cases will become native forest. The active facilitation of tree species' regeneration through the removal of grazing stock would, for example, result in a land-use change from *Grassland* to *Forest land*. In 2018, the post-1989 natural forest area covers an estimated 49,067 hectares.

Estimates of carbon stock and stock change in post-1989 natural forest are calculated using measurements taken from the 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 have been established and were 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). The second round of plot measurements was completed in 2019 with the analysis currently under way.

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 have also been taken outside of the plots and are used to create plot-specific allometric equations, which are then applied to these measurements to calculate above-ground live biomass.

The 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 back-casting of biomass through time. Back-cast 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 was 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 forest 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_2O emissions from nitrogen fertilisation of forest land and other land

New Zealand activity data on nitrogen fertilisation are not currently disaggregated by land use, therefore, all direct N_2O emissions from nitrogen fertilisation of *Forest land* and *Other land* are reported in the Agriculture sector under the category *Direct N_2O emissions from managed soils*.

Pre-1990 planted forest

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.

Pre-1990 planted forest inventory

New Zealand's pre-1990 planted forest was sampled in 2010, again in 2015, and has now moved onto a continuous measurement cycle from 2016 onwards. 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.

The pre-1990 planted forest inventory consists of 212 circular 0.06-hectare plots (see figure 6.4.5) established on a systematic 8-kilometre grid (consistent with that used for all forest categories). These plots are ground measured using procedures described in Herries et al. (unpublished). Stand records and ground measurements are recorded between June and September at each plot. Measurements include: 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. LiDAR plots included those that were ground measured in addition to LiDAR-only plots, which are at 1 kilometre intervals nested within the 8 kilometre grid (Paul et al., unpublished(e)).

Living biomass and dead organic matter

The crop tree plot data collected from the planted forest inventories are modelled using a forest carbon modelling system (the Forest Carbon Predictor, version 4.12; Beets and Garrett, 2018; Beets et al., 2018a, 2018b; Paul et al., unpublished(a)) developed for the two most common plantation tree species in New Zealand: *Pinus radiata* and *Pseudotsuga menziesii*. 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 6.4.7.

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.

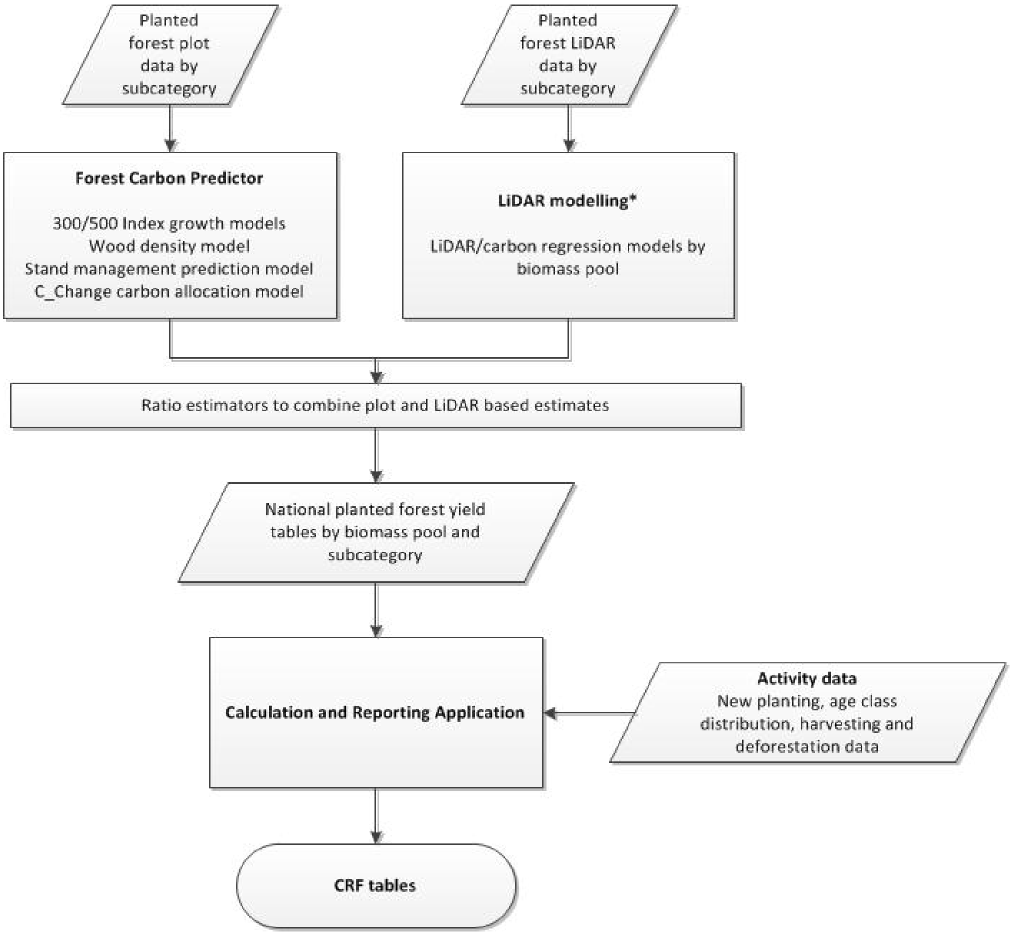
The C_Change carbon allocation model is designed to apportion carbon to needles, branches, stems, roots and reproductive parts via growth partitioning functions and is integrated into the Forest Carbon Predictor. Dead wood and litter pools are estimated by accounting for losses to the live pools from 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 both post-1989 forest and pre-1990 planted forest (Paul et al., unpublished(e)).

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 a 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 6.4.7 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 have been measured once, a ratio estimator derived from plots that have been measured twice is 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 is used to develop a LiDAR-adjusted yield table for pre-1990 planted forests. For LiDAR plots that were not coincident with a ground-measured plot, forest age is obtained from forest owners' stand records. A regression model was developed for predicting carbon stocks using LiDAR metrics and forest age. A ratio estimator was developed using the LiDAR-derived estimate of age 20 carbon and the estimate obtained from the ground measured plots. This ratio estimator is used to adjust the yield table. The adjustment is used for all ages in the yield table and is 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 forest plot network, is 130.72 ± 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 forests 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 (2006a) 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_2O 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_2O emissions from nitrogen fertilisation of *Forest land* and *Other land* are reported in the Agriculture sector under the category *Direct N_2O emissions from managed soils*.

Post-1989 planted forest

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). In the post-1989 planted forest inventory, circular 0.06 hectare 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 carried out during the winters of 2007 and 2008 at 246 sites consisted of up to four sample plots in a cluster arrangement. The plots were sampled using the methods 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 new 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 carbon stock estimates.

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 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, is gathered from forest owners and estimated by field teams on site. Ground plot centres are located using a 12-channel differential GPS for relocation in future inventories (Beets et al., 2011a).

Stock change in the productive area of post-1989 planted forest 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 carbon stock estimates for unstocked areas of post-1989 planted forests (Paul et al., unpublished(d)). 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(c)).

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 is 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 are combined as weighted means in a national yield table for the productive area of post-1989 planted forest (Paul et al., unpublished(d)).

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 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 163.4 ± 21.5 tonnes C ha^{-1} (at the 95 per cent confidence interval) as at 31 December 2018 (Paul et al., unpublished(d)). 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.

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. 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*, provided the forest has already been established for 28 years.

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 2018, approximately 58 per cent of the non-forest land converted to post-1989 forest has been from low producing grassland, with 23 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 due to the amount of biomass present prior to land-use conversion.

Details on the methods, plot network, sampling framework and biomass pools for both post-1989 planted and post-1989 natural forest are described in the *Forest land remaining forest land* section above.

6.4.3 Uncertainties and time-series consistency

Emissions from *Forest land* are 7.8 per cent of New Zealand's net emissions uncertainty in 2018 (annex 2). *Forest land* introduces 8.3 per cent uncertainty into the trend in the national total from 1990 to 2018.

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.

The estimates for carbon stock and carbon stock change in pre-1990 natural forests were adapted from Paul et al. unpublished(b). The uncertainty in carbon stock estimates for pre-1990 natural forests was ± 4.1 per cent at the 95 per cent confidence interval for tall forests (250 ± 5.3 tonnes C ha^{-1}) and ± 14 per cent for regenerating forests (61.7 ± 8.4 tonnes C ha^{-1}; adapted from Paul et al. unpublished(b)). The uncertainty in the estimate of carbon stock change was ± 40 per cent for regenerating forest (0.62 ± 1.6 tonnes C $ha^{-1} yr^{-1}$) and ± 533 per cent for tall forest (–0.04 ± 0.21 tonnes C $ha^{-1} yr^{-1}$). Due to the small estimate of change in carbon stocks in tall forest with a very high associated uncertainty, this estimate was considered to not be significantly different from zero and so no emissions factor was applied (i.e., a rate of zero sequestration was applied to tall forest).

Table 6.4.7 Uncertainty in New Zealand's 2018 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 tall forest biomass carbon stocks	±6.5
Uncertainty in regenerating forest biomass carbon change	±40.3
Uncertainty in soil carbon stocks	±7.9
Uncertainty introduced into net emissions for LULUCF	**±4.7**

Note: Land area includes land in transition in 2018. 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). As the emission factor for carbon stock change in tall forests is reported to be zero, the uncertainty associated with this figure is effectively zero when following the IPCC guidelines for the propagation of uncertainty (IPCC, 2006a).

Pre-1990 planted forest

A national plot-based inventory system, in conjunction with a suite of models, is used to estimate carbon stock and carbon stock 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'. 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.

Beets et al. (2011b) discuss the validation of the Forest Carbon Predictor model used to produce carbon yield tables for the LULUCF sector. For the plots in this study, the estimates of total carbon stock per plot made using the Forest Carbon Predictor were found to be 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. 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 2020 submission is provided in table 6.4.8.

Table 6.4.8 Uncertainty in New Zealand's 2018 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 unstocked forest biomass carbon stocks	±146.0
Uncertainty in riparian forest biomass carbon stocks	±75.0
Uncertainty in soil carbon stocks	±12.3
Uncertainty introduced into net emissions for LULUCF	**±34.9**

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 2018 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 2018. 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 then 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 ±12.25 per cent (Paul et al., unpublished(d)).

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 2020 submission is provided in table 6.4.9.

Table 6.4.9 Uncertainty in New Zealand's 2018 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	±12.2
Uncertainty in soil carbon stocks	±10.4
Uncertainty introduced into net emissions for LULUCF	**±10.0**

Note: Land area includes land in transition in 2018. 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 (Paul et al., unpublished(b)).

Pre-1990 planted forest and post-1989 planted forest

Of the planted forest inventory plots, 7.5 per cent are randomly audited without the prior knowledge of the inventory teams. Plots are fully and partially re-measured, with feedback supplied no later than one month after measurement to ensure prompt identification of any data collection errors and/or 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 would 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 any potential sources of error or ambiguity.

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 163.4 ± 21.0 tonnes C ha^{-1} for post-1989 planted forest as at 31 December 2018 (Paul et al., unpublished(d)) and 130.72 ± 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). The same audit process was conducted for the re-measurement of the post-1989 natural forest plot network. These results are described in Paul and Dowling (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 2017

Net emissions (kt CO_2-e)	2019 submission	2020 submission	Change from the 2019 submission (kt CO_2-e)	% change
1990	–29,891.0	–26,961.3	2,929.7	+9.8
2017	–21,760.7	–19,058.0	2,702.6	+12.4
Area (hectares)				
1990	9,425,570	9,387,694	–37,876	–0.4
2017	9,923,595	9,897,987	–25,608	–0.3

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, updated natural forest yield tables and land use mapping improvements across the time series, as explained below.

Activity data

The total area of *Forest land*, as at 1 January 1990, has been reduced by –37,876 hectares as a result of reassessment of some areas of tree species, previously classed as pre-1990 natural forest, occurring within vegetated wetlands. These areas have been remapped as vegetated wetland throughout the time series, in recognition that this is the dominant land use of the vegetation.

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 2020 submission. The revised yield table is based on two full measurement inventories of permanent sample plots in post-1989 planted forest carried out in 2008–09 and 2011–12, and a partial re-measure in 2016, 2017 and 2018 (due to the transition to the continuous five-year inventory cycle). 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.

The pre-1990 natural forest emissions factors have also been revised for the 2020 submission. A revised analysis of the pre-1990 natural forest plot data was undertaken for the 2020 submission (Paul et al., unpublished(b)). Improvements included:

- using an updated vegetation classification system (Wiser and De Cáceres, 2018) to determine the split between tall and regenerating pre-1990 natural forest

- including stem data from circular measurement plots. This eliminated the bias caused by the over-sampling of large stems in the inner 20 metre × 20 metre plots (Paul et al., 2019)
- updating the method of calculating carbon stock and carbon stock changes in the above-ground biomass pool, by applying a 'stem following' method rather than a 'stock change' method (as outlined in Paul et al., unpublished(b)). See section 6.4.2 for further detail
- adding 44 plots measured during 2013–14, as well as including unmeasured plots, using imputation from regression analysis
- updating the method for estimating the dead wood pool, to account for under-sampling in the field measurements (as outlined in Kimberley et al., 2019). See section 6.4.2 for further detail.

6.4.6 Category-specific planned improvements

New Zealand will continue to measure the pre-1990 natural forest plot network on a 10-year cycle and analyse the data collected as they become available. Work is also under way to improve the classification of pre-1990 natural forest into its tall and regenerating components. These data will be incorporated into the National Inventory Report as they become available.

The re-measurement of the post-1989 natural forest ground plot inventory has recently been completed. These data are currently being analysed, and revised emissions factors for this forest type will be available for inclusion in the 2021 submission.

Mapping of forest areas will be improved through improvements to the 2016 land use map, which includes a number of forest-specific mapping improvement tasks such as:

- mapping of newly planted forests through data supplied from the NZ ETS
- developing a methodology for mapping age cohorts for forest planted after 1990
- tracking of carbon equivalent forests within the land use maps.

Currently, pre-1990 forest is disaggregated into natural and planted forest and reported as such. However, post-1989 forest is not disaggregated into natural and planted at the reporting level. In the next submission, New Zealand intends to report on planted and natural post-1989 forest separately, to improve transparency.

The assumption that controlled burning of post-harvest residues on afforested land does not occur will be revisited for a future submission, due to the increasing harvest rate in these forests as they reach maturity.

In the 2019 in-country review, it was suggested that the approach New Zealand had taken to determine the country-specific transition period was not in line with the 2006 IPCC Guidelines. To address this, New Zealand will be moving to the 20-year default transition period of the 2006 IPCC Guidelines (IPCC, 2006a).

The complete planted forest plot network (pre-1990 and post-1989) is being re-measured on a continuous basis (at five-year intervals). These data will be incorporated into the National Inventory Report as they become available. Work is also under way to improve the pre-1990 planted forest back-casting estimates through the use of multiple yield tables. This will involve using a stratified analysis based on rotation, age class and historic inventory data.

6.5 Cropland (CRF 4B)

6.5.1 Description

In 2018, the net emissions from *Cropland* were 391.3 kt CO_2-e, comprising 383.1 kt CO_2 from carbon stock change and 0.03 kt N_2O (8.2 kt CO_2-e) from the nitrogen mineralisation on *Land converted to cropland*. Net emissions from *Cropland* have decreased by 84.9 kt CO_2-e (17.8 per cent) from the 1990 level when net emissions were 476.2 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 2018

Cropland land use category	Net area as at 1990 (ha)	Net area as at 2018 (ha)	Net emissions (kt CO_2-e) 1990	2018	Change from 1990 (%)
Cropland remaining cropland	384,444	417,779	357.8	333.6	–6.7
Land converted to cropland	39,511	58,274	118.4	57.7	–51.3
Total	**423,955**	**476,053**	**476.2**	**391.3**	**–17.8**

Note: Net area in 1990 is as at 1 January 1990; net area in 2018 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 85.2 per cent of all *Cropland* area in 2018.

The majority of emissions due to carbon stock change that have occurred in the *Cropland* category since 1990 are in the SOC pool (3,997.7 kt C or 14,218.2 kt CO_2) (see table 6.5.2). Within the SOC pool, the majority of emissions result from organic soils (10,078.6 kt CO_2). This is because organic soils continue to lose carbon even after the 20-year transition period (IPCC, 2006a).

Table 6.5.2 New Zealand's carbon stock change by carbon pool for the Cropland category from 1990 to 2018

Land use	Net carbon stock change 1990–2018 (kt C) Living biomass	Dead organic matter	Soils	Total	Emissions 1990–2018 (kt CO_2)
Annual cropland	–177.9	–10.6	–2,689.6	–2,878.0	10,552.7
Perennial cropland	315.0	–6.6	–1,308.1	–999.7	3,665.5
Total	**137.1**	**–17.2**	**–3,997.7**	**–3,877.7**	**14,218.2**

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 2018, annual cropland accounted for 1.4 per cent of total land area, and perennial cropland accounted for 0.4 per cent of total land area in New Zealand.

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 2018

Land use	Net area in 1990 (ha)	Net area in 2018 (ha)	Change from 1990 (%)	Net emissions (kt CO_2 only) 1990	2018	Change from 1990 (%)
Annual cropland	354,900	371,357	+4.6	342.9	317.2	–7.5
Perennial cropland	69,055	104,696	+51.6	125.7	65.9	–47.6
Total	**423,955**	**476,053**	**+12.3**	**468.7**	**383.1**	**–18.3**

Note: Net area in 1990 is as at 1 January 1990; net area in 2018 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 2018

Cropland category		Net area in 1990 (ha)	Net area in 2018 (ha)	Change from 1990 (%)
Cropland remaining cropland	Annual remaining annual	324,888	346,086	6.5
	Perennial remaining perennial	58,656	63,231	7.8
	Annual to perennial	900	6,188	587.6
	Perennial to annual	0	2,274	NA
	Subtotal	384,444	417,779	8.7
Land in conversion to cropland	Annual cropland	30,012	22,997.2	–23.4
	Perennial cropland	9,499	35,276	+271.4
	Subtotal	39,511	58,274	+47.5
Total		**423,955**	**476,053**	**+12.3**

Note: NA = not applicable. This table shows the change between 1 January 1990 and 31 December 2018. Columns may not total due to rounding.

In 2018, *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 stock 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 instantly oxidised in the year of conversion).

To estimate growth after conversion of annual cropland 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 available activity data do not provide information on areas of perennial cropland temporarily destocked; therefore, no losses in carbon stock due to temporary destocking are reported.

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 Tier 1 method 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 and vice versa 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). Biomass accumulation stops at the end of the transition period, 28 years. It is assumed that any biomass gains after the 28-year transition period are compensated for by biomass loss from pruning and other management practices, resulting in a net zero change in biomass stock of perennial cropland remaining perennial cropland. This assumption, while applied to the 2020 submission, is being reviewed for the 2021 submission (see section 6.5.6 below).

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 instantly oxidised in the year of conversion). 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 2018 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 2018 (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 the 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 resulting from improvements made to the land use maps. However, none of the mapping improvement activities carried out this year were targeted at the *Cropland* category.

Table 6.5.7 Recalculations of New Zealand's net emissions from the Cropland category in 1990 and 2017

	Net emissions (kt CO_2-e)		Change from the 2019 submission	
Year	2019 submission	2020 submission	(kt CO_2-e)	(%)
1990	476.9	476.2	–0.7	–0.15
2017	396.3	395.7	–0.6	–0.1

6.5.6 Category-specific planned improvements

In the 2019 in-country review, it was suggested that the approach New Zealand had taken to determine the country-specific transition period was not in line with the 2006 IPCC 2006 Guidelines. To address this, New Zealand will be moving to the 20-year default transition period of the 2006 IPCC Guidelines (IPCC, 2006a).

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 the effect of land-use change 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.

Research indicates that under business-as-usual grassland farming operations in New Zealand, 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 use the land for grazing animals. When it becomes evident that the farmer has modified land management in a way that encourages sustained growth of woody vegetation that will undergo succession to forest, 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 that does not meet the forest definition and is not expected to do so under current ecological, management or environmental conditions. This 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 3,699.9 kt CO_2-e in 2018 (see table 6.6.1). These emissions comprise 3,610.1 kt CO_2 emissions from carbon stock change, 0.09 kt N_2O (27.3 kt CO_2-e) and 2.5 kt CH_4 (62.5 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 2018.

Net emissions from *Grassland* have increased by 3,513.6 kt CO_2-e (1,885.9 per cent) from the 1990 level of 186.3 kt CO_2-e (see table 6.6.1). The majority of this change occurred in 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 2018

Grassland land use category	Area as at 1990 (ha)	Area as at 2018 (ha)	Net emissions (kt CO_2-e) 1990	2018	Change from 1990 (%)
Grassland remaining grassland	14,545,481	14,443,202	–99.8	1,250.3	–1,353.2
Land converted to grassland	713,037	206,608	286.1	2,449.7	+756.3
Total	**15,258,518**	**14,649,809**	**186.3**	**3,699.9**	**+1,885.9**

Note: Net area in 1990 is as at 1 January 1990; net area in 2018 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 2018, there were 6,872,829 hectares of high producing grassland (25.5 per cent of total land area), 6,400,945 hectares of low producing grassland (23.8 per cent of total land area) and 1,376,035 hectares of grassland with woody biomass (5.1 per cent of total land area).

From 1990 to 2018, the net carbon stock change attributed to *Grassland* was a decrease of 37,107.5 kt C, equivalent to 136,060.7 kt CO_2 emissions (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 2018

Grassland category	Net carbon stock change 1990–2018 (kt C) Living biomass	Dead organic matter	Soils	Total	Emissions 1990–2017 (kt CO_2)
Grassland – high producing	–15,627.8	–1,824.7	–8,546.9	–25,999.4	95,331.2
Grassland – low producing	–8,598.9	–1,129.8	567.9	–9,160.9	33,589.8
Grassland – with woody biomass	–697.2	–319.2	–930.8	–1,947.2	7,139.7
Total	**–24,924.0**	**–3,273.7**	**–8,909.8**	**–37,107.5**	**136,060.7**

Note: Columns may not total due to rounding.

Grassland remaining grassland

There were 14,443,202 hectares of *Grassland remaining grassland* as at 2018, equivalent to 53.6 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 grassland (deforestation).

Between 2017 and 2018, an estimated 4,214 hectares of land was converted to *Grassland*, while 12,494 hectares of *Grassland* was converted to other land use categories.

The majority (91.8 per cent) of *Land converted to grassland* since 1 January 1990 is land that was previously *Forest land*. The 199,099 hectares of *Forest land* converted to *Grassland* since 1 January 1990 comprise an estimated 43,575 hectares of natural forest and 125,011 hectares of pre-1990 planted forest. A further 30,513 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 2018.

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
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), with a carbon fraction of 0.47 applied to both. Note that carbon stock and carbon accumulation values have been rounded to two decimal places.

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 gain 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, a significant area (1,187,423 hectares) is currently 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 stock change in living biomass on land converted from one category to another (e.g., low producing grassland converted to high 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 forest 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 there are no Tier 1 defaults provided in the 2006 IPCC Guidelines. There is insufficient information to develop default coefficients for estimating the dead organic matter pool for these two categories (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 forest plot network (Wakelin and Beets, unpublished), and estimates of changes in dead organic matter stocks with conversion to and from this land use are reported.

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

Grassland type	Soil carbon stock (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 applies 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 instantly oxidised in the year of conversion). New Zealand applies the Tier 1 default method 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 (table 6.6.5). 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 forest 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).

Table 6.6.5 Uncertainty in New Zealand's 2018 estimates for the Grassland category (including land in transition)

	Uncertainty at a 95% confidence interval		
Land use	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	**±4.5**	**±0.6**	**±0.4**

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 2017

	Net emissions (kt CO_2-e)		Change from the 2019 submission	
Year	2019 submission	2020 submission	(kt CO_2-e)	(%)
1990	249.0	186.3	–62.7	–25.2
2017	3,760.6	4,164.3	403.7	+10.7

Recalculations of the entire time series were carried out for this category as a result of updates made to the activity data on the land area of the *Grassland* categories. This resulted in an increase in the area of deforestation reported for 2017 and hence an increase in the emissions in the *Land converted to grassland* category.

6.6.6 Category-specific planned improvements

In the 2019 in-country review, it was suggested that the approach New Zealand had taken to determine the country-specific transition period was not in line with the 2006 IPCC Guidelines. To address this, New Zealand will be moving to the 20-year default transition period for grassland with woody biomass of the 2006 IPCC Guidelines (IPCC, 2006a).

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 and Stats NZ, 2017). 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 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.[68]

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 originally mapped its vegetated wetlands using existing LCDB data (see section 6.2, for more information). Areas of open water were originally mapped using hydrological boundaries defined by Land Information New Zealand.

Improvements to the mapping of wetland extent have been made using ancillary national and regional data sets. Changes to wetland extent have been mapped into the 2008, 2012 and 2016 land use maps based on changes detected in satellite imagery.

Improvements in mapping that occurred in conjunction with the creation of the 2016 Land Use Map have enabled the area of artificially flooded land to be identified and distinguished from naturally occurring open water (e.g., natural lakes). Examples of artificially flooded lands in New Zealand include irrigation reservoirs and the Clyde Dam hydroelectric dam. The acquisition of this activity data will enable the associated stock changes for land converted to flooded land to be estimated once methods to interpolate and extrapolate to fill in the time series are developed.

In 2018, there were 534,688 hectares of open water and 226,933 hectares of vegetated wetlands. Together these two land use types make up 2.8 per cent of the total New Zealand land area.

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[68] 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.

In 2016, a study was commissioned to identify and map current and historical (from 1990) horticultural peat mining areas, peat type and quantity, and post-mining activities (Clarkson unpublished). The results of this study have been incorporated into New Zealand's 2016 land use map. In 2018, there were 273 hectares under peat extraction.

In 2018, there were 13.6 kt CO_2-e emissions from *Wetlands*, compared with emissions of –10.7 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 2018 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 2018, there were 7,524 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.

Table 6.7.1 New Zealand's land-use change for the Wetlands category, and associated CO_2-e emissions, in 1990 and 2018

	Net area (ha) as at		Net emissions (kt CO_2-e)		
Wetlands land use category	**1990**	**2018**	**1990**	**2018**	**Change from 1990 (%)**
Wetlands remaining wetlands	749,906	754,096	9.4	18.8	+99.3
Land converted to wetlands	14,386	7,524	–20.1	–5.3	+73.9
Total	**764,292**	**761,621**	**–10.7**	**+13.6**	**+227.2**

Note: Net area in 1990 is as at 1 January 1990; net area in 2018 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 2018, the net carbon stock in *Wetlands* decreased by 3.5 kt C, equivalent to emissions of 12.7 kt CO_2 in total since 1990 (see table 6.7.2).

Table 6.7.2 New Zealand's carbon stock change by carbon pool for the Wetlands category from 1990 to 2018

	Net carbon stock change 1990–2018 (kt C)				Emissions
Land use	**Living biomass**	**Dead organic matter**	**Soils**	**Total**	**1990–2018 (kt CO_2)**
Wetlands – vegetated	–22.7	–1.6	7.9	–16.3	59.8
Wetlands – open water	–77.7	–5.5	96.0	12.8	–47.1
Total	**–100.3**	**–7.1**	**104.0**	**–3.5**	**12.7**

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 because 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. As such, the expert review team recommendation, L.7, 2017 (FCCC/ARR/2017/NZL), cannot be addressed. However, New Zealand is following the methodology for reporting N_2O emissions from *Wetlands remaining wetlands*, in line with volume 4, section 7.2.1.2 of the 2006 IPCC Guidelines (IPCC, 2006a).

Activity data

For this submission, the definition of the vegetated wetland subcategory has been amended to explicitly include areas of forest that are part of the wetland ecosystem. As a result of this redefinition, areas of forest associated with vegetated wetland have been reviewed in the time series of land use maps and, where the forest area has been judged to be part of the wetland ecosystem, it has been reclassed as vegetated wetland.

Land converted to wetlands (CRF 4.D.2)

Between 1990 and 2018, 8,378.4 hectares of land were converted to *Wetlands*, while 11,133.0 hectares of *Wetlands* were converted to other land uses (mainly *Grassland*, at 9,279 hectares). This resulted in a net decrease in total area reported under *Wetlands* of 2,755 hectares. The wetland losses were mainly related to the conversion of vegetated wetland to grassland (3,182 hectares), however, these losses were offset by gains in the area of wetland open water (6,823 hectares). This was mainly due to the development of irrigation ponds in the Canterbury and Otago regions, however, approximately 760 hectares of new open water has resulted from new lakes forming within the Southern Alps, often at the foot of glaciers.

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 the 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 (IPCC, 2006a) for estimating carbon stock following land-use change to *Wetlands*. All emissions from land-use change to *Wetlands* from removal of the previous vegetation are instantly emitted.

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-CO_2 emissions

Non-CO_2 emissions from drainage of soils and wetlands

New Zealand has not prepared estimates for this category. 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 the total net emissions for LULUCF is also very small.

Table 6.7.3 Uncertainty in New Zealand's 2018 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 CO_2 emissions from peat extraction)	±90.0	NA
Uncertainty introduced into net emissions for LULUCF	**±0.074**	**±0.008**

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 updating activity data because of mapping improvements, as described in section 6.2.

Table 6.7.4 Recalculations for New Zealand's net emissions from the Wetlands category in 1990 and 2017

	Net emissions (kt CO_2-e)		Change from the 2019 submission	
Year	2019 submission	2020 submission	(kt CO_2-e)	(%)
1990	–10.0	–10.7	–0.7	–7.1
2017	13.9	13.7	–0.2	–1.7

6.7.6 Category-specific planned improvements

The following improvements are planned for the *Wetlands* category:

- estimating emissions from land converted to flooded land
- estimating non-CO_2 emissions from the drainage of soils and wetlands.

In the 2019 in-country review, it was suggested that the approach New Zealand had taken to determine the country-specific transition period was not in line with the 2006 IPCC Guidelines. To address this, New Zealand will be moving to the 20-year default transition period of the 2006 IPCC Guidelines (IPCC, 2006a).

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 2018, there were 236,357 hectares of *Settlements* in New Zealand, an increase of 28,810 hectares since 1990. This category comprised 0.9 per cent of New Zealand's total land area in 2018. The largest area of change to *Settlements* between 1990 and 2018 was from high producing grassland, with 21,618 hectares of high producing grassland converted to *Settlements* between 1990 and 2018.

In 2018, the net emissions from *Settlements* were 103.4 kt CO_2-e, an increase of 42.7 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 2018.

Table 6.8.1 New Zealand's land-use change for the Settlements category, and associated CO_2-e emissions, from 1990 to 2018

Settlements land use category	Net area (ha) as at 1990	Net area (ha) as at 2018	Net emissions (kt CO_2-e) 1990	Net emissions (kt CO_2-e) 2018	Change from 1990 (%)
Settlements remaining settlements	184,268	208,565	+65.1	+65.9	+1.3
Land converted to settlements	23,279	27,792	7.3	37.4	+409.9
Total	**207,547**	**236,357**	**72.4**	**103.4**	**+42.7**

Note: Net area in 1990 is as at 1 January 1990; net area in 2018 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.

The emissions in the *Settlements remaining settlements* 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 2018, the net carbon stock change for *Settlements* decreased by 918.6 kt C, equivalent to emissions of 3,368.2 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 2018

Land use category	Net carbon stock change 1990–2018 (kt C) Living biomass	Dead organic matter	Soils	Total	Emissions 1990–2018 (kt CO_2)
Settlements	–392.9	–26.4	–499.3	–918.6	3,368.2

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 2018 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 (table 6.8.4) as a result of new activity data resulting from improvements to the land use maps, as described in section 6.2.

Table 6.8.4 Recalculations for New Zealand's net emissions from the Settlements category in 1990 and 2017

	Net emissions (kt CO_2-e)		Change from the 2019 submission	
Year	2019 submission	2020 submission	(kt CO_2-e)	(%)
1990	72.7	72.4	–0.2	–0.30
2017	100.7	101.9	1.2	+1.2

6.8.6 Category-specific planned improvements

No improvements are planned for the *Settlements* category for the 2021 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 2018, the net emissions from *Other land* were 51.6 kt CO_2-e (see table 6.9.1). This is 39.4 kt CO_2-e (299.7 per cent) higher than the 1990 level of 12.9 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 2018 shows that, of the 7,545 hectares converted from *Other land* to different land use categories, 3,804 hectares were converted to post-1989 forest and 1,498 hectares were converted to grassland with woody biomass.

Between 1 January 1990 and 31 December 2018, there were 7,628 hectares of *Land converted to other land*; most (4,800 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 2018, *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 2018

Land use category – Other land	Net area as at 1990 (ha)	Net area as at 2018 (ha)	Net emissions (kt CO_2-e) 1990	2018	Change from 1990 (%)
Other land remaining other land	896,081	889,182	0.1	3.8	+3,529.2
Land converted to other land	0	6,983	12.8	47.9	+273.4
Total	**896,081**	**896,164**	**12.9**	**51.6**	**+299.7**

Note: Net area in 1990 is as at 1 January 1990; net area in 2018 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 national land use maps as described 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 and instantly oxidised 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 ±0.1 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 2018 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	**±0.1**

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 resulting from improvements made to the land use maps as described in section 6.2.

Table 6.9.4 Recalculations for New Zealand's net emissions from the Other land category in 1990 and 2017

	Net emissions (kt CO_2-e)		Change from the 2019 submission	
Year	2019 submission	2020 submission	(kt CO_2-e)	(%)
1990	13.6	12.9	–0.7	–5.0
2017	49.2	52.2	3.0	+6.0

6.9.6 Category-specific planned improvements

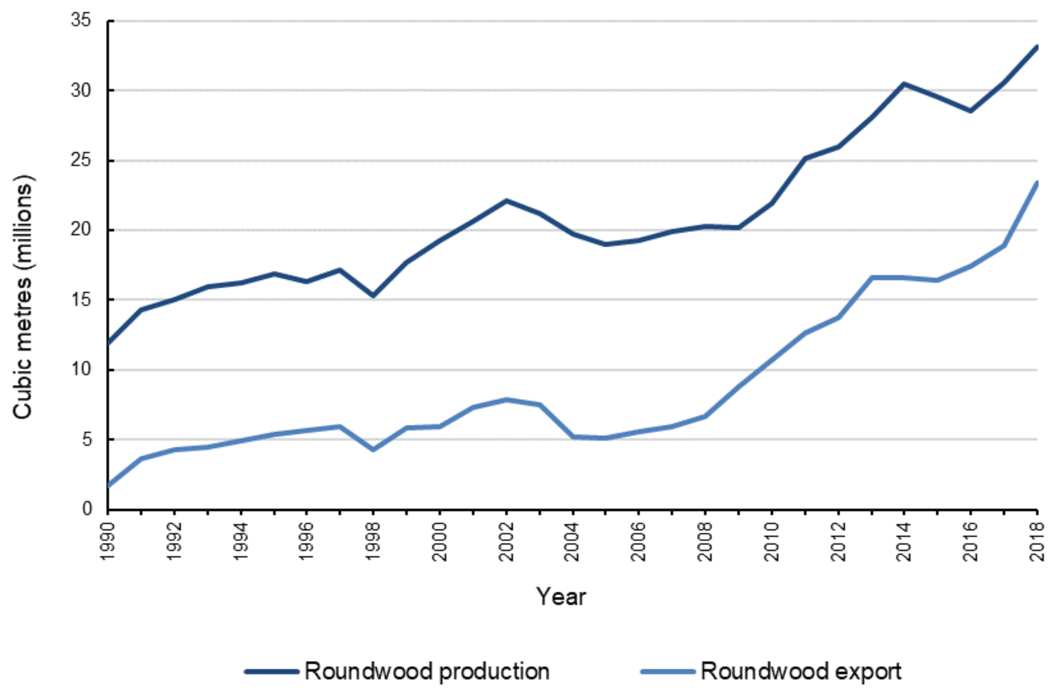
In the 2019 in-country review, it was suggested that the approach New Zealand had taken to determine the country-specific transition period was not in line with the 2006 IPCC Guidelines. To address this, New Zealand will be moving to the 20-year default transition period of the 2006 IPCC Guidelines (IPCC, 2006a).

6.10 Harvested wood products (CRF 4G)

6.10.1 Description

In 2018, the net emissions from *Harvested wood products* were –10,746.7 kt CO_2-e. This is –8,673.8 kt CO_2-e (418.4 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 2018



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 and deforestation of natural forests. Forest planting from the 1960s provides a resource specifically established to provide products to the export market. New Zealand currently processes around 40 per cent of its annual harvest. The remaining harvest is exported in raw material form. New Zealand is currently the largest exporter of softwood logs followed by the Russian Federation and United States of America. 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 2018, *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(g)).

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.

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 60 per cent) of New Zealand's harvest was exported as raw materials in the form of logs or wood chips in 2018 (figure 6.10.1) (Ministry for Primary Industries, 2018a). 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, 2016). 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

The default wood carbon content value of 50 per cent, from table 12.4 of the 2006 IPCC Guidelines, is used in the harvested wood products model (IPCC, 2006a). This value is consistent with the planted forest model that uses a country-specific value of 50 per cent. 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 kilograms per square metre 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 a half-life 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 completed in 2016 provided 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, 2016). 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 are 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 second-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 2018 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(g))
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(g))
Oven dry product weight to carbon weight	±5	Country specific (Wakelin, unpublished(g))
Discard rate, domestic	±50	Country specific (Wakelin, unpublished(g))
Discard rate, export	±90	Country specific (Wakelin, unpublished(g))

Table 6.10.3 Uncertainty in New Zealand's 2018 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	**±31.3**

6.10.4 Category-specific QA/QC and verification

No category-specific quality assurance, quality control and verification processes were undertaken. However, a process is planned to be introduced in the next submission.

6.10.5 Category-specific recalculations

Harvested wood product data from the FAOSTAT database are regularly updated. At the time of the 2019 inventory submission, 2017 roundwood actual data was not available and a projected value was used instead. In 2019, actual data for both the 2017 and 2018 years have been updated in the FAOSTAT database. To account for the updated provisional data within the FAOSTAT database, recalculations for New Zealand's emissions from harvested wood products were undertaken (table 6.10.4). The 2017 actual value is much higher, 18,805,663 cubic metres, than the projected value of 15,916,265 cubic metres, leading to a 28.6 per cent change in emissions from *Harvested wood products* for the 2017 year.

Table 6.10.4 Recalculations for New Zealand's net emissions from the Harvested wood products category in 1990 and 2017

Year	Net emissions (kt CO_2-e)		Change from the 2019 submission	
	2019 submission	2020 submission	(kt CO_2-e)	(%)
1990	−2,072.91	−2,072.91	0.0	+0.0
2017	−6,518.52	−8,379.90	−1,861.4	−28.6

6.10.6 Category-specific planned improvements

A quality assurance, quality control and verification process is planned to be implemented in the next submission. The process will ensure New Zealand data from FAOSTAT are checked against data from the Ministry for Primary Industries (the agency responsible for the collection of these data). Any missing totals in aggregate categories will be identified and filled by summing individual product categories, and any incorrect estimates are to be identified and replaced.

6.11 Non-CO_2 emissions (CRF 4(I–V))

6.11.1 Direct N_2O 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_2O emissions from nitrogen fertilisation of *Forest land* and *Other land* are reported in the Agriculture sector under the category *Direct N_2O 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 for land use change 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 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 N_2O 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 2018 compared with 0.6 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 (15:1) 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 2018 estimates for N_2O emissions from land-use change

Variable	Uncertainty at a 95% confidence interval (%)
Activity data	
Uncertainty in land area	±8.0
Emission factors	
Uncertainty in N_2O calculation	±40.0
Uncertainty in carbon calculation	±33.0
Uncertainty introduced into net emissions for LULUCF	**±0.2**

Source-specific planned improvements

No improvements are planned for this category at this time.

6.11.4 Indirect N_2O 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 N_2O 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 can occur as a result of wildfires or controlled burning, and results in emissions of CO_2, CH_4, N_2O, CO and NO_x. *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.

The two types of biomass burning (i.e., wildfire and controlled burning) that occur in New Zealand are reported in two main land use categories: *Forest land* and *Grassland*. Emissions reported in forest land are further separated by forest type, and emissions from grassland are reported from the controlled burning of tussockland (in ecosystems dominated by *Chionochloa* spp.) and from wildfires in exotic pasture grassland.

Non-CO_2 emissions from *Biomass burning* in 2018 were 3.0 kt CH_4 (75.3 kt CO_2-e) and 0.08 kt N_2O (23.1 kt CO_2-e) (see table 6.11.2).

Table 6.11.2 Non-CO_2 emissions from Biomass burning

Emissions	1990	2018	Change since 1990 (%)
CH_4 emissions (kt CH_4)	3.8	3.0	–20.2
N_2O emissions (kt N_2O)	0.11	0.08	–30.2

Methodological issues

The general approach for estimating greenhouse gas emissions from *Biomass burning* is the same regardless of the specific land use type. New Zealand employs Tier 2 methodologies to estimate emissions from *Biomass burning*. A combination of country-specific carbon fractions (Beets, unpublished), emission factors (Thomas et al., 2011) and combustion factors (Wakelin, unpublished(a), (i); Payton and Pearce, 2009) are employed along with the 2006 IPCC Guidelines default carbon fractions, emission factors, combustion factors and equations to derive emissions (sections 2.4, 4.2.4 and 6.2.4, IPCC, 2006a).

For all land uses, CO_2 emissions are captured in the general stock change calculation following the 2006 IPCC Guidelines (IPCC, 2006a). Carbon dioxide emissions resultant from biomass burning are reported as IE (included elsewhere), where emissions are captured in the stock change calculation within the land use category, or NE (not estimated), where no data exist or subsequent regrowth is not captured.

In grassland, CO_2 emissions from biomass burning are assumed to be equal to subsequent regrowth. The assumption of equivalence is accepted as reasonable in this scenario as per the 2006 IPCC Guidelines, sections 2.4 and 6.2.4 (IPCC, 2006a).

In cropland, CH_4 and N_2O emissions from controlled burning are reported as IE (included elsewhere). This is because emissions from the burning of crop stubble associated with controlled burning in cropland are reported under the Agriculture sector (chapter 5) and reported within CRF table 3.F.

Wildfire

Wildfire activity data has historically been compiled by the New Zealand Rural Fire Authority (NRFA). This responsibility has passed to Fire and Emergency New Zealand (FENZ) following the merger of the NRFA and New Zealand Fire Service in July 2017 (Wakelin, unpublished(h)).

Wildfire activity data are sourced from the FENZ database, which has data from 1991/92 onwards (Wakelin and Clifford, unpublished). 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 (National Institute of Water and Atmospheric Research, 2018).

Wildfires induced by natural disturbances (e.g., 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(b)). Non-CO_2 emissions from wildfires induced by natural disturbances are reported using data collected by FENZ. FENZ 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.

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 until 2007, and then using the actual areas from the wildfire database from that point on. The split prior to 2007 assumes 87.5 per cent to planted forest and the remainder to natural forest (Wakelin, unpublished(h)). 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(d)). The individual forest type estimates that make up the single weighted figure are derived from the national forest plot network described in section 6.4.

An estimate for wildfire in *Land converted to grassland* is provided in the inventory. 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.

Controlled burning

Controlled burning emissions are reported within *Grassland converted to forest land* (due to site preparation for conversion), within *Forest land remaining forest land* (from the clearing of vegetation (natural forest) prior to the establishment of exotic planted forest and the burning of post-harvest slash prior to restocking), within *Forest land converted to grassland* (from controlled burning associated with deforestation) and within *Grassland remaining grassland* (due to savanna (tussock) and pasture land management practices).

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(e)).

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.

Activity data are combined with emission factors derived from the national forest 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 (category: all 'other' temperate forests) in land clearing fires is 0.51 (table 2.6, IPCC, 2006a) and, for the burning of shrublands (grassland with woody biomass), there is a New Zealand-specific combustion factor of 0.7 (Wakelin, unpublished(a), (i)), which is then applied to estimate emissions from the activity data.

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(e)).

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 are captured at the time of conversion or harvest.

The burning of tussock (*Chionochloa* spp.) grassland occurs 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 combustion factor of 0.619 (spring burn carbon fractions averaged across two sites (Payton and Pearce, 2009)) 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 in the inventory. 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 forest 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 New Zealand-specific default combustion proportion for the burning of shrublands of 0.7 (Wakelin, unpublished(a), (i)) 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).

Biomass burning is not a key category for New Zealand.

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 2018 estimates for CH_4 and N_2O 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	**±0.2**

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(b), (d), (e), (i); 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

The assumption that controlled burning of post-harvest residues on afforested land does not occur will be revisited in a future submission, due to the increasing harvest rate in these forests as they reach maturity.

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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 and commercial waste is placed in managed municipal landfills. 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. Before 2010, some municipal waste was also disposed to unmanaged or uncategorised sites.

Most wastewater treatment in New Zealand is aerobic, including domestic, commercial and industrial wastewater that release methane (CH_4) emissions. Methane emissions from domestic wastewater are mainly from rural septic tank usage. Wastewater emissions are also from some municipal treatment plants, which use semi-aerobic processes, and from industries in New Zealand, in particular, the meat and the pulp and paper industries.

Municipal waste is not incinerated 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.

Emissions from composting and open burning are included. No other emission sources for direct greenhouse gases are applicable to New Zealand and no other activity data are available.

New Zealand reports emissions from Tokelau, which is a dependent territory of New Zealand. Emissions from Tokelau for all activities are reported in annex 7 of the National Inventory Report and within the 'Other' sector in the common reporting format (CRF) tables. This is due to the significantly different methods applied and the prohibitive complexity of integrating emissions within the main sectors. Therefore, all emissions reported in this sector are from New Zealand excluding Tokelau. Please refer to chapter 8 and annex 7 for details of methods applied and the emissions for Tokelau.

7.1.2 Emissions summary

The Waste sector in New Zealand produces mainly CH_4 emissions (96.7 per cent) followed by nitrous oxide (N_2O) emissions (3.3 per cent) and carbon dioxide (CO_2) emissions (0.09 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.

2018

In 2018, emissions from the Waste sector contributed 4,057.4 kilotonnes of carbon dioxide equivalent (kt CO_2-e), or 5.1 per cent, of New Zealand's gross greenhouse gas emissions. The largest source category is *Solid waste disposal*, as shown in table 7.1.1 (emissions by source category).

1990–2018

Total Waste sector emissions in 2018 were 9.8 kt CO_2-e (0.2 per cent) above 1990 emissions of 4,047.6 kt CO_2-e. Annual emissions increased between 1990 and 2002, peaking at 4,838.2 kt CO_2-e in 2002, and have generally decreased since that time. Growth in population and economic activity since 1990 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 have meant total Waste sector emissions have been trending down since 2005 in spite of increasing volumes of solid waste and wastewater. The reduction of emissions is particularly the result of increased CH_4 recovery driven by the National Environmental Standards for Air Quality introduced in 2004 and also by the New Zealand Emissions Trading Scheme (NZ ETS) since 2013. The trends are shown in figure 7.1.1 and figure 7.1.2.

2017–2018

Total Waste sector emissions in 2018 were 35.2 kt CO_2-e (0.9 per cent) lower than in 2017. This decrease is largely the result of decreases in CH_4 emissions in the *Solid waste disposal* category, due to an increase in CH_4 recovery and a slight reduction in farm waste.

Table 7.1.1 New Zealand's greenhouse gas emissions for the Waste sector by source category 1990 and 2018

	Emissions (kt CO_2-e)		Difference (kt CO_2-e)	Change (%)	Share (%)	
Source category	**1990**	**2018**	**1990–2018**	**1990–2018**	**1990**	**2018**
Solid waste disposal (5.A)	3,711.1	3,651.8	–59.3	–1.6	91.7	90.0
Biological treatment of solid waste (5.B)	4.7	34.9	30.3	644.3	0.1	0.9
Incineration and open burning of waste (5.C)	24.6	8.6	–16.0	–65.0	0.6	0.2
Wastewater treatment and discharge (5.D)	307.2	362.1	54.8	17.8	7.6	8.9
Total	**4,047.6**	**4,057.4**	**9.8**	**0.2**	**–**	**–**

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

Figure 7.1.1 Profile of emissions from New Zealand's Waste sector by source from 1990 to 2018

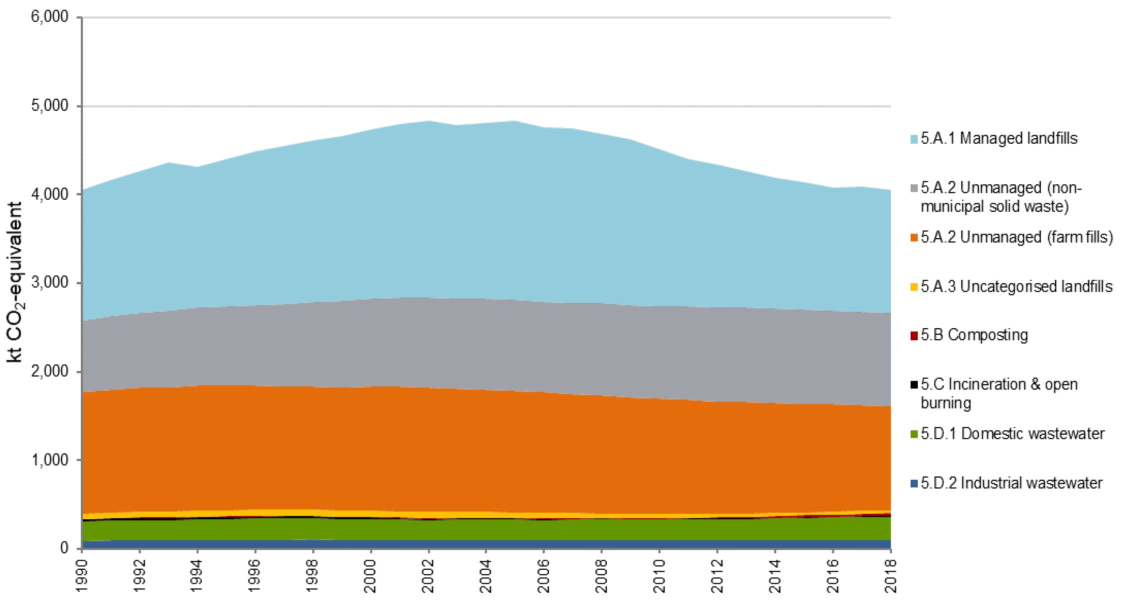
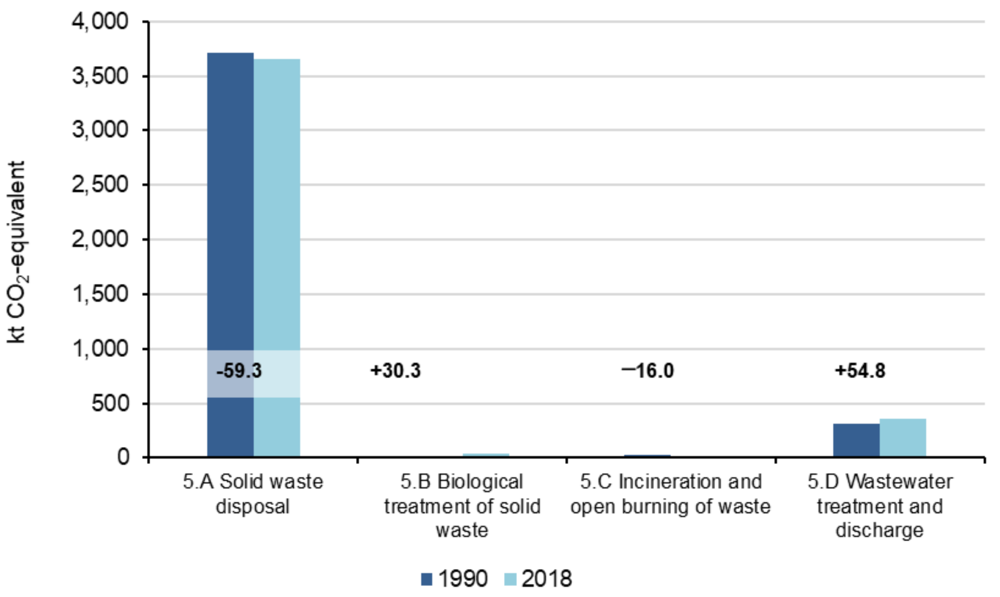


Figure 7.1.2 Change in New Zealand's emissions from the Waste sector by source category from 1990 to 2018



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 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 from 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 unmanaged waste, due to uncertainty in the activity data, and for indirect N_2O emissions from wastewater going into rivers and sea water due to uncertainty in the emission factors.

7.1.6 Verification

Where available, data from different sources were used for verification. Most of the municipal landfills report their activity data monthly 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

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 responses to issues found during reviews of previous submissions. Due to these changes, emissions in the Waste sector have increased by 5.8 kt CO_2-e (0.1 per cent) in 1990 and decreased by 32.1 kt CO_2-e (–0.8 per cent) in 2017.

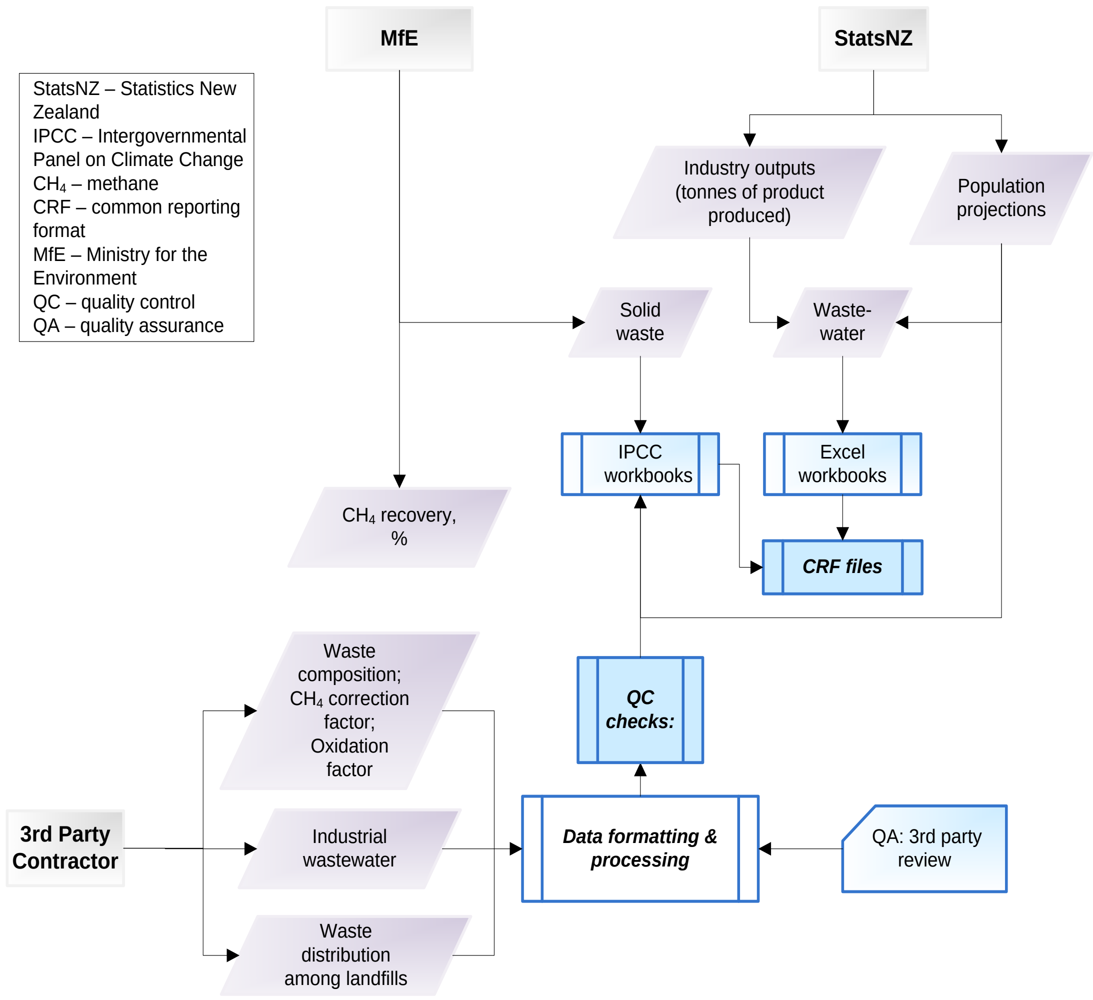
The most significant changes have been made to the *Unmanaged waste disposal sites* source category and have resulted in the largest recalculation for the Waste sector. This has decreased emissions by 0.3 kt CO_2-e (0.0 per cent) in 1990 and decreased by 25.2 kt CO_2-e (1.1 per cent) in 2017. This change is due to correcting errors in the calculations for non-municipal solid waste sites.

In addition, several other minor improvements and corrections have been made to other categories in the Waste sector. Further details can be found under methodological issues for each source category 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 quality-assurance and quality-control 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 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
- the National Environmental Standards for Air Quality (2004) set under the Resource Management Act 1991, which require large landfills to capture landfill gas. This has significantly increased the use of LFG collection technology
- 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 estimated by mass balance.

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. In 2018, 38 significant municipal landfill sites were active, 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 2018, the *Solid waste disposal* source category contributed 3,651.8 kt CO_2-e (90.0 per cent) of total emissions from the Waste sector. Emissions from *Solid waste disposal* in 2018 were –59.3 kt CO_2-e (–1.6 per cent) below the 1990 level of 3,711.1 kt CO_2-e. While there is year to year variation, this net increase 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 LFG recovery, have offset this increase, resulting in emissions peaking in 2005.

Methane emissions from *Solid waste disposal* were identified as a key category in the 2018 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 25 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.

The data included annual waste placement history and intentions. Some of these sites have since closed and are no longer accepting waste, but they all still generate CH_4 emissions. One new large landfill site has opened in New Zealand since 2009, and an existing landfill installed a landfill gas (LFG) system in 2018, and both have subsequently been included. From 2010 onwards, all municipal landfills report placement under the Waste Minimisation Act 2008. Table 7.2.2 shows the latest numbers of managed landfills.

Table 7.2.2 Landfill categories in 2018

	Sites with LFG recovery	Sites without LFG recovery	National total
Landfills under the NZ ETS and waste levy	19	19	38
Closed landfills (still emitting)	7	Not reported	Not reported
Total	26	Not reported	Not reported

Note: LFG = landfill gas; NZ ETS = Emissions Trading Scheme.

For 1950 to 1995, the waste placement for the uncategorised category (5.A.3) is estimated as a fixed fraction (10 per cent) of the difference between the national total and sites with LFG recovery as shown in the equation:

$$disposal\ for\ 5.A.3 = 10\% \times (national\ total - disposal\ for\ LFG\ sites)$$

Between 1995 and 2010, the 10 per cent fraction declines to zero, and activity data for uncategorised sites is reported as not occurring (NO) from 2010 onwards.

Table 7.2.3 shows waste placement from the beginning of the model in 1950 to 2018. Landfill sites that had LFG recovery at any time since 1950 are included in the 'sites with LFG recovery' category even though no sites had LFG recovery before 1985. A small amount of sludge is also disposed of in sites without LFG recovery, and this has increased steadily from 2.4 kt in 1950 to 5.3 kt in 2017 (Tonkin and Taylor Ltd, unpublished(a)). This amount is estimated separately and is additional to the amounts reported in table 7.2.3.

Table 7.2.3 Solid waste deposited to municipal and uncategorised landfills from 1950 to 2018

Year	Sites with LFG recovery (kt)	Sites without LFG recovery (kt)	Uncategorised sites (kt)	National total (kt)
1950	33.7	74.7	8.3	116.6
1951	77.5	164.7	18.3	260.6
1952	77.5	118.7	13.2	209.4
1953	77.5	127.3	14.1	219.0
1954	77.5	195.3	21.7	294.5
1955	181.7	180.3	20	382.1
1956	181.7	202.7	22.5	407.0
1957	181.7	241.8	26.9	450.4
1958	181.7	267.1	29.7	478.5
1959	181.7	281.5	31.3	494.5
1960	181.7	349.3	38.8	569.9
1961	181.7	438.5	48.7	668.9
1962	181.7	447.2	49.7	678.6
1963	447.9	297.3	33	778.2
1964	447.9	369.1	41	858.0
1965	447.9	477.2	53	978.1
1966	447.9	566.8	63	1,077.6
1967	495.8	486.0	54	1,035.8
1968	495.8	485.2	53.9	1,034.9
1969	495.8	489.1	54.3	1,039.2
1970	654.1	497.4	55.3	1,206.9
1971	654.1	554.4	61.6	1,270.1
1972	672.5	746.9	83	1,502.5
1973	672.5	889.1	98.8	1,660.4
1974	844.5	839.4	93.3	1,777.1
1975	844.5	736.6	81.8	1,662.9
1976	984.9	578.2	64.2	1,627.4
1977	984.9	713.0	79.2	1,777.2
1978	984.9	588.6	65.4	1,639.0
1979	984.9	581.8	64.6	1,631.4
1980	984.9	572.1	63.6	1,620.6
1981	984.9	581.8	64.6	1,631.4
1982	984.9	937.7	104.2	2,026.8
1983	984.9	1,017.6	113.1	2,115.7
1984	1,156.5	943.2	104.8	2,204.5
1985	1,259.1	930.9	103.4	2,293.4
1986	1,259.1	1,010.9	112.3	2,382.3

Year	Sites with LFG recovery (kt)	Sites without LFG recovery (kt)	Uncategorised sites (kt)	National total (kt)
1987	1,342.7	1,015.6	112.8	2,471.1
1988	1,432.6	1,014.7	112.7	2,560.0
1989	1,432.6	1,094.7	121.6	2,648.9
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	2,829.3
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	2,286.6	224.7	NO	2,511.3
2011	2,249.4	212.2	NO	2,461.5
2012	2,301.7	208.9	NO	2,510.7
2013	2,492.4	192.0	NO	2,684.4
2014	2,740.6	190.6	NO	2,931.2
2015	3,002.4	205.9	NO	3,208.4
2016	3,188.2	217.6	NO	3,405.8
2017	3,300.1	194.6	NO	3,494.7
2018	3,557.0	147.8	NO	3,704.8

Note: Sludge is not included. LFG = landfill gas, NO = not occurring. Columns may not total due to rounding.

Non-municipal landfills and farm fills (5.A.2)

Non-municipal landfills are 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. 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, which 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 based on the number of farms in each region for each year. Farming practices regarding farm fill sites are 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 averaged 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 7.2.4 shows waste placement for farm fills and non-municipal landfills from the beginning of the model in 1950 to 2018.

Table 7.2.4 Solid waste deposited to unmanaged landfills from 1950 to 2018

Year	Farm fills (kt)	Non-municipal landfills (kt)	Total waste disposed (kt)
1950	1,660.8	764.1	2,424.9
1951	1,659.7	792.1	2,451.8
1952	1,660.7	821.2	2,481.9
1953	1,665.2	851.3	2,516.5
1954	1,686.6	882.5	2,569.1
1955	1,699.5	914.8	2,614.3
1956	1,558.0	948.3	2,506.3
1957	1,556.2	983.0	2,539.2
1958	1,527.1	1,018.9	2,546.1
1959	1,533.1	1,056.2	2,589.3
1960	1,415.0	1,094.7	2,509.7
1961	1,345.8	1,134.7	2,480.5
1962	1,338.2	1,176.1	2,514.4
1963	1,329.7	1,219.0	2,548.7
1964	1,318.7	1,263.4	2,582.2
1965	1,296.2	1,309.5	2,605.7
1966	1,285.7	1,357.2	2,642.8
1967	1,254.1	1,406.6	2,660.6
1968	1,229.9	1,457.7	2,687.6
1969	1,221.0	1,510.7	2,731.7
1970	1,201.7	1,565.6	2,767.3
1971	1,193.4	1,622.5	2,815.9
1972	1,154.9	1,681.4	2,836.3
1973	1,162.4	1,742.4	2,904.8
1974	1,167.2	1,805.6	2,972.8
1975	1,233.5	1,871.0	3,104.6

Year	Farm fills (kt)	Non-municipal landfills (kt)	Total waste disposed (kt)
1976	1,246.6	1,938.8	3,185.4
1977	1,261.3	2,009.0	3,270.3
1978	1,276.5	2,081.7	3,358.3
1979	1,295.9	2,088.4	3,384.2
1980	1,315.2	2,134.1	3,449.4
1981	1,333.8	2,161.5	3,495.4
1982	1,359.8	2,262.2	3,621.9
1983	1,393.2	2,283.2	3,676.4
1984	1,409.6	2,362.9	3,772.5
1985	1,449.6	2,476.2	3,925.8
1986	1,468.3	2,516.2	3,984.4
1987	1,486.1	2,584.3	4,070.4
1988	1,509.5	2,609.3	4,118.8
1989	1,520.9	2,600.1	4,121.0
1990	1,502.7	2,604.3	4,107.0
1991	1,491.7	2,608.3	4,100.0
1992	1,474.5	2,579.8	4,054.4
1993	1,504.6	2,608.1	4,112.6
1994	1,284.9	2,774.8	4,059.6
1995	1,272.4	2,916.8	4,189.2
1996	1,222.3	3,054.6	4,276.8
1997	1,313.6	3,165.1	4,478.7
1998	1,404.8	3,229.8	4,634.7
1999	1,496.1	3,255.4	4,751.5
2000	1,430.6	3,433.0	4,863.6
2001	1,365.0	3,532.7	4,897.7
2002	1,299.4	3,655.2	4,954.7
2003	1,220.7	3,826.3	5,047.0
2004	1,229.9	4,000.9	5,230.8
2005	1,191.6	4,162.3	5,353.9
2006	1,194.6	4,300.6	5,495.2
2007	1,172.2	4,422.9	5,595.0
2008	1,120.9	4,556.1	5,677.1
2009	1,097.7	4,510.2	5,607.9
2010	1,108.2	4,500.5	5,608.7
2011	1,073.5	4,569.6	5,643.1
2012	1,076.2	4,676.8	5,753.0
2013	1,048.8	4,780.6	5,829.4
2014	1,049.5	4,903.9	5,953.4
2015	1,022.2	5,086.2	6,108.4
2016	1,026.8	5,268.3	6,295.1
2017	969.5	5,460.9	6,430.4
2018	940.7	5,517.2	6,457.9

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)

Different approaches are used to model sites with and without LFG recovery respectively, due to the different sizes of the landfills and the available data.

For each of the 26 landfill sites with LFG recovery, 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 approach based on bulk waste. These sites that are still operational account for approximately 90 per cent of waste disposed to municipal landfills as per table 7.2.3.

Municipal waste outside of these 26 sites is disposed to smaller landfills that have never had gas recovery. In 1990, there were more than 300 of these sites and in 2017 approximately 19 were still in operation. This number includes 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 approach for the waste types described in table 7.2.4, as well as sludge.

Non-municipal landfills and farm fills (5.A.2)

Non-municipal landfills include privately owned industrial landfills and a large number of landfill sites (clean fills and construction and demolition fills) that are consented for largely inert waste and accept a maximum of 5 per cent municipal waste. 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 farm fills, the FOD model has been applied to estimate 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 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 7.2.5 shows the resulting estimated composition data from 1950 to 2018. These have been used for the waste disposed to all municipal landfills.

Table 7.2.5 Estimated composition of waste to municipal landfills from 1950 to 2018

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
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	45	Interpolation
2011	17	9	10	12	5	3	44	Interpolation
2012	17	8	11	12	6	3	44	Survey
2013–18	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 CH_4 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.

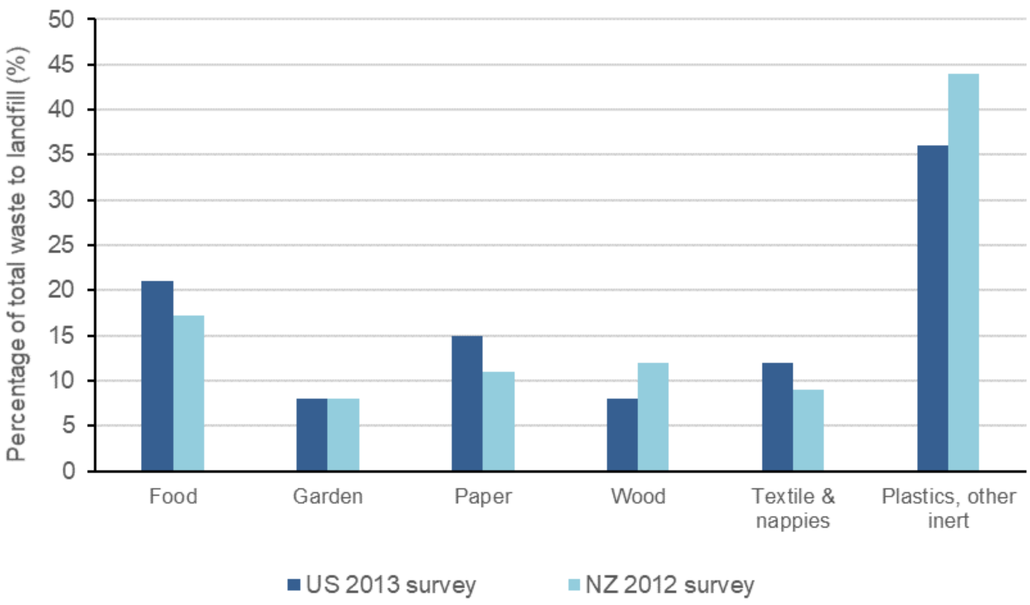
For all sites other than managed landfills, there was an unknown mix of shallow and deep disposal areas. A survey carried out in 1971 revealed that larger sites in operation were assessed at that time to be roughly half deep (more than 5 metres) and half shallow. The use of cover material was variable. Therefore, for uncategorised sites, a CH_4 correction factor of 0.6 and an oxidation factor of zero have been used.

Methane generation rates

In the study (SKM, unpublished(b)) that informs the CH_4 generation parameters for landfills with LFG recovery, the amount of CH_4 generated by the identified landfills between 1990 and 2012 was estimated by using the United States Environmental Protection Agency Landfill Gas Emissions Model (LandGem) version 3.02. The 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. Figure 7.2.1 shows the similarity in composition of municipal solid waste to landfills between the United States and New Zealand (United States Environmental Protection Agency, 2014).

The LandGem and IPCC models produce the same results because they are first order decay models. The principal difference between these models is that LandGem assumes constant values for L_o and K, while these can be different each year in the IPCC model. However, this is not a significant problem for New Zealand because there is not enough information to be able to differentiate the L_o and k values on an annual basis (SKM, unpublished(b)).

Figure 7.2.1 The composition of municipal solid waste landfilled in New Zealand and the United States



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) because 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 7.2.6, along with data on the proportion of placement managed by each group of landfills with common k-values.

Table 7.2.6 Methane generation rates used for landfills with landfill gas recovery, 1990 and 2018

k-value	Number of sites applying this k-value	Comment	Percentage of waste disposed to site group 1990	2018
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	–	0.8
0.0475	1	k-value modified for site-specific conditions	6.3	2.5
0.057	13	US default for sites with more than 1,000mm of annual rainfall	57.1	46.3
0.05985	2	k-value modified for site-specific conditions	6.2	27.9
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 because 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 determined based on the data that are available. Recovery rates for some years since 2014 and for some landfill sites can be determined using data from the NZ ETS and have been applied where available. The LFG data itself is not available from the NZ ETS, instead a unique emissions factor (UEF) is published for certain landfills each year. A UEF is based on piped LFG data, which is compared against generated emissions to determine the recovery rate. This data is verified by a third party as part of a landfill operator's application for a UEF.

The generated emissions are modelled for each UEF using an FOD approach similar to the inventory. The main difference between the inventory and the ETS is that generated emissions in the NZ ETS are modelled using a per-waste-type, multi-phase decay model with default k-values. This is compared to the inventory, which uses a single-phase bulk waste model with non-default k-values as per table 7.2.5. The NZ ETS also includes 3.9 per cent sludge in the composition for these sites whereas the inventory accounts for sludge in sites without LFG collection. Furthermore, it is assumed that the historical placement amounts used in calculating the UEF are the same as that used in the inventory. This is reasonable because landfill operators contributed to the historical data that are also used in the inventory. While the generated emissions data in the NZ ETS is confidential, the overall difference to modelled emissions is understood to be small such that the recovery rates from the NZ ETS are also applicable to the inventory.

When the UEF is published in the form of a single-phase bulk waste approach, the LFG recovery rate is able to be calculated from the UEF by the equation:

$$Recovery\,rate\ (\%) = 100 - \frac{UEF}{1.19}$$

Where the UEF is the unique emission factor under the NZ ETS, and 1.19 is the default bulk waste emission factor without LFG recovery under the ETS. The UEF data is published each year for landfill sites that have been successful in calculating and applying for the UEF (New Zealand Gazette, 2014, 2015, 2016, 2017). The maximum recovery rate allowed under the NZ ETS is 90 per cent, and this is consistent with the maximum recovery rates determined by other methods.

For all other years and/or sites without a UEF, recovery rates are estimated based on 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 7.2.7 shows the different methods of determining recovery rates and the total amounts of CH_4 recovered. The majority of the CH_4 recovered is validated by the NZ ETS data, and there is overall good consistency in recovery rates whether or not gas flow data or NZ ETS data are available. Therefore, while the data on recovery rates are limited, available evidence indicates these are accurate and emissions are not over estimated or underestimated.

Table 7.2.7 Methane recovery rates and amounts for landfill sites with landfill gas recovery 2018

Recovery rate for 2018 from the NZ ETS	Method for determining recovery rate for years without NZ ETS data	Number of sites	Recovery rate applied for 2018 (%)	Methane recovered in 2018 (kt CH_4)		
				Energy generation	Flaring	Total
Yes	Indirect methods based on site conditions	7	4–90	9.9	4.0	13.9
No	Direct evidence of gas-flow rate in 2009	4	41–90	25.1	1.6	26.7
	Evidence of energy generation in 2009	1	47	1.0	–	1.0
	Indirect methods based on site conditions	14	25–90	22.5	3.2	25.7
Total		**26**	**N/A**	58.6	8.7	67.3

Note: N/A = not applicable; NZ ETS = New Zealand Emissions Trading Scheme.

For the sites and years that NZ ETS data are available, the UEF, which is based on gas collection data, determines the CH_4 recovery rate applied in the inventory model. When NZ ETS data are not available, the amount of CH_4 recovered is based on the assumptions used to model recovery rates, where only some historical gas-flow data are available from the research conducted on the recovery rates in 2009 (SKM, unpublished(b)).

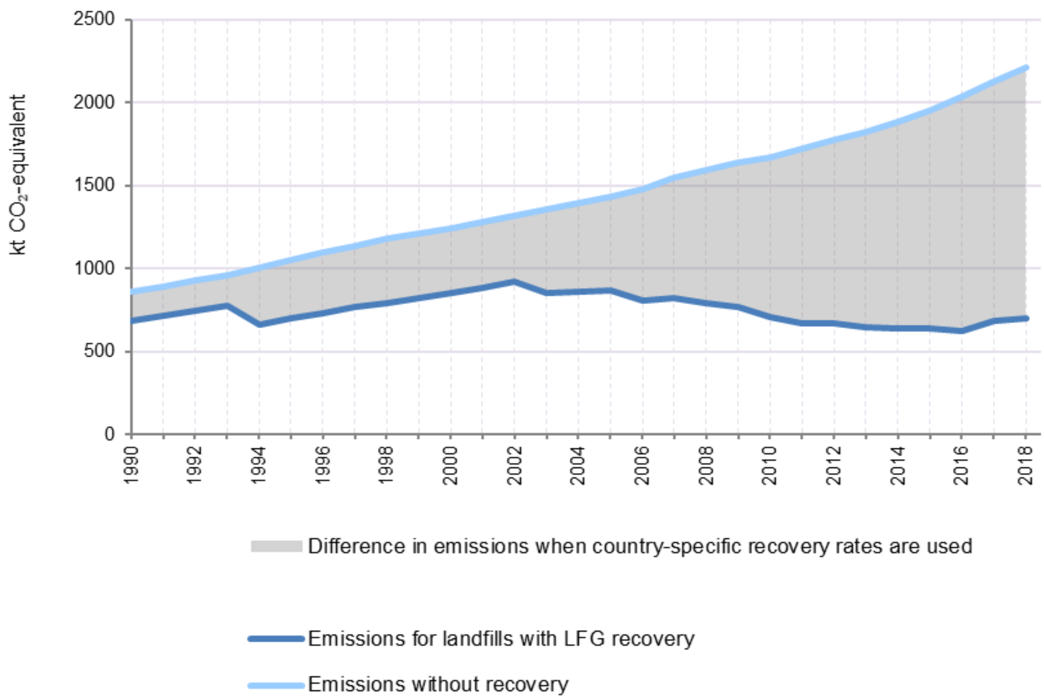
Based on reviews of previous submissions, New Zealand was recommended to use a recovery rate of 20 per cent. The 2006 IPCC Guidelines state that, when CH_4 recovery is estimated on the basis of the number of solid waste disposal sites with LFG recovery, a default estimate of recovery would be 20 per cent (IPCC, 2006a). However, it is known that the collection efficiency varies greatly, depending on the technology used. New Zealand has detailed information about its municipal landfills, as well as evidence of actual recovery rates from historical metered data and from the NZ ETS. This provides assurance that the site-specific recovery rates used are appropriate. If New Zealand were to use the suggested recovery rate of 20 per cent it would have the effect of substantially underestimating CH_4 recovery and therefore overestimating emissions for landfills with LFG recovery. Figure 7.2.2 demonstrates the effect on 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 because the LFG recovery technology has been progressively installed and upgraded. In the emissions estimates, the CH_4 recovery rate is specified for each site by year based on either NZ ETS data, older gas-flow data or site-specific factors described above, taking into account when CH_4 recovery began for each site. One site ceased CH_4 recovery in 2006, and this is also taken into account. In 2018, recovery efficiencies varied from 4 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 25 landfills can be determined. In 2018, 68 per cent of the CH_4 generated was recovered. Even as waste placement volumes have increased across the time series, overall emissions from landfills with LFG recovery have generally declined since 2002. This is due to LFG recovery technology being progressively deployed across landfills, which has increased the amount of CH_4 being recovered faster than the increase in generated CH_4. Figure 7.2.2 shows how emissions have changed over the time series, as well as the emissions from landfills with LFG calculated when applying the IPCC default recovery rate of 20 per cent. The absolute amount of emissions and the trend of the emissions are significantly different when applying the default recovery rate and do not reflect the improvements to landfill management in New Zealand over the past 25 years.

According to United States Environmental Protection Agency estimates, collection efficiencies for a typical landfill collection system range between 60 per cent and 85 per cent. Nevertheless, various international reports and studies have confirmed that collection efficiencies can be greater than 90 per cent in sites with effective LFG management. In New Zealand, the landfill sites registering the highest values correspond to larger regional facilities operating for a long time, therefore, it is reasonable that the high collection efficiencies reported here are not too high (Tonkin and Taylor Ltd, unpublished(c)).

Figure 7.2.2 Effect on emissions from landfills with landfill gas (LFG) recovery when using default methane recovery rate from 1990 to 2018



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 municipal landfills.

Table 7.2.8 Summary of parameters for municipal landfills

Parameter	Values	Source	Reference
Managed landfills with CH_4 recovery			
k-value (bulk phase, by site)	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	4–90%	Site specific	SKM (unpublished(b)), New Zealand Gazette, 2014, 2015, 2016, 2017, 2018
Degradable organic carbon (DOC) (kt C/kt waste) (bulk DOC)	0.145–0.175	Country specific	Waste Not Consulting (unpublished(b)); Eunomia Research and Consulting and Waste Not Consulting (unpublished)
Managed landfills without CH_4 recovery			
k-value (multi-phase by waste type)	0.030–0.185	IPCC default	IPCC (2006a)
Methane correction factor	1.0	IPCC default	IPCC (2006a)
Oxidation factor	10%	IPCC default	IPCC (2006a)
DOC (kt C/kt waste) (by waste type)	0.15–0.43	IPCC default	IPCC (2006a)
Uncategorised landfills			
k-value (multi-phase by waste type)	0.030–0.185	IPCC default	IPCC (2006a)
Methane correction factor	0.6	IPCC default	IPCC (2006a)
Oxidation factor	0	IPCC default	IPCC (2006a)
DOC (kt C/kt waste) (by waste type)	0.15–0.43	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 (DOCf) that decomposes	0.5	IPCC default	IPCC (2006a)
Fraction of CH_4 in gas	0.5	IPCC default	IPCC (2006a)

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 each waste type produced in each region could be determined from the general 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 from the 2016 year (MWH, 2017).

For farm fills, based on information resulting from the non-natural rural wastes survey (GHD, 2013), the DOC for bulk municipal solid waste has been adopted for farm waste because it is expected to comprise a mixture of domestic refuse, inert wastes (scrap metal and glass) and wastes associated with the particular farming activity. This is similar to the kinds of waste in municipal solid waste, therefore, applying the DOC for bulk municipal solid waste is appropriate (Tonkin and Taylor Ltd, unpublished(b)).

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 CH_4 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 CH_4 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 CH_4 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 7.2.9 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 7.2.9 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)	0.040–0.43	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 (kt C/kt 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 and activity data used for most of the *Solid waste disposal* category, the uncertainty estimate is ±40 per cent (table 7.2.10). This is consistent with the estimates provided in the IPCC Guidelines (IPCC, 2006a).

For managed municipal landfills, the emission factor uncertainty is set at this level because, while better-quality parameters are used in this category, 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.

The overall uncertainty in activity data for solid waste disposal is calculated using approach 1 for adding uncertainties together. The overall uncertainty in emission factor is set as the same as the uncertainty for the underlying categories because they are consistent.

Table 7.2.10 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	±92	±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 QA/QC 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

Minor changes made within the *Solid waste disposal* category have led to recalculations of estimates for the full time series in the 2020 submission. Overall, recalculations and improvements have resulted in a decrease to emissions in 1990 of 0.3 kt CO_2-e and a decrease of 28.5 kt CO_2-e in 2017.

The largest change is the result of corrections to the non-municipal solid waste sites model, resulting in a decrease to emissions in 1990 of 0.3 kt CO_2-e and a decrease of 25.2 kt CO_2-e in 2017. Other changes are minor. Recalculations are described in greater detail in chapter 10 of this submission.

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 budget and resourcing.

New Zealand is planning to review data and methods for the *Managed solid waste disposal sites* category in 2020. This review aims to address some of the issues for this category, including CH_4 recovery rates and k-values. The review efforts will focus on areas that have the most potential for improvement.

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)

7.3.1 Description

New Zealand has seen an increase in the use of commercial-scale composting of solid waste in recent years, in addition to ongoing household-scale composting of solid waste. Emissions from composting are reported for the first time in the 2019 submission in 5.B.1. No other biological treatment of solid waste occurs in New Zealand.

In 2018, *Biological treatment of solid waste* accounted for 34.9 kt CO_2-e (0.9 per cent) of Waste sector emissions. This was an increase of 30.3 kt CO_2-e (644.3 per cent) above the 1990 level of 4.7 kt CO_2-e, and an increase of 5.0 kt CO_2-e (16.6 per cent) from 2017.

7.3.2 Methodological issues

Choice of activity data

Activity data has been estimated based on expert judgement, in part using evidence of large-scale commercial composting operating around New Zealand. Between 1990 and 2009, before large scale commercial composting, it is estimated that an equivalent of 1 per cent of total municipal solid waste was composted (refer to the total solid waste reported in table 7.2.2). Between 2009 and 2018, this fraction increased by 0.5 percentage points per year, with an equivalent of 5.5 per cent being composted in 2018. This reflects the increase in commercial scale composting estimated since 2010. Activity data for composting can be derived from table 7.2.3 using this description.

It is assumed that the increase in composted waste over time has not affected the composition of landfill waste since 2012, as per table 7.2.4, where the composition of waste sent to landfill is assumed to be constant from 2012 in the absence of more recent data. Because most composted waste is likely to be diverted from managed landfills where it would otherwise be disposed of, it is possible that landfill emissions could be lower than reported. This reduction in landfill emissions would be driven by changes to the average composition of waste disposed to managed landfills. The risk of double-counting is small because food waste has a similar DOC to the overall DOC, which means reducing the food waste proportion has a minimal effect on the overall DOC. Furthermore, the composition of waste disposed at managed landfills will be updated over time as more recent data on the composition of landfill waste become available.

Choice of methods

Estimates of direct emissions from the composting of solid waste are made using the default Tier 1 methodology (IPCC, 2006a).

Choice of emission factors

IPCC default parameters are used, as detailed in table 7.3.1.

Table 7.3.1 Emission factors applied to estimate emissions from composting

Emission factor for composting	Emission factor (g/kg)	Source
Methane	4.0	IPCC (2006a)
Nitrous oxide	0.24	IPCC (2006a)

The emission factors are sourced from table 4.1 of volume 5, chapter 4 of the IPCC Guidelines (2006a).

7.3.3 Uncertainties and time-series consistency

Uncertainties

As per the IPCC recommendation for uncertainties relating to activity data (IPCC, 2006a), when data quality is poor it can vary by more than a factor of two, or ±>100 per cent. In this case, ±100 per cent is applied because, while data quality is poor, there are some data available.

Uncertainties in emission factors are based on the range of the emission factors relative to the default (IPCC, 2006a), and the uncertainty for the default CH_4 emission factor is about ±100 per cent. The range for the N_2O emission factor is +150 per cent and –75 per cent, so the uncertainty is given as ±150 per cent. Table 7.3.2 presents uncertainties for composting.

Table 7.3.2 Uncertainty in emissions from compost

Emissions category	Uncertainty in activity data (%)	Uncertainty in emission factors (%)
Compost (CH_4)	±100	±100
Compost (N_2O)	±100	±150

Time-series consistency

Time-series consistency is ensured by the use of consistent models and parameters across the period.

7.3.4 Source-specific QA/QC and verification

These emissions are very small, and basic quality-assurance and quality-control checks are carried out where possible. Detailed quality-assurance and quality-control efforts for the Waste sector focus on the disposal to land and wastewater categories.

7.3.5 Source-specific recalculations

The 2019 submission is the first to report emissions from composting.

7.3.6 Source-specific planned improvements

No specific improvements are planned for this category. Over time, better activity data will be applied to the inventory if and when they become available.

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 clinical 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. Some farms practice open burning of small volumes of rural waste (Tonkin and Taylor Ltd, unpublished(b)) and, while limited information is available on the extent of the practice, emissions from open burning are reported for the first time in the 2019 submission. The majority of farm waste is buried in farm fills rather than burned, and the emissions from farm fills are reported in *Solid waste disposal* (CRF 5.A).

On its website, the Ministry of Education indicates that waste incineration is still practised in a small number of primary schools located in remote rural areas. Although information is not available on the exact number of schools practising waste incineration, it is estimated that around 10 per cent of the total number of schools in New Zealand still incinerate their waste production (direct communication with the Ministry of Education). Emissions from this source are not estimated for this submission and are reported as not estimated (NE). See annex 6.2 for more information.

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 2018, *Incineration and open burning of waste* accounted for 8.6 kt CO_2-e (0.2 per cent) of Waste sector emissions (table 7.4.1). This was a decrease of 16.0 kt CO_2-e below the 1990 level of 24.6 kt CO_2-e, and a decrease of 0.2 kt CO_2-e (–2.1 per cent) from 2017.

Table 7.4.1 Emissions from Incineration and open burning of waste (5.C)

	Emissions (kt CO_2-e)		Difference (kt CO_2-e)	Change (%)
Source category	**1990**	**2018**	**1990–2018**	**1990–2018**
Incineration (5.C.1)	14.8	2.4	–12.3	–83.5
Open burning (5.C.2)	9.9	6.2	–3.7	–37.4
Total (5.C)	**24.6**	**8.6**	**–16.0**	**–65.0**

Note: Percentages presented are calculated from unrounded values.

7.4.2 Methodological issues

Choice of activity data

Incineration (5.C.1)

Limited information was available from individual site operators on the amount of waste burned between 1990 and 2007. For most sites, these activity data needed to be inferred 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.

Table 7.4.2 presents activity data for incineration.

Table 7.4.2 Amounts of waste incinerated 1990 to 2018

Year	Clinical wastes (kt)	Hazardous wastes (kt)	Sewage sludge (kt)	Total waste incinerated (kt)
1990	21.5	0.3	4.4	26.2
1991	21.5	0.3	4.4	26.2
1992	21.5	0.3	4.4	26.2
1993	21.3	0.3	4.4	26.0
1994	21.3	0.3	4.4	26.0
1995	21.0	0.3	4.4	25.7
1996	20.3	0.3	4.4	25.0
1997	20.3	0.3	4.4	25.0
1998	20.0	0.3	4.4	24.7
1999	18.9	0.3	4.4	23.6
2000	17.8	0.3	4.4	22.4
2001	9.3	0.3	4.4	13.9
2002	8.2	0.3	4.4	12.9
2003	7.3	0.3	4.4	12.0
2004	7.2	0.3	4.4	11.9
2005	5.3	0.3	4.4	10.0
2006	3.2	0.3	4.4	7.9
2007	0.6	0.3	4.4	5.3
2008	0.6	0.3	4.5	5.4
2009	0.6	0.3	4.5	5.4
2010	0.6	0.3	4.5	5.4
2011	0.6	0.3	4.5	5.4
2012	0.6	0.3	4.5	5.4
2013	0.6	0.3	4.5	5.4
2014	0.6	0.3	4.5	5.4
2015	0.6	0.3	4.5	5.4
2016	0.6	0.3	4.5	5.4
2017	0.6	0.3	4.5	5.4
2018	0.6	0.3	4.5	5.4

Note: Columns may not total due to rounding.

Open burning (5.C.2)

There is little information available on the quantities of farm wastes burned. Tonkin and Taylor Ltd (unpublished(b)) reported that 92 per cent of rural waste is either buried, bulk stored or burned, most of which is buried. The other 8 per cent is disposed of in other ways. It has been assumed that the amount burned is equivalent to 2 per cent (wet weight) of the volume of waste that is buried in farm fills (waste disposed in farm fills is reported in table 7.2.3). Activity data for open burning can be derived from table 7.2.3 using this description.

Choice of methods

Incineration (5.C.1)

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 site operators (SKM, unpublished(a)).

Open burning (5.C.2)

Estimates of direct emissions from the open burning of rural waste are made using the default Tier 1 methodology (IPCC, 2006a). Farm waste comprises a mix of household and other wastes, which have a composition and diversity similar to general municipal solid waste (Tonkin and Taylor Ltd, unpublished(b)). Therefore emissions from CH_4 and N_2O were estimated using default emission factors for bulk municipal solid waste.

Emissions of CO_2 were calculated using an equivalent composition to New Zealand municipal solid waste (as reported in table 7.2.4), and assumed an even distribution between materials that are inert from a landfill perspective across rubber and leather, plastics, metal, glass and other inert waste types. Table 7.4.3 shows the parameters that determine dry matter content, total carbon content and fossil carbon content as weighted averages.

Table 7.4.3 Values applied to estimate carbon dioxide emissions from open burning of rural waste

Waste type	Composition (%)	Dry matter content (%)	Total carbon content (%)	Fossil carbon content of total carbon (%)
Paper/card	10.7	90	43	1
Textiles	5.6	80	50	20
Food waste	16.8	40	38	0
Wood	11.9	85	50	0
Garden and park waste	8.3	40	49	0
Nappies	3.0	40	70	10
Rubber and leather	8.8	84	67	20
Plastics	8.8	100	75	100
Metal	8.8	100	–	–
Glass	8.8	100	–	–
Other, inert	8.8	90	3	100
Weighted average	**–**	**76.9**	**38.6**	**20.8**

Source: Dry matter content, total carbon content and fossil carbon content values are from table 2.4 (IPCC, 2006a).

Choice of emission factors

Incineration (5.C.1)

The parameters used to calculate emissions from incineration are detailed in table 7.4.4.

Table 7.4.4 Parameter values applied to estimate emissions from incineration

Parameter	Hazardous waste	Clinical waste	Sewage sludge	Source
Dry-matter content in waste (%)	50 (table 2.6)	65 (table 2.6)	10 (section 2.3.2)	IPCC (2006a)
Fraction of carbon	0.275 (wet) (table 2.6)	0.6 (dry) (table 5.2)	0.45 (dry) (table 5.2)	IPCC (2006a)
Fraction of fossil carbon in total carbon	1 (table 2.6)	0.4 (table 5.2)	0.0 (table 5.2)	IPCC (2006a)
Oxidation factor	1.0	1.0	1.0	IPCC (2006a), table 5.2
Molar ratio to convert from carbon to carbon dioxide	44/12	44/12	44/12	
Overall carbon dioxide emission factor (kg/kt)	0.504	0.572	0.165	
Methane emission factor (kg/kt) as directly referenced	N/A	N/A	9.7 (section 5.4.2)	IPCC (2006a)
Methane energy factor (kg gas/TJ)	30 (table 2.3, Industrial wastes)	300 (table 2.4, Municipal/ Industrial wastes)	N/A	IPCC (2006b)
Methane (MJ/kg waste)	12.8	16.8	N/A	Ministry of Commerce (1993)
Methane emission factor (kg/kt) calculated as a quotient of the above parameters	2.34	17.86	N/A	
Nitrous oxide emission factor (kg/kt)	100	60	900	IPCC (2006b), table 5.6

Note: N/A = Not applicable.

These parameters are as given in the IPCC Guidelines (IPCC, 2006a, 2006b), noting that:

- some parameters have been chosen as being the closest available to the specific type of waste
- 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 using factors from the *New Zealand Energy Information Handbook* (Ministry of Commerce, 1993), which only had gross calorific values.

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.

Open burning (5.C.2)

Parameters are used as detailed in table 7.4.5.

Table 7.4.5 Parameters used to estimate emissions from open burning

Parameter	Value	Source
Carbon dioxide		
Dry matter content (%)	76.9	Calculated (see table 7.4.3)
Total carbon content (%)	38.6	Calculated (see table 7.4.3)
Fossil carbon content (%)	20.8	Calculated (see table 7.4.3)

Parameter	Value	Source
Oxidation factor (%)	58	IPCC default
Conversion factor	44/12	
Methane emission factor (kg/kt wet waste)	6,500	IPCC default
Nitrous oxide emission factor (kg/kt dry waste)	150	IPCC default

To calculate N_2O emissions, the activity data is converted using the weighted average dry matter content in table 7.4.3 because the default emission factor is presented in terms of dry waste.

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 7.4.6).

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.

Table 7.4.6 Uncertainty in emissions from incineration and open burning

Emissions category	Uncertainty in activity data (%)	Uncertainty in emission factors (%)
Waste incineration and open burning (CO_2)	±50	±40
Waste incineration and open burning (CH_4)	±50	±100
Waste incineration and open burning (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 small, and basic quality-assurance and quality-control checks are carried out where possible. Detailed quality-assurance and quality-control efforts for the Waste sector focus on the disposal to land and wastewater categories.

7.4.5 Source-specific recalculations

No recalculations have been made for incineration (5.C.1). Open burning is reported for the first time in the 2019 submission.

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 may provide a better understanding of open burning in the farm sector. Also see section 7.2.6.

7.5 Wastewater treatment and discharge (5.D)

7.5.1 Description

In 2018, *Wastewater treatment and discharge* contributed 362.1 kt CO_2-e (8.9 per cent) of emissions from the Waste sector. This was an increase of 54.8 kt CO_2-e (17.8 per cent) from the 1990 level of 307.2 kt CO_2-e and is due to increases in 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 and are reported as 'not estimated' in the Agriculture sector (see chapter 5, section 5.5.2). Table 7.5.1 presents emissions from wastewater treatment and discharge.

Sludge amounts are reported as IE (included elsewhere) for domestic and industrial wastewater because most of the sludge is sent to landfills, and activity data and emissions from its disposal are reported in the *Solid waste disposal* source category (Tonkin and Taylor Ltd, unpublished(a)).

Table 7.5.1 Emissions from Wastewater treatment and discharge (5.D)

	Emissions (kt CO_2-e)		Difference (kt CO_2-e)	Change (%)
Source category	**1990**	**2018**	**1990–2018**	**1990–2018**
Domestic wastewater (5.D.1)	215.4	259.4	44.1	20.5
Industrial wastewater (5.D.2)	91.9	102.6	10.8	11.7
Total (5.D)	**307.2**	**362.1**	**54.8**	**17.8**

Note: Percentages presented are calculated from unrounded values.

Methane emissions from the *Wastewater treatment and discharge* source category were identified as a key category in the 2018 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 around 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 produces the most CH_4 emissions from domestic wastewater, because emissions from other treatment types are small or the CH_4 is destroyed.

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, to capture any changes in industry activity and 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). Emissions from the wastewater treatment plants are calculated for 1997, 2001, 2006, and every year from 2013 onwards. Emissions from years before 1997 are calculated based on a fixed aggregate methane correction factor from 1997. Emissions from the remaining years are interpolated.

Emissions are proportional to the population treated by each plant, and population data are updated based on the population growth rate of the district in which the plant is located. This information is obtained from Statistics New Zealand. For the 2020 submission, interpolations between the years 2003–19 were conducted due to a lack of available data. This will be updated for the 2021 submission with revised data. For intermediate years, data is interpolated. Years before 1997 are driven by national population growth using the CH_4 correction factor from 1997.

In 2018, the total population connected to treatment plants was estimated to be 4.0 million. The connected population excludes people connected to rural septic tanks, estimated at 479,000 people in 2018, and approximately 53,000 people using other aerobic plants. A remaining population of 380,000 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 plants being estimated. To account for domestic wastewater emissions from the unaccounted for 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, less the population using septic tanks because there is no liquid effluent from septic tanks. Activity data for domestic wastewater are reported in table 7.5.2. Also included in table 7.5.2 is an aggregate CH_4 correction factor that is determined by the sum of the CH_4 correction factor for various treatment types, weighted by the population served by each type.

Table 7.5.2 Activity data and key factors for domestic wastewater from 1990 to 2018

Year	National population	Aggregate methane correction factor	Domestic wastewater total organic product (kt)
1990	3,410,400	Same as 1997	140.4
1991	3,516,000	Same as 1997	144.7
1992	3,552,200	Same as 1997	146.4
1993	3,597,800	Same as 1997	148.4
1994	3,648,300	Same as 1997	150.6
1995	3,706,700	Same as 1997	153.1
1996	3,762,300	Same as 1997	155.5
1997	3,802,700	0.043	157.4
1998	3,829,200	Interpolated	156.2
1999	3,851,100	Interpolated	155.1
2000	3,873,100	Interpolated	153.9
2001	3,916,200	0.038	152.7
2002	3,989,500	Interpolated	155.9
2003	4,061,600	Interpolated	159.0
2004	4,114,300	Interpolated	162.2
2005	4,161,000	Interpolated	165.5
2006	4,209,100	0.032	168.0
2007	4,245,700	Interpolated	170.3
2008	4,280,300	Interpolated	172.0
2009	4,332,100	Interpolated	173.5
2010	4,373,900	Interpolated	175.2
2011	4,399,400	Interpolated	176.8
2012	4,425,900	Interpolated	178.5
2013	4,471,500	0.032	181.5
2014	4,546,700	0.032	184.3
2015	4,633,700	0.032	187.9
2016	4,725,300	0.032	190.7
2017	4,805,400	0.032	193.6
2018	4,886,100	0.032	198.0

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 7.5.3 reports the activity data for the amount of total organic product in wastewater (TOW) across the main industries.

Table 7.5.3 Total organic product producing methane from industrial wastewater 1990 to 2018

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	20.2	147.5
1991	59.2	78.2	18.8	156.1
1992	64.1	76.4	17.2	157.8
1993	59.3	73.0	15.7	147.9
1994	62.1	79.4	14.4	156.0
1995	64.5	80.5	13.3	158.3

Year	Meat industries TOW (kt)	Pulp and paper industry TOW (kt)	All other industries TOW (kt)	Total industrial TOW (kt)
1996	65.7	82.7	11.9	160.4
1997	66.6	81.2	10.3	158.1
1998	68.7	82.5	9.2	160.4
1999	61.4	79.7	7.8	148.9
2000	65.8	84.9	6.4	157.1
2001	67.7	88.0	4.9	160.6
2002	65.0	85.3	5.5	155.8
2003	70.1	85.1	5.0	160.2
2004	73.8	83.1	6.1	163.1
2005	72.6	90.3	5.9	168.8
2006	71.3	90.1	6.4	167.8
2007	72.5	86.4	6.7	165.7
2008	72.8	87.0	7.7	167.5
2009	68.3	85.7	7.7	161.7
2010	66.6	87.6	7.5	161.8
2011	65.6	90.7	4.1	160.4
2012	65.7	86.9	3.3	155.9
2013	67.9	83.5	4.3	155.7
2014	68.7	79.2	5.5	153.5
2015	71.7	77.7	4.0	153.5
2016	69.2	89.0	5.4	163.6
2017	71.2	87.2	4.9	163.4
2018	72.7	77.7	5.2	155.7

Note: TOW = Total organic product in wastewater. Columns may not total due to rounding.

Table 7.5.4 reports the activity data for the total nitrogen in effluent from industrial wastewater.

Table 7.5.4 Nitrogen in effluent from industrial wastewater 1990 to 2018

Year	Meat industries N in effluent (kt)	Pulp and paper industry N in effluent (kt)	Dairy processing N in effluent (kt)	Leather & skins N in effluent (kt)	Total industrial N in effluent (kt)
1990	1.37	0.07	0.16	1.22	2.82
1991	1.45	0.07	0.17	1.22	2.92
1992	1.58	0.08	0.17	1.22	3.05
1993	1.44	0.09	0.19	1.22	2.95
1994	1.50	0.10	0.19	1.22	3.02
1995	1.56	0.11	0.21	1.22	3.10
1996	1.59	0.11	0.23	1.22	3.15
1997	1.61	0.11	0.24	1.22	3.18
1998	1.65	0.12	0.24	1.22	3.23
1999	1.46	0.13	0.26	1.22	3.07
2000	1.56	0.14	0.29	1.22	3.21
2001	1.60	0.14	0.31	1.22	3.28
2002	1.51	0.16	0.31	0.61	2.60
2003	1.63	0.17	0.33	0.61	2.75
2004	1.71	0.19	0.32	0.61	2.83

Year	Meat industries N in effluent (kt)	Pulp and paper industry N in effluent (kt)	Dairy processing N in effluent (kt)	Leather & skins N in effluent (kt)	Total industrial N in effluent (kt)
2005	1.67	0.20	0.33	0.61	2.81
2006	1.65	0.18	0.34	0.61	2.79
2007	1.68	0.19	0.33	0.61	2.81
2008	1.69	0.18	0.36	0.61	2.85
2009	1.59	0.17	0.37	0.61	2.74
2010	1.53	0.18	0.39	0.61	2.72
2011	1.48	0.20	0.43	0.61	2.73
2012	1.47	0.21	0.42	0.61	2.72
2013	1.53	0.22	0.46	0.61	2.82
2014	1.54	0.23	0.48	0.61	2.86
2015	1.59	0.25	0.47	0.61	2.92
2016	1.51	0.27	0.47	0.61	2.85
2017	1.55	0.28	0.47	0.61	2.91
2018	1.56	0.30	0.48	0.61	2.95

Note: N = nitrogen. 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, because 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 and fellmongers, are based on the outputs obtained by SCS Wetherill Environmental (unpublished) for the years up to 2001. From 2002, all wastewater from the tanneries is accounted for in domestic wastewater because all tanneries now discharge to the municipal wastewater system, however, some fellmongers still use aerobic treatment (Cardno, unpublished).

Nitrous oxide emissions from wastewater for the leather and skins industry are based on the outputs obtained by SCS Wetherill Environmental (unpublished), reducing in 2002 to account for the tanneries that discharge entirely to the domestic system.

Choice of methods

Methods used to calculate emissions from wastewater handling are summarised in table 7.5.5. For domestic wastewater, the TOW is estimated for each individual treatment plant based on the population in the district served by the plant.

Table 7.5.5 Methods used for calculating emissions from wastewater treatment

Emissions category	Gas	Comment	Method	Source
Domestic wastewater (5.D.1)	CH_4		Tier 2	SCS Wetherill Environmental (unpublished), Beca Infrastructure Ltd (unpublished)
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)

Emissions category	Gas	Comment	Method	Source
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 was 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. There is one wastewater treatment plant in Auckland that serves about a million people, however, direct N_2O emissions are not estimated because they are likely to be small.

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 7.5.6 provides a summary of the parameter values applied for estimating CH_4 emissions from domestic wastewater treatment.

Table 7.5.6 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 0.032–0.043	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	New Zealand specific	SCS Wetherill Environmental (unpublished)

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 CH_4 correction factor ranging between 0.032 and 0.043. Table 7.5.2 shows the aggregate CH_4 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 about 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 7.5.7 provides a summary of the parameter values applied for estimating N_2O emissions from domestic and commercial wastewater treatment.

Table 7.5.7 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 7.5.8 provides a summary of the parameter values applied for estimating CH_4 emissions from wastewater treatment by the meat industry.

Table 7.5.8 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	0.036 (meat excluding poultry) 0.0344 (poultry)	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 7.5.9 provides a summary of the parameter values applied for estimating CH_4 emissions from wastewater treatment by the pulp and paper industry.

Table 7.5.9 **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 7.5.10 provides a summary of the parameter values applied for estimating CH_4 emissions from wastewater treatment by the wine industry.

Table 7.5.10 **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 7.5.11 provides a summary of the parameter values applied for estimating CH_4 emissions from wastewater treatment by the wool scouring industry.

Table 7.5.11 **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 7.5.12 provides a summary of the parameter values applied for estimating CH_4 emissions from wastewater treatment by the leather and skins industry.

Table 7.5.12 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 7.5.13 provides a summary of the parameter values applied for estimating N_2O emissions from wastewater treatment by the meat 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)	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 7.5.14 provides a summary of the parameter values applied for estimating N_2O emissions from wastewater treatment by the dairy processing industry.

Table 7.5.14 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 7.5.15 provides a summary of the parameter values applied for estimating N_2O emissions from wastewater treatment by the leather and skins industry.

Table 7.5.15 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 7.5.16 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_2O)	±10	±90

Methane emissions

The parameters used to estimate CH_4 emissions from domestic and industrial wastewater (table 7.5.16) 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_2O 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

Emissions from domestic wastewater have been recalculated for the entire time series due to:

- changes in the CH_4 calculations for domestic wastewater (5.D.1) that have increased emissions by 6.9 kt CO_2-e (4.9 per cent) in 1990 and reduced them by 2.8 kt CO_2-e (1.8 per cent) in 2017. The main change was driven by an update on the population growth rate based on new revised data released by Statistics New Zealand
- recalculation of emissions from industrial wastewater for some industries resulting in small changes and that have cumulatively reduced emissions by a maximum of 0.1 kt CO_2-e (–0.1 per cent) in 2017 due to activity data for meat and poultry (5.D.2) being adjusted based on revised data released by the Ministry for Primary Industries and the Poultry Industry Association of New Zealand.

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: Tokelau (other) sector

New Zealand ratified the United Nations Framework Convention on Climate Change (the Convention) on 16 September 1993 and the Paris Agreement on 4 October 2016. The extension to Tokelau (as of 13 November 2017) of New Zealand's ratification of the Convention and of the Paris Agreement requires New Zealand to include Tokelau in the obligatory climate change reporting managed by the Ministry for the Environment. Delivering on this obligation, *inter alia*, means that New Zealand's national greenhouse gas (GHG) inventory shall include the GHG estimates from Tokelau.

Roles and responsibilities in relation to GHG inventory reporting from Tokelau are outlined below in section 8.1.3. The information on quality assurance and quality control planning for Tokelau is included in annex 6.

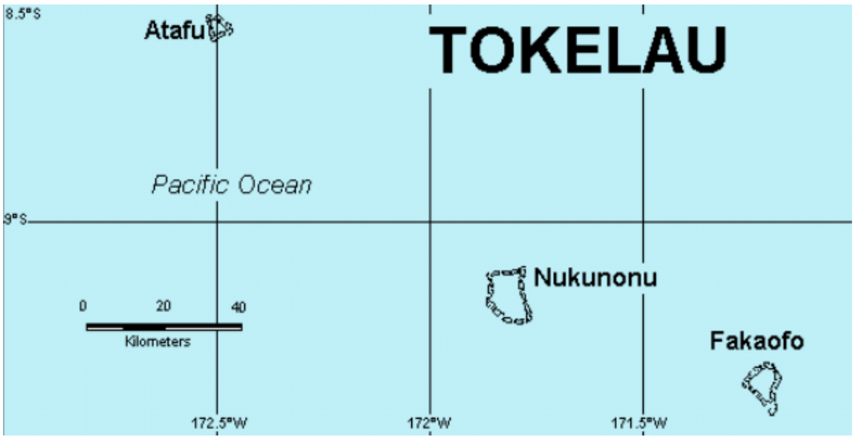
To maintain transparency of the inventory and visibility of the GHG data from Tokelau, common reporting format (CRF) sector 6 (Other) is used to present emissions from Tokelau by sector in the CRF. This chapter provides an overview of Tokelau's economy and industry. It includes information on emissions trends and methodological notes in regard to the GHG emissions from Tokelau.

8.1 Tokelau overview

8.1.1 Geography

Tokelau is a non-self-governing territory[69] of New Zealand. Tokelau is made up of three small coral atolls: Atafu, Nukunonu and Fakaofo. The total land area is only 12 square kilometres within an Exclusive Economic Zone (EEZ) covering 318,990 square kilometres. Atafu, the 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 8.1.1).

Figure 8.1.1 Map of Tokelau



69 In the United Nations Charter (UN, 1945), a non-self-governing territory is defined as a territory "whose people have not yet attained a full measure of self-government". Tokelau has been on the United Nations list of non-self-governing territories since 1946, following the declaration of the intention by New Zealand to transmit information on the Tokelau Islands under Article 73e of the United Nations Charter.

From Atafu in the north to Fakaofo in the south, Tokelau extends for less than 200 kilometres. The atolls are approximately 3 to 5 metres above sea level. The maximum width of any island (motu) on the atolls' rims is 200 metres. Tokelau is therefore particularly vulnerable to natural hazards.

8.1.2 Censuses of dwellings and population

Tokelauans have New Zealand citizenship.

Tokelau has carried out independent censuses of population and dwellings five yearly; detailed data are available on the number of inhabitants, livestock, housing, and some appliances. Only the past three censuses in Tokelau (2006, 2011 and 2016) have used a precise definition of who is a '*de jure* Tokelauan' and the people who actually lived in Tokelau during the census night (*de facto* population). Tokelau's *de jure* population on 18 September 2016 was 1,499 people. The *de facto* population has been used for the purposes of estimating emissions, which was 1,285 people in 2016. From 1990 to 2016, the population was fluctuating but generally declined for both *de facto* and *de jure* measures. For reference, about 15,000 people identify as Tokelauan that live overseas, mainly in New Zealand.

Tokelau has a subsistence economy in which sharing (inati) plays an important and significant role. The inhabitants are dependent on local natural resources, particularly fishing in the lagoon and deep sea, growing coconuts and breadfruit, and keeping domesticated pigs and chickens.

The coral atolls provide a subsistence lifestyle within a fragile environment. Tokelau imports most of its foodstuffs from Samoa. The Tokelau economy is dependent on two major financial resources: economic and administrative assistance from New Zealand, and income from fisheries. New Zealand provides general budget support to help the delivery of essential services, consistent with its constitutional and United Nations Charter obligations.

8.1.3 Emissions reporting

Due to the small land size area, small population and absence of industry, Tokelau has a very low impact on the environment and emits very small amounts of GHGs. The total amount of all GHGs from all sources in Tokelau in 2018 was 3.62 kilotonnes carbon dioxide equivalent (kt CO_2-e), contributing approximately 0.005 per cent to New Zealand's gross emissions, which is below the significance threshold as defined in paragraph 37(b) of the United Nations Framework Convention on Climate Change (UNFCCC) reporting guidelines for GHG inventories (UNFCCC, 2014). The emission in Tokelau are limited to:

- carbon dioxide (CO_2) from boat engines and vehicles
- CO_2 from back-up power generators
- fluorinated gases from the use of refrigerants
- methane (CH_4) and nitrous oxide (N_2O) from livestock (pigs and poultry)
- CH_4, CO_2 and N_2O from waste.

2018

Carbon dioxide dominates emissions from Tokelau, contributing 51.7 per cent (1.87 kt CO_2-e) of its total emissions. At 1.83 kt CO_2, the Energy sector contributes 97.9 per cent of total CO_2 emissions, mostly from *Domestic navigation*; with the remaining 2.1 per cent (0.04 kt) coming from *Open burning of waste* in the Waste sector.

Methane emissions contribute 40.7 per cent (1.47 kt CO_2-e) to the total emissions from Tokelau. The Agriculture sector in Tokelau contributes 56.0 per cent of CH_4 emissions (0.82 kt CO_2-e), that mostly come from *Manure management*. A significant portion of CH_4 emissions, 17.7 per cent (0.64 kt CO_2-e), comes from the Waste sector, largely from *Solid waste disposal*. The Energy sector contributes the remaining 0.2 per cent of CH_4 emissions (0.01 kt) that mostly come from *Domestic navigation*.

Nitrous oxide emissions contribute 1.1 per cent (0.04 kt CO_2-e) to the total emissions from Tokelau. The IPPU sector contributes the largest amount of N_2O, 40.8 per cent (0.02 kt CO_2-e) of the total N_2O, from the use of metered dose inhalers. The Energy sector contributes a further 31.4 per cent (0.01 kt CO_2-e) that comes largely from domestic navigation. The Waste sector contributes the remaining 27.7 per cent of N_2O (0.01 kt CO_2-e) from open burning and wastewater treatment and discharge.

Emissions of fluorinated gases from Tokelau consist of hydrofluorocarbon (HFC) emissions only, contributing 6.5 per cent (0.23 kt CO_2-e) to the total emissions from Tokelau. These emissions are largely coming from the use of refrigerants in domestic fridges and freezers. Emissions of perfluorocarbons (PFCs), nitrogen trifluoride and sulphur hexafluoride are not occurring in Tokelau.

Figures 8.1.2 and 8.1.3 show emissions from Tokelau by gas and by sector.

Figure 8.1.2 Tokelau's emissions by gas in 2018

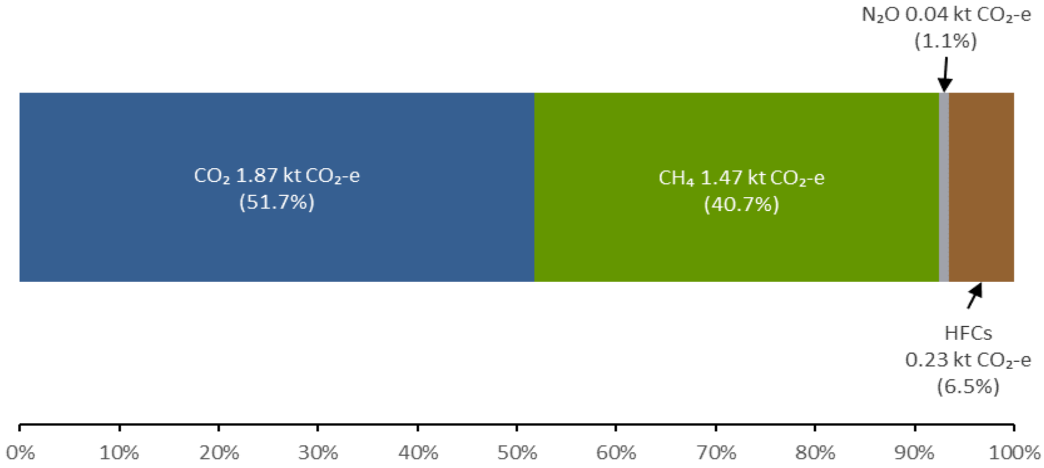
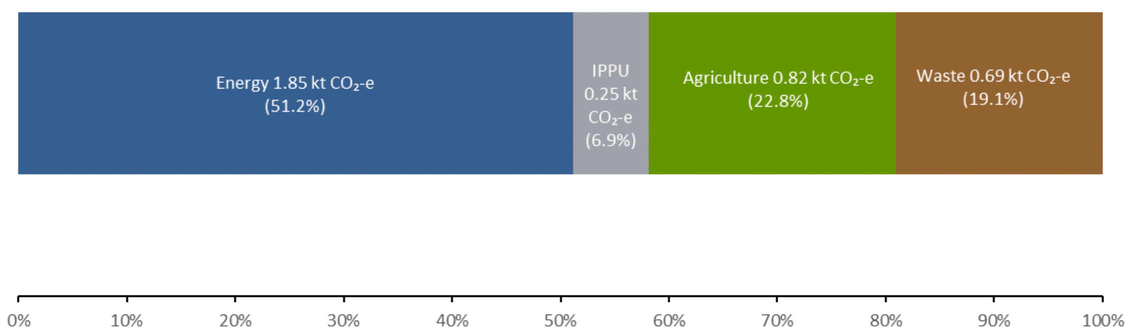


Figure 8.1.3 Tokelau's emissions by sector in 2018



1990–2018

In 1990, the total emissions from Tokelau were 3.17 kt CO_2-e. Between 1990 and 2018, the total emissions increased by 14.2 per cent (0.45 kt CO_2-e) to 3.62 kt CO_2-e (table 8.1.1). From 1990 to 2018, the average annual increase in gross emissions was 0.60 per cent.

Table 8.1.1 Gross emissions from Tokelau by gas in 1990 and 2018

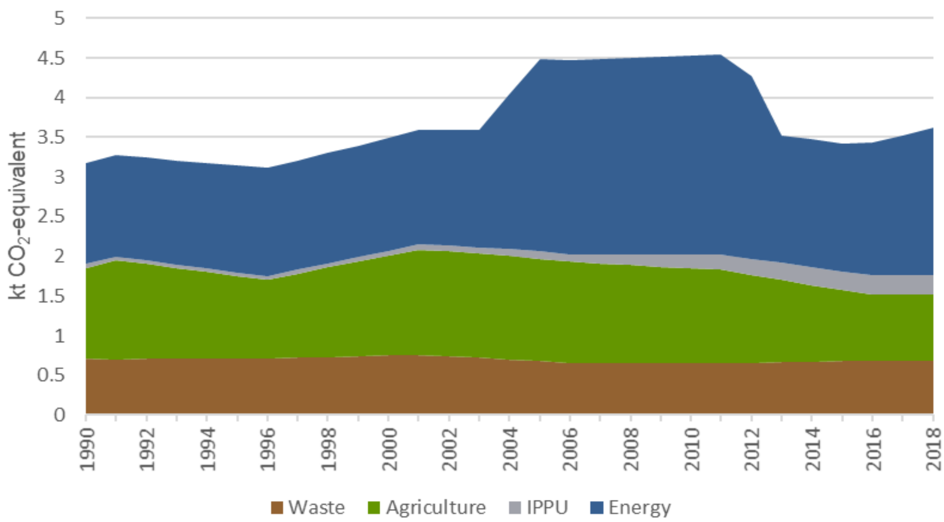
Direct greenhouse gas emissions	kt CO_2-e 1990	kt CO_2-e 2018	Change from 1990 (kt CO_2-e)	Change from 1990 (%)
CO2	1.30	1.87	0.57	44.2
CH4	1.78	1.47	–0.31	–17.5
N2O	0.09	0.04	–0.05	–53.5
HFCs	NO	0.23	0.23	NA
PFCs	NO	NO	NA	NA
SF6	NO	NO	NA	NA
NF3	NO	NO	NA	NA
Gross, all gases	**3.17**	**3.62**	**0.45**	**14.2**

Note: Emissions from LULUCF are not estimated for Tokelau. The percentage change for HFCs is not applicable (NA) because HFC production or use was not occurring (NO) in 1990. Columns may not total due to rounding. Presented percentages are calculated from unrounded values.

A significant rise, then drop (by approximately 400 per cent and 82.5 per cent, respectively) in consumption of imported petroleum products used for electricity production in Tokelau drove most of the changes in Energy emissions. This is the result of, first, the introduction of 24 hour, 7 days a week availability of electricity to households in 2004. (Before 2004, power was 'on' daily between 6 pm and 10 pm only.) Second, in 2012, a solar photovoltaics energy system was installed, once again reducing emissions. Tokelau's ownership and use of the ferry *Mataliki* in 2016 and cargo vessel *Kalopaga* in 2018 (as opposed to chartering boats) led to an increasing number of sea voyages between the atolls, which increased transport emissions. Emissions have also increased slightly from IPPU because fridges and freezers have become more common. Emissions from agriculture have decreased slightly as a result of a reduced population of pigs.

Figure 8.1.4 shows emission trends by sector for Tokelau.

Figure 8.1.4 Emissions by sector for Tokelau (kt CO_2-e) from 1990 to 2018



2017–2018

Total Tokelau emissions in 2018 were 0.10 kt CO_2-e (2.8 per cent) higher than emissions in 2017. This increase is largely the result of increases in CO_2 emissions in the *Domestic navigation* category, due to increasing shipping within Tokelau.

Key categories

Emission categories from Tokelau have been included in the key category analysis, along with all categories reported in New Zealand's inventory. None of the emission categories from Tokelau are key categories (either level or trend) in the 2020 submission.

Reporting arrangements

Including Tokelau in New Zealand's inventory reporting is a gradual process. This requires building the expert capacity and establishing connections with the various organisations and businesses in Tokelau that participate in data collection and processing. Estimates include emissions from the largest Tokelau contributors, which are the Energy, Industrial Processes and Product Use (IPPU), Agriculture and Waste sectors using Tier 1 methodologies with Intergovernmental Panel on Climate Change (IPCC) default emission factors for all reported categories (IPCC, 2006a). Improvements made for the 2020 submission include improved modelling of the energy sector and its division into electricity and transport. The Land Use, Land-Use Change and Forestry (LULUCF) sector is not estimated because there are no planted or managed forests in Tokelau and any emissions are expected to be negligible.

New Zealand and Tokelau signed a Memorandum of Understanding (MoU) on 18 January 2018 to establish the relationship between Tokelau and New Zealand regarding the governance of international climate change reporting relating to the inclusion of Tokelau in New Zealand's national inventory system. According to the MoU, both New Zealand's central inventory agency (MfE) and the Tokelau Department for Climate Change have roles in inventory reporting.

MfE will take responsibility for the following:

- coordination of communications between New Zealand and Tokelau officials, as well as communications with project consultants in New Zealand and overseas
- coordination with other New Zealand government agencies participating in the inventory production, should their consulting or advice be required for the project
- initial consultation on developing a national GHG inventory system for Tokelau, together with the relevant instructive materials, principles, protocols and procedures of Tier 1 statistics, and methodological guidance for the inventory
- technical advice on various aspects of the project regarding the subject matter, the legal background (the Convention reporting guidance), software issues, and the quality assurance and quality control (QA/QC) issues associated with the changes in the national inventory system
- final integration of the Tokelau GHG inventory component into the joint inventory submission to the Convention
- submitting the joint inventory to the Convention and coordinating communication with the Convention associated with the inventory submission and review
- publication of the joint inventory report and the CRF tables online, as well as all supplementary materials.

The Tokelau Ministry for Climate, Oceans and Resilience (MiCORE; formerly known as the Climate Change Agency) will take responsibility for the following:

- coordinating the project implementation in Tokelau by communicating with the relevant agencies, organisations and individuals involved in the GHG inventory; coordinating their efforts and delegating responsibilities to ensure that sufficient information and support are provided to those agencies, organisations and individuals to enable GHG inventory production
- providing timely advice on all cultural aspects of the project and assisting in resolving any issues associated with potential cultural issues
- ensuring that the agreed project schedule is fully complied with and the relevant timeframes are met, which includes submission of Tokelau's GHG data and information to New Zealand's national inventory compiler within the agreed timeframe
- coordinating Tokelau's efforts in activity data collection for the inventory reporting and data processing
- producing the complete set of the data tables in agreed formats, and a peer-reviewed draft of the Tokelau Annex for the inventory submission based on the 2006 IPCC guidelines and the Convention reporting guidelines, and in compliance with the Convention inventory quality principles and good practices.

Both MfE and MiCORE are responsible for adhering to the principles and protocols for producers of Tier 1 statistics.

Methodological issues

Methods and emission factors

Tokelau is making its first steps in GHG inventory reporting. Consequently, Tier 1 methodological approaches with default emission factors were used for estimating emissions from all Tokelau source categories.

Tokelau is in a different climate zone from New Zealand and has a different lifestyle and technologies. There are also differences in the scale of operations, especially in the Agriculture sector, that do not allow applying New Zealand's definition of a farm to Tokelau. For estimating emissions from Tokelau, the 2006 IPCC default emission factors for Oceania with a warm climate are used, whereas New Zealand uses default emission factors associated with a temperate climate.

The calorific values for fuels used for Tokelau are also different from those used for New Zealand because those fuels are coming from different sources. Relevant emission factors used for estimating emissions and references to the methods are included in sections 8.2 to 8.5 dedicated to the inventory sectors reported by Tokelau.

Activity data

The Tokelau National Statistics Office collects and processes activity data from Tokelau for inventory preparation. Table 8.1.2 contains the key sources of the activity data from Tokelau used in the GHG inventory.

Table 8.1.2 Key sources for activity data in Tokelau

Item	Name/abbreviation	Explanation	Used where
1	Census	Tokelau Census of Population and Dwellings 2006, 2011, 2016 www.tinyurl.com/TokelauCensus	Census data; interpolations for populations of people and livestock; solid and water waste disposal (flush toilets), number of private aluminium boats/outboard motors, home appliances
2	Archives NZ	Archives New Zealand, Wellington	Historic Census records going back to 1951, at five-year intervals (TNSO collation and analysis)
3	HIES	Tokelau Household Income and Expenditure Survey 2015/16 www.tinyurl.com/TokelauHIES	Population and dwellings data supplementary to Census, in partnership with Pacific Community (SPC)
4	SNZ, StatsNZ	Statistics New Zealand, Wellington www.stats.govt.nz	Major partner in collection, analysis and publication of Tokelau Census data
5	TNSO	Tokelau National Statistics Office, Apia www.tokelau.org.nz/Stats.html	Joint collection, analysis and publication of Tokelau Census data
6	DoE	Tokelau Department of Energy	Estimate of diesel use for 24/7 power generation in 2004, plus before and after installation of solar in July–September 2012 (personal communication Mr Robin Pene, DoE director)
7	PPS	Petroleum Product Supplies Ltd Apia	Fuel prices and volumes supplied for shipping and on-atoll use of diesel, petrol, kerosene and lubricant oil
8	DoF	Tokelau Department of Finance	Paid invoices and payment records to PPS, Origin, and on-atoll stores
9	2018 vehicle survey	Photo survey of Tokelau motorised vehicles on-atoll, August–December 2018	Personal communication JA Jasperse, TNSO
10	Origin	Origin Energy Samoa Ltd, Apia	Prices and volumes supplied for on-atoll use of propane for cooking
11	PCTrade-Green	Excel version of PCTrade package developed by StatsNZ, Christchurch	Used for analysing cargo shipping manifests, providing number of return voyages Apia–Tokelau over time, imports of goods, and exports of recyclables to date (2014 – June 2019 data available)
12	DoH	Tokelau Department of Health	Anecdotal information on inhalers, laser gas, fire extinguishers
13	TSS	Tokelau Department of Transport and Support Services, Apia	Cargo shipping manifests for analysis of imports of all goods, and export of recyclables
14	2014 Imports study	Jasperse JA. 2016. *Analysis of 2014 imports into Tokelau from Samoa, Part 2: Stores' invoices reconciled with cargo manifests, and quality of life implications*, Tokelau National Statistics Office	Various Energy and Waste sector data, for example, calculation of per capita protein consumption www.tokelau.org.nz/Bulletin/September+2016/2014+imports+final.html
15	EDNRE	Tokelau Department of Economic Development, Natural Resources and Environment	Anecdotal information on waste disposal and export
16	PCRAFI	Koroisamanunu, Iva; Joy Papao; Mereoni Ketewai; and Arieta Sokota: *Mission Preliminary Report (Fieldwork undertaken from 8 August – 2 September 2013). SOPAC technical note (PR193)*, May 2014. Water and Sanitation Programme and Disaster Reduction Programme. Applied Geoscience and Technology Division (SOPAC), Suva, Fiji Islands	Information on drinking water, wastewater and sanitation
17	MiCORE	Tokelau Ministry of Climate, Oceans and Resilience	Partner to Memorandum of Understanding (MOU) with New Zealand Ministry for the Environment (MfE) leading to the present inventory

Tokelau's data and information in the Common Reporting Format Reporter

Because methodologies for estimating emissions in Tokelau and New Zealand differ, adding Tokelau and New Zealand's activity data at a category level and estimating combined emissions within each category is currently not possible. Due to limitations of the CRF software, including specific categories for Tokelau consistently across all inventory sectors was also not possible.

Tokelau requested New Zealand's inventory team to maintain visibility of the data from Tokelau in the CRF, so that Tokelau officials could use them for other reporting and policy purposes. Reporting Tokelau as a different inventory sector provides this visibility.

To maintain transparency of the inventory and visibility of the GHG data from Tokelau, CRF sector 6 (Other) was used to present emissions from Tokelau by sector in the CRF. Currently, the CRF Reporter does not allow creating subcategory levels in sector 6. To avoid double counting in the CRF, the data and information are aggregated for each of the Energy, IPPU, Agriculture and Waste sectors. In addition, annex 7 includes detailed tables with time series from 1990 to 2018 for each category reported for Tokelau. For comparability reasons, these tables are in the same format as the CRF entry tables, and the table names follow the CRF naming convention for emission categories. The executive summary and chapter 2 of the National Inventory Report include comparisons between Tokelau and New Zealand's emissions.

8.1.4 Recalculation and improvements

There have been significant changes and improvements in the Tokelau emission estimates since the 2019 submission. These improvements are a combination of refinements as a result of historic information coming to hand (for electricity in 2004 and for transport 1990–2014); improved fuel calculations (based on a full year rather than 9 months; estimated number of roundtrips Apia–Tokelau during 1990–2014; average fuel use per trip), and the correction of errors including to the number of pigs. Improvements and recalculations made for the Tokelau sector have resulted in a 13 per cent (–0.5 kt CO_2-e) decrease in emissions in 1990 and a 22.9 per cent (0.7 kt CO_2-e) increase in emissions in 2017.

The previously reported decrease of on-island diesel use of 80 per cent in 2012 negated an increase of 400 per cent in 2004, when Tokelau households and the public sector got access to electric power for 24 hours, 7 days a week.

Several other improvements and minor corrections have been made to all categories, in the process of automating the calculation of Tokelau's emissions using a model developed in an Excel spreadsheet, based on the IPPC reporting framework. It requires annual updates of input data such as fuel purchases, number of voyages (roundtrips Apia–Tokelau, inter-island trips) and 5 yearly Census data to be input into a single worksheet.

Further details on improvements can be found under methodological issues for each category as relevant and also in chapter 10.

8.2 Energy emissions from Tokelau (CRF 6. Tokelau_1)

The total amount of all energy emissions in Tokelau in 2018 was 1.85 kt CO_2-e. They contributed 51.2 per cent to the total emissions from Tokelau and 0.0023 per cent to New Zealand's gross emissions including Tokelau. The categories that contributed to the energy emissions were *Domestic navigation*, *Public electricity and heat production* and *Residential*.

For all energy categories, emissions were estimated using the Tier 1 methodological approach with default emission factors (2006 IPCC Guidelines). Default uncertainty values from the 2006 IPCC Guidelines were used for all estimates (IPCC, 2006a).

Tokelau predominately uses diesel oil and petrol (for back-up generators and transport) and liquefied petroleum gas (LPG) (for cooking purposes). Solid fuels are not used in Tokelau, other than on a small scale and are not estimated, for instance the husks of locally grown coconuts.

Miniscule amounts of other fossil fuels are imported by Tokelau, which are assumed to be combusted. These include gasoline, other kerosene and lubricants: their combustion is accounted for under *Gas/diesel oil*. Approximately 40 drums (205-litre capacity per drum) of oil were imported annually, the bulk of which was presumably mixed with petrol and used for 'outboard' engines and combusted, with only a few drums used to lubricate cars and other engines. Because none of those were recycled, combustion is the most likely outcome. Oil changes carried out in Apia during servicing of the ferries *Mataliki* and *Kalopaga*, after every five roundtrips, has the more significant amount of waste oil remaining in Samoa not Tokelau.

For consistency with New Zealand's Energy sector, gross calorific values were used for Energy sector estimates from Tokelau. The relevant default IPCC emission factors were adjusted accordingly by multiplying them by 0.95 and 0.90 for liquid and gaseous fuels respectively.

8.2.1 Reference approach

The reference approach calculations were performed according to the methods described in the 2006 IPCC Guidelines. Equations 6.1 – 6.4 from chapter 6 in the 2006 IPCC Guidelines were used for calculating apparent consumption and estimating emissions (IPCC, 2006a). Gross calorific values were used for all calculations.

In 2018, total CO_2 emissions from the reference approach in Tokelau were 1.80 kt, which differs from the sectoral approach by 2.0 per cent. The average variation of differences between the sectoral and reference approach across the time series was 2.2 per cent.

8.2.2 International bunker fuels

There is no fuel usage for international navigation in Tokelau, because only domestic voyages are made by Tokelau's vessels. All international voyages use the fuel loaded in Samoa and there is no refuelling in Tokelau for the international routes.

There is no aviation transportation (domestic or international) in Tokelau.

8.2.3 Stationary combustion: *Public electricity and heat production*

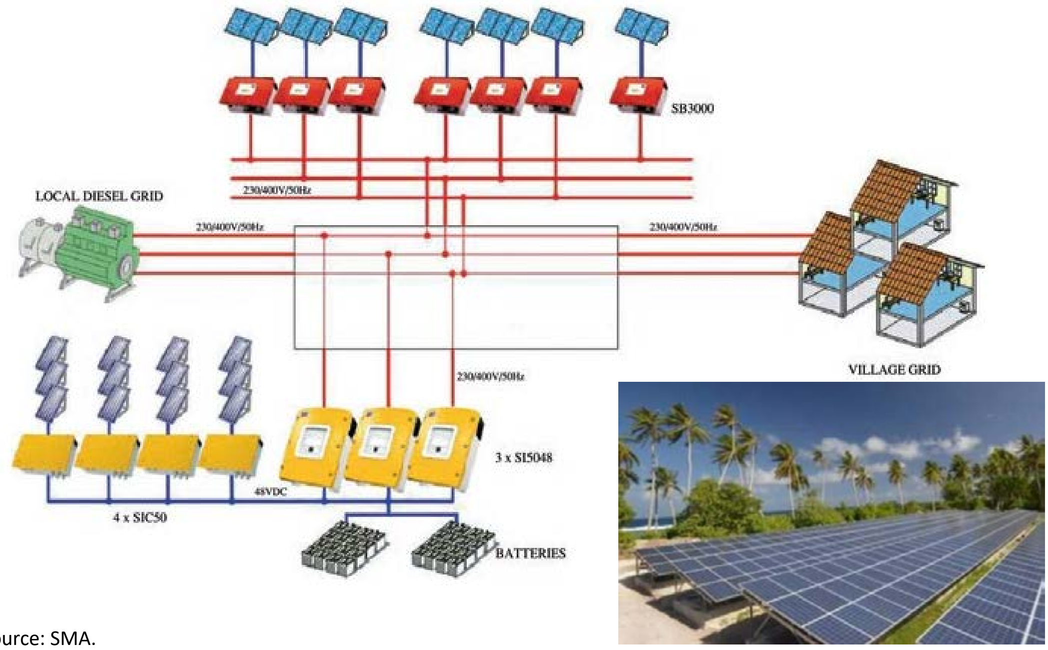
Description

The main source of emissions from this category in Tokelau includes electricity production from back-up generators. Tokelau uses liquid fossil fuels for these purposes, therefore, only liquid fossil fuels are reported under the *Energy industries* category.

Like most small Pacific Island nations and territories, Tokelau has been heavily reliant on the importation of fossil fuels for energy generation. Imports increased significantly in 2004, when electric power became available for households 24 hours a day, 7 days a week. Prior to that, electricity was generated between 6 pm and 10 pm daily, and annual diesel consumption was about 20 per cent of the value in 2011.

In 2012, the installation of about 4,000 solar panels across the three atolls was completed (figure 8.2.1). Each of the three Tokelau atolls now has a significant array of solar panels that cater for almost all local electric power requirements.

Figure 8.2.1 Cluster block diagram for Tokelau's solar project



Source: SMA.

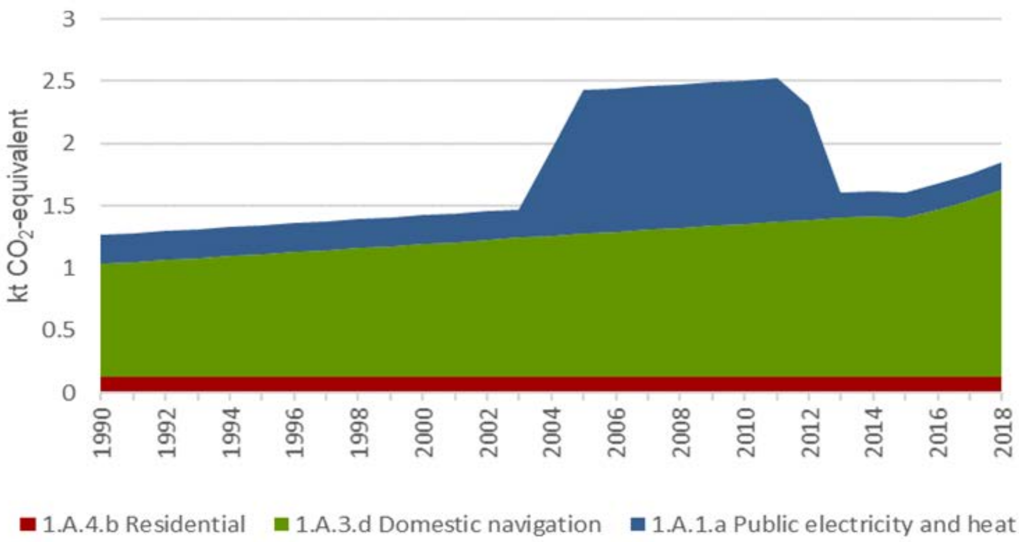
Tokelau received wide media coverage for their solar installation.[70] The change resulted in a significant drop in liquid fossil fuels consumption for electricity production in Tokelau (by approximately 82.5 per cent) and a decrease of the total energy emissions by 36.4 per cent between 2011 and 2013. However, some power generation using diesel remains necessary as backup, during prolonged cloudy spells, and to meet the steadily increasing demand from households and the public sector.

Energy emission trends

For Tokelau, the *Public electricity and heat production* category accounted for 100 per cent of the emissions from the *Energy industries* category for the entire time series. In 2018, emissions from the *Energy industries* category totalled 0.22 kt CO_2-e (12.0 per cent of all energy emissions from Tokelau). Emissions from energy industries have decreased by 0.01 kt CO_2-e (–3.7 per cent) since the 1990 level of 0.23 kt CO_2-e. Effectively, the increase in emissions due to continuously generating electricity from fossil fuels in 2004 was offset by the decrease due to installing the solar units in 2012 and solar energy dominating the electricity production sources in Tokelau since then. Figure 8.2.2. shows emission trends in the Energy sector by category for Tokelau.

[70] See www.mfat.govt.nz/assets/Aid-Prog-docs/Evaluations/2016/June-2016/Tokelau-Programme-Evaluation-Final-2015.pdf.

Figure 8.2.2 Energy emissions by category for Tokelau (kt CO_2-e) from 1990 to 2018



Methodological issues

Activity data

The sources of activity data for the energy industries category are included in table 8.1.2. Key sources for the energy supply and consumption data are the Tokelau Department of Energy and Petroleum Product Supplies Ltd (Apia, Samoa). The Tokelau Department of Energy provided background data for estimates of diesel use for power generation around the time that electricity changed to 24 hours a day, 7 days a week in Tokelau in 2004; as well as before and after installation of solar panels in July–September 2012 and participated in making those estimates (item 6 in table 8.1.2). Based on purchase information, the Department of Finance provided the data on fuel prices and volumes supplied by Petroleum Product Supplies Ltd for shipping and on-atoll use of diesel, petrol, kerosene and lubricant oil (item 7 in table 8.1.2). Only liquid fossil fuels (gas and diesel oil) are used in the *Energy industry* category. Because all fossil fuels in Tokelau are imported, activity data are mostly obtained from analysis of invoices from main suppliers and shipping manifests.

In the course of the analysis of available data, big discrepancies were discovered between the fuel imports shown on shipping manifests and the more reliable financial fuel purchase data that were audited. Detailed data were not available for each year from 1990–2018 (or data reliability was not high), so a trade-off was made between data granularity and data quality. The biggest and most reliably recorded data variations are reflected in the time series. For electricity generation, there were two important events: first, the changeover to 24 hour, 7 days a week electricity in 2004 (from 6 pm to 10 pm prior to that, at an estimated 20 per cent of the 24 hour, 7 days a week value in 2011); and second the introduction of solar power in 2012. The change during 2012 due to the installation of solar units was reasonably well documented and, therefore, reflected in the time series. For the years 1990–2003, 2005–11 and 2013–15, the activity data (and corresponding emissions) are shown as constant.

The diesel data for 2013–17 were entirely based on analysis during 2018 of fuel purchases, when, for the first time, Tokelau's analysts could clearly separate out the diesel used on-atoll and for shipping. The methodology for such analyses that was put in place for the 2019 inventory submission was refined for the 2020 submission and can be re-used in the coming years.

Diesel is delivered on 'dangerous goods sailings' to Tokelau in the ships' fuel bunkers. On arrival, it is pumped into drums on a barge, for shipping to shore and transport to the generator sites.

Methods and emission factors

A Tier 1 method was applied for estimating emissions from the *Public electricity and heat production* category. The method required the data on the amount of LPG combusted in the source category and a default emissions factor from table 2.2, section 2.3.2.1, volume 2, of the 2006 IPCC Guidelines. Default emission factors from the 2006 IPCC Guidelines were converted from net calorific values to gross calorific values using the Organisation for Economic Co-operation and Development (OECD) and International Energy Agency (IEA) assumptions to make these conversions:

Gross Emission Factor (liquid fuels) = 0.95 x Net Emission Factor

Equations 2.1 and 2.2 from section 2.3.1.1 in the 2006 IPCC Guidelines were used for estimating emissions (IPCC, 2006a).

Uncertainties

For this submission, it was not possible to develop Tokelau-specific uncertainty values, so, for emission factors, default uncertainty values provided in the 2006 IPCC Guidelines were used for CO_2 and CH_4 (for public power, co-generation and district heating) (IPCC, 2006a). Because no quantified default emissions factor is provided for N_2O, New Zealand's emission factor uncertainty across the Energy sector for N_2O was used for this category.

For activity data, due to the lack of detailed pre-2018 fuel data, an upper level of the default uncertainty range for the main activity electricity and heat production associated with data extrapolation from the 2006 IPCC Guidelines was applied (IPCC, 2006a). Table 8.2.1 shows the use of uncertainties for the *Energy industries* category.

Table 8.2.1 Uncertainties for the Energy industries category

Gas	Fuel type	Activity data (AD) uncertainty (%)	Emission factor (EF) uncertainty (%)	Source
CO_2	Liquid fuels	10	±7	AD: page 2.41, IPCC, 2006a (table 2.15) EF: page 2.38, IPCC, 2006a
CH_4	Liquid fuels	10	±50.0	AD: page 2.41, IPCC, 2006a (table 2.15) EF: page 2.38, IPCC, 2006a (table 2.12)
N_2O	Liquid fuels	10	±50.0	AD: page 2.41, IPCC, 2006a (table 2.15) EF: New Zealand's value is used (table 3.3.1, chapter 3)

Source-specific recalculations

The estimates for energy have undergone significant improvement since analysis done for the 2019 submission. This is because fuel purchase data for the Tokelau ships are now available for the entirety of 2018 (as opposed to 9 months extrapolated to a year in the 2019 submission). Prior to 2018, a significant number of voyages were made by Samoan charter boats, whose fuel use is commercially sensitive and not readily obtainable.

However, the 2018 data allowed calculation of the average use of diesel, about 16,000 litres per voyage, with the balance of purchased diesel being used on-atoll. Accurate annual voyage numbers are available from 2014 onwards; prior voyage numbers were calculated from an estimate of two trips per month during the 1990s (confirmed by the Director of Transport and Support Services, Mr Simona Mei), then interpolated to the 2014 value.

The 2020 submission also better separates emissions from electricity generation and transport and helps to identify the reasons for the major changes (major power changes in 2004 and 2012, and the increase in shipping over the time series).

Source-specific planned improvements

There are no planned improvements for energy industries. Some areas identified for possible improvements are better monitoring of diesel fuel actually landing on-atoll at the power sites, and clearly separating fuel used for power generation from heavy machinery and diesel-powered vehicles. Data on gross electricity production from oil were acquired late 2019 from the International Renewable Energy Agency; these could provide additional detail and verification of energy use back to their base year 2000. Future imports of coolants (ethylene glycol) for the solar power plant may also be considered in future.

8.2.4 Stationary combustion: *Other sectors – residential*

Description

There is no significant industry in Tokelau. All energy is used by domestic and fishing activities and community–government activities (for example, meeting halls and offices, village freezers, building projects, stevedoring). Therefore, emissions associated with energy consumption in Tokelau (except fishing) are included in the category *Other sectors – Residential*. The small amount of emissions associated with communal activities is not easily distinguishable from those coming from residential activities and so are therefore included under the *Other sectors – Residential* category. Emissions from fishing are included under *Domestic navigation*. This is because it is very difficult to distinguish fuel use for fishing from fuel use for domestic navigation in Tokelau, because families use the same boats for both purposes.

According to the 2016 Tokelau Census, every household has a fridge and a freezer, and some households now have air conditioning. Most households (over 60 per cent) also own a washing machine, a computer and a television. The United Nations Development Programme, under the Tokelau Energy Sector Support Project, has recently funded a programme of replacing old inefficient fridges and freezers with new ones. Home appliances in Tokelau mainly use the power provided by solar units, supplemented as needed by back-up diesel-powered generators. Emissions associated with the use of diesel-powered back-up generators are included under the *Energy industries* category.

Gas cooking using imported natural gas (LPG) 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). Associated activity data and emissions are included under *Other sectors – Residential* category.

In 2018, emissions from the *Other sectors – Residential* category were 0.13 kt CO_2-e (6.8 per cent of all energy emissions from Tokelau).

Methodological issues

Activity data

The sources of activity data for the *Other sectors – Residential* category are included in table 8.1.2. The key data source for the category is paid invoices from Origin Energy Samoa Ltd (Apia, Samoa) providing prices and volumes of propane supplied on-atoll for cooking.

Methods and emission factors

A Tier 1 method was applied for estimating emissions from the *Other sectors – Residential* category. The method required the data on the amount of LPG combusted in the source category and a default emissions factor from table 2.2, section 2.3.2.1, volume 2 of the 2006 IPCC Guidelines. Default emission factors from the 2006 IPCC Guidelines were converted from net calorific values to gross calorific values using the OECD and IEA assumptions to make these conversions:

Gross Emission Factor (gaseous fuels) = 0.90 x Net Emission Factor

Equations 2.1 and 2.2 from section 2.3.1.1 in the 2006 IPCC Guidelines were used for estimating emissions (IPCC, 2006a).

Uncertainties

For this submission, it was not possible to develop Tokelau-specific uncertainty values, so for emission factors, default uncertainty values provided in the 2006 IPCC Guidelines were used for CO_2 and CH_4 (for commercial, institutional and residential combustion) (IPCC, 2006a). Because no quantified default emissions factor is provided for N_2O, New Zealand's emission factor uncertainty across the Energy sector for N_2O was used for this category.

For activity data, a mid-range level of default uncertainty range associated with data extrapolation from the 2006 IPCC Guidelines was applied (IPCC, 2006a). Table 8.2.2 shows the use of uncertainties for the *Other sectors – Residential* category.

Table 8.2.2 Uncertainties for the *Other sectors – Residential* category

Gas	Fuel type	Activity data (AD) uncertainty (%)	Emission factor (EF) uncertainty (%)	Source
CO_2	Liquid fuels	20	±7	AD: page 2.41, IPCC, 2006a (table 2.15) EF: page 2.38, IPCC, 2006a
CH_4	Liquid fuels	20	±50.0	AD: page 2.41, IPCC, 2006a (table 2.15) EF: page 2.38, IPCC, 2006a (table 2.12)
N_2O	Liquid fuels	20	±50.0	AD: page 2.41, IPCC, 2006a (table 2.15) EF: New Zealand's value (table 3.3.1, chapter 3)

Source-specific planned improvements

There are no planned improvements for the *Other sectors – Residential* category. One area identified for possible improvement is to consider additional LPG imports purchased from Aute Gas (Apia, Samoa), for Nukunonu. However, the difference is likely to be small, compared with the current approach (where Nukunonu is taken as the average between the fuel purchases from Origin, by Atafu and Fakaofo). For future submissions, further analysis of activity data from Tokelau, to reflect year-to-year variations, will be considered as far as resources will allow.

8.2.5 Mobile combustion: *Domestic navigation*

Description

The only means of transport to and from Tokelau is by sea; there is no air transportation. All travel and supplies to Tokelau originate and terminate in Samoa, Tokelau's closest neighbour. A direct trip from any of the three atolls to the nearest port, Apia, usually takes between 26 hours and 40 hours. There are no ports and terminals in Tokelau, and no offshore anchorage is available: barges that can enter the fringe reef are used for loading and offloading ships.

The passenger ferries and cargo ships arriving from Apia (distance approximately 500 kilometres) generally visit the three atolls in succession: they are 60 kilometres and 90 kilometres apart, respectively. A round trip is about 1,300 kilometres using diesel from Apia, of which the fraction (300/1300) is included in domestic navigation within Tokelau.

Until recently, the main forms of road transport on the atolls were trucks, pick-ups, motorbikes and a range of golf carts. Some vehicles are electric, fuelled by solar energy. Solar-powered streetlights ensure safety on the roadways. The private importation of other vehicles has increased recently.

The number of petrol cars has been very small in Tokelau and in 2018 there were only about 40 cars (in addition to the vehicles above) and 30 motorbikes, with the entire network of unsealed roads being about 10 kilometres. Census 2001 and prior record only four registered cars. Aluminium boats with an outboard motor are widely used by families. Emissions from fuels used for road transport are orders of magnitude lower than from boats, and it was not possible to distinguish the small amounts of fuels used by cars from the total amount used by boats and cars. That is why emissions from road transport are included under the Domestic navigation category.

According to its 2016 census, Tokelau has 176 aluminium boats with 160 outboard motors, which use most of the imported petrol to travel within and outside the large lagoons. Most of the diesel use is by the ferries travelling to and from Samoa. Fetu o te Moana is a new search and rescue vessel that will also provide general inter-atoll transport. It was delivered early in 2019, and this is expected to increase the use of diesel within Tokelau, as will be addressed in future submissions.

For Tokelau, the category *Domestic navigation* accounted for 100 per cent of the emissions from the *Transport* category for the entire time series. In 2018, emissions from the *Domestic navigation* category totalled 1.50 kt CO_2-e (81.2 per cent of all energy emissions from Tokelau).

Methodological issues

Activity data

The sources of activity data for the *Transport* category are included in table 8.1.2. Activity data sources for the category are paid invoices from Petroleum Product Supplies Ltd (Apia, Samoa) with data on fuel prices and volumes supplied for shipping and on-atoll use: diesel, petrol, kerosene and lubricant oil (item 7 in table 8.1.2); the Tokelau Department of Finance's invoices and payment records to Petroleum Product Supplies Ltd, Origin and on-atoll stores; and a photo survey of Tokelau motorised vehicles on-atoll, August–December 2018. Additional energy data related to cargo manifests were obtained from an *Analysis of 2014 Imports into Tokelau from Samoa, Part 2: Stores' invoices reconciled with cargo manifests, and quality of life* *implications* (Tokelau National Statistics Office, 2016). Only liquid fossil fuels (gas and diesel oil) are used for fuelling Tokelau's transport.

Due to large discrepancies between different sources of raw data, reliable statistics on fuel consumption across the period 1990–2018 are not available. Some anecdotal transport data exist for the number of roundtrips Apia–Tokelau during the years 1990–2014; after this period actual records are available. Applying the statistics for fuel-use data assembled during 2018 was the best available accurate estimate and was applied for the entire time series from 1990 to 2018. The results of raw data analysis and conversion of raw data to activity data in energy units are included in annex 7, table A7.1.1.

Methods and emission factors

A Tier 1 method was applied for estimating emissions from the *Domestic navigation* category. The method required the data on the amount of fuel combusted in the source category and a default emissions factor from tables 3.5.2 (for CO_2) and 3.5.3 (for non-CO_2 gases), section 3.5.1.2, volume 2 of the 2006 IPCC Guidelines. Default emission factors from the 2006 IPCC Guidelines were converted from net calorific values to gross calorific values using the OECD and IEA assumptions to make these conversions:

Gross Emission Factor (liquid fuels) = 0.95 x Net Emission Factor

Equation 3.5.1 in section 3.5.1.1 in the 2006 IPCC Guidelines was used for estimating emissions (IPCC, 2006a).

Uncertainties

For this submission, it was not possible to develop Tokelau-specific uncertainty values, so for emission factors, default uncertainty provided in the 2006 IPCC Guidelines were used for CO_2 (for diesel) and CH_4 (upper value) (IPCC, 2006a). For N_2O, New Zealand's emissions factor uncertainty across the Energy sector for N_2O was used for this category, which is within the default uncertainty range.

For activity data, due to discrepancies between different data sources, an upper level of default uncertainty range associated with incomplete surveys from the 2006 IPCC Guidelines was applied (IPCC, 2006a). Table 8.2.3 shows the use of uncertainties for *Domestic navigation* (diesel).

Table 8.2.3 Uncertainties for the Mobile combustion category

Gas	Fuel type	Activity data (AD) uncertainty (%)	Emission factor (EF) uncertainty (%)	Source
CO_2	Liquid fuels	±50	±1.5	Section 3.5.1.7, IPCC, 2006a
CH_4	Liquid fuels	±50	±50.0	Section 3.5.1.7, IPCC, 2006a
N_2O	Liquid fuels	±50	±50.0	New Zealand's value is used (table 3.3.1, chapter 3), section 3.5.1.7, IPCC, 2006a

Source-specific planned improvements

There are no planned improvements for *Transport*. For future submissions, further analysis of activity data to reflect year-to-year variations will be considered as far as resources allow.

8.3 Emissions from Industrial Processes and Product Use in Tokelau (CRF 6. Tokelau_2)

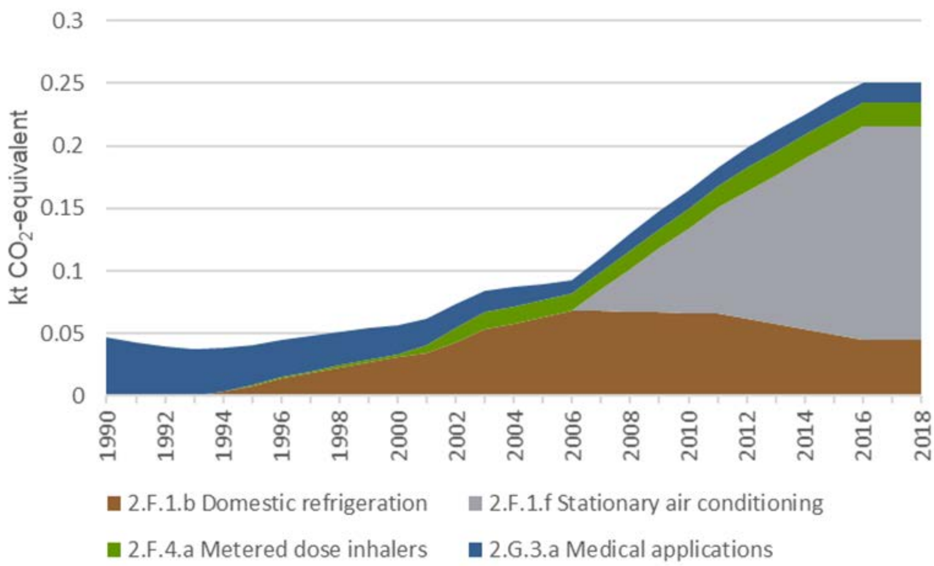
There is no significant industry in Tokelau. The emissions associated with the IPPU sector are coming from the following activities:

- use of refrigeration and air conditioning – HFCs
- use of metered dose inhalers – HFC-134a and HFC-227ea
- medical applications of N_2O.

Thus, the source categories included in this report are *Refrigeration and air conditioning* (2.F.1), *Metered dose inhalers* (2.F.4) and *Medical applications* (2.G.3).

The total amount of all IPPU emissions in Tokelau in 2018 was 0.25 kt CO_2-e. They contributed 6.9 per cent to the total emissions from Tokelau and 0.0003 per cent to New Zealand's gross emissions including Tokelau. The biggest contributor to the total IPPU HFC emissions is *Stationary air conditioning* followed by *Domestic refrigeration*, with 68.0 per cent and 17.8 per cent of IPPU emissions from Tokelau, respectively. Figure 8.3.1 shows emission trends in the IPPU sector by category for Tokelau.

Figure 8.3.1 IPPU emissions by category for Tokelau (kt CO_2-e) from 1990 to 2018



8.3.1 Emissions from Refrigeration air conditioning in Tokelau

Due to a very small number of air-conditioned vehicles in Tokelau, all emissions from this category are reported under *Stationary air conditioning* (2.F.1.f).

Because most fridge and freezer appliances are installed in households, the emissions associated with refrigeration are reported under *Domestic refrigeration* (2.F.1.b). Emissions from fridge and freezer appliances are based on the number of those appliances, however, no HFCs were used before 1994. To account for the phase-in of HFCs, it has been assumed that the proportion of appliances using HFCs increased 10 per cent per year, starting at 10 per cent of appliances in 1994 and reaching 100 per cent of appliances in 2003. This phase-in is reflected in figure 8.3.1. Emissions continue to change after 2003 due to changes in the overall number of appliances.

Source-specific planned improvements

Due to resource constraints, improvements were prioritised according to the amount of emissions contributed by each sector to the total emissions from Tokelau. Because the IPPU sector contributes only a very small amount of emissions, no improvements, except ongoing data refinement as far as resources allow, are planned for the next inventory submission.

Methodological issues

Activity data

The data for the number of appliances are sourced from:

- Tokelau Census of Population and Dwellings (2006, 2011, 2016) (item 1 in table 8.1.2) for 2006–16 data points
- Archives New Zealand (Wellington, New Zealand) for historic Census records going back to 1950, mostly at five-year intervals
- Tokelau Household Income and Expenditure Survey 2015/16 for population and dwellings data supplementary to the Census
- Tokelau Department of Health for anecdotal information on inhalers, the laser gas, and fire extinguishers
- Tokelau Department of Transport and Support Services (Apia, Samoa) for cargo shipping manifests for analysis of imports of all goods
- Statistics New Zealand (Wellington, New Zealand), which helped in the collection, analysis and publication of Tokelau Census data
- Tokelau National Statistics Office, which performed collection, analysis and publication of Tokelau Census data with subsequent data collation and analyses.

The raw data on the number of appliances used in Tokelau obtained from the Census have been further analysed and cross-referenced through other sources (for example, see those listed in table 8.1.2); available data points are increased by equal increments between the data collection years.

Method and emission factors

For both air conditioning and domestic refrigeration, the following assumptions were made:

- no chemicals are imported or exported, except as a component of each sort of equipment; emissions are assumed to be derived from current equipment only
- HFCs and PFCs are neither produced nor exported or disposed of in Tokelau. Therefore, the net consumption is essentially equal to imports
- a composite default emissions factor of 15 per cent can be used for estimating emissions for both domestic refrigeration and stationary air conditioning
- assumed percentage of new equipment exported (0 per cent for Tokelau)
- assumed percentage of new equipment imported (100 per cent for Tokelau)
- the HFC emissions from stationary air conditioning did not occur until 2006
- the HFC emissions from domestic refrigeration did not occur until 1994 (the same as for New Zealand)

- the average charge for fridges and freezers has the upper limit of the mass of gas of 0.5 kilograms (from table 7.9 of the 2006 IPCC Guidelines (IPCC, 2006b))
- the average charge for an air conditioning unit is 10 kilograms (default value from 2006 IPCC Guidelines (IPCC, 2006a))
- for air conditioning units and fridges and freezers, Tokelau reports the same set of HFCs as New Zealand. These are HFC-32, HFC-125 and HFC-134a for air conditioning units, and HFC-134a for refrigeration.

The Tier 1a method from the 2006 IPCC Guidelines is used for estimating emissions from category 2.F.1 in Tokelau (IPCC, 2006b). In this method, activity data are represented by a net consumption value (equation 7.1 from volume 3 of the 2006 IPCC Guidelines), while the emission factor is a value that represents a weighted average of several parameters as shown in table 7.9 from volume 3 of the 2006 IPCC guidelines below (IPCC, 2006b).

The calculation formula for net consumption within the Tier 1a method is as follows.

EQUATION 7.1
CALCULATION OF NET CONSUMPTION OF A CHEMICAL IN A SPECIFIC APPLICATION

$$\textit{Net Consumption} = \textit{Production} + \textit{Imports} - \textit{Exports} - \textit{Destruction}$$

Net consumption values for each HFC are then used to calculate annual emissions for applications exhibiting prompt emissions as follows.

EQUATION 7.2A
CALCULATION OF EMISSIONS OF A CHEMICAL FROM A SPECIFIC APPLICATION

$$\textit{Annual Emissions} = \textit{Net Consumption} \bullet \textit{Composite EF}$$

Uncertainties

Because a composite emission factor was used for both 2.F.1.b and 2.F.1.f categories, the uncertainty level for activity data is assumed at a level of ±32 per cent. The 2006 IPCC Guidelines (IPCC, 2006b) do not provide a default value for the composite factors, so New Zealand’s value for uncertainties to describe refrigerant leakages was used for both categories.

Table 8.3.1 Uncertainties for Refrigeration and air conditioning category

Gas	Subcategory	Activity data uncertainty (%)	Emission factor uncertainty (%)	Source
HFCs	2.F.1	±32	NA	New Zealand’s value is used (table 4.7.3, chapter 4)

8.3.2 Emissions from Metered dose inhalers and Medical applications in Tokelau

The *Metered dose inhalers* (2.F.4.a) and *Medical applications* categories (2.G.3.a) contribute negligible amounts of HFC (HFC-134a and HFC-227ea) and N_2O emissions respectively to the total emissions from the IPPU sector in Tokelau. They are reported by scaling New Zealand’s emissions from the same category by Tokelau’s *de facto* population.

In 2018, the *Metered dose inhalers* category contributes 7.6 per cent to total IPPU emissions from Tokelau, and the category *Medical applications* contributes 6.5 per cent to the sector, which amounts to 0.04 kt CO_2-e from both categories.

Methodological issues

Activity data

Only anecdotal evidence associated with the activity data for both categories is available from Tokelau's Department of Health (see table 8.1.2). They are reported by scaling New Zealand's emissions from the same category by Tokelau's *de facto* population for the entire time series to each gas.

Method and emission factors

For both categories, effectively a Tier 1a methodology was applied because New Zealand applied this methodology for estimating emissions from 2.F.4 and Tier 1 methodology for 2.G.3 (IPCC, 2006b). In addition, population ratios from population statistics of Tokelau and New Zealand have been calculated for each year of the time series except the years when the emissions were not occurring (until 1995 for HFC-134a and 2011 for HFC-227ea).

For 2.F.4.a, a product life factor of 100 per cent was used. For 2.G.3a, it was assumed that N_2O is used as a propellant in pressurised and aerosol food products, none of the N_2O is reacted during the process and all of the N_2O is emitted to the atmosphere. Therefore, a default emission factor of 1.0 was used for this category.

Uncertainty

For consistency of reporting, the same uncertainty values for categories 2.G.3.a were applied for Tokelau and New Zealand (see section 4.8.1 in chapter 4 and table 8.3.2). The same uncertainty for 2.F.1 has also been applied to 2.F.4 in the absence of further information.

Table 8.3.2 Uncertainty in emissions from other product manufacture and use

Category	Uncertainty in activity data (%)	Uncertainty in emission factors
N_2O from other product uses	±30 (2002–12) ±5 (2013–18) For simplicity, an average of 15% has been used	NA

8.4 Emissions from the Agriculture sector in Tokelau (CRF 6. Tokelau_3)

Fish, not locally produced plants or animals, are the most important food source in Tokelau. The low fertility of the coral soil means few crops are supported. Food needs are not met by locally grown produce and are heavily supplemented by imports.

Cultivated food crops are 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*), pumpkin (*Cucurbita* sp.) and coconut (*Cocos nucifera*).

There is a small amount of subsistence agriculture 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 'fala' (*Pandanus odoratissimus*) for traditional crafts (mats, hats, fans).

A recent United Nations Development Programme-sponsored project for the establishment of keyhole gardens[71] by Tokelau youth has been abandoned.

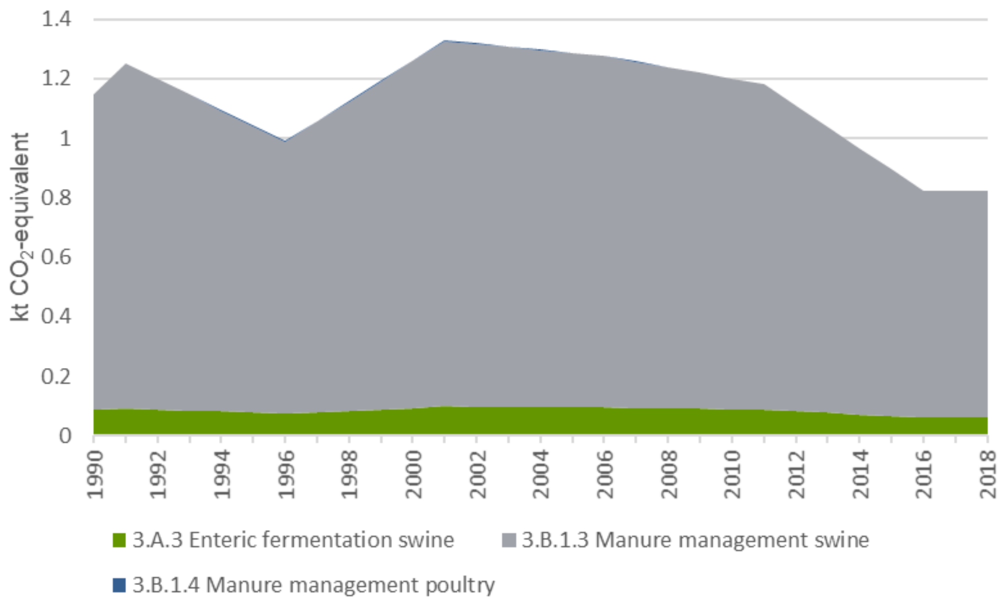
There is no industrial-scale farming in Tokelau. Tokelau atolls do not have any large agricultural and horticultural development that would fall under New Zealand's definition of a farm. There are no cows, sheep or deer, with agricultural livestock represented by small numbers of pen-kept pigs and free-range chickens only.

There is also no pasture in Tokelau and no managed agricultural soils, therefore emissions from the *Direct N_2O emissions from managed soils* and *Indirect N_2O emissions from managed soils* categories are discounted and reported as NO (not occurring).

This submission includes agricultural emissions from Tokelau associated with enteric fermentation and manure management from swine and poultry.

Total emissions from the Agriculture sector in Tokelau amount to 0.82 kt CO_2-e, making this sector the second biggest emitter in Tokelau: 22.8 per cent of the total emissions from Tokelau and 0.001 per cent of New Zealand's gross emissions. Figure 8.3.1 shows emission trends in the Agriculture sector by category for Tokelau.

Figure 8.3.2 Agriculture emissions by category for Tokelau (kt CO_2-e) from 1990 to 2018



Source-specific planned improvements

There are no planned improvements for agriculture. For future submissions, further analysis of historical activity data, to reflect year-to-year variations, will be considered as far as resources allow.

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[71] A keyhole garden is a small (approximately 2.5 metre diameter) circular raised garden with a keyhole-shaped indentation on one side. Moisture and nutrients flow from an active compost pile placed in the centre of a round plant bed.

8.4.1 Emissions from Enteric fermentation in Tokelau

The only domestic farm animals kept are pigs (in community pens) and chickens (free range) (table 8.4.1). There is the potential of generating energy from the piggery waste and reducing the effluent pollution of the lagoon.

Table 8.4.1 Number of livestock in Tokelau (2016)

Atoll	Households	Pigs	Chickens
Atafu	88	742	270
Fakaofo	85	419	50
Nukunonu	83	536	305
Tokelau	256	1,697	625

Because the 2006 IPCC Guidelines do not provide a default emission factor for enteric fermentation for poultry, this category is reported as NE (not estimated) (paragraph 37(b), footnote 6 of the UNFCCC reporting guidelines) (UNFCCC, 2014). Therefore, only swine (pigs) are included under the *Enteric fermentation* (3.A.3) category.

The *Enteric fermentation – Swine* category contributes 7.5 per cent to the total Agriculture emissions in Tokelau, and amounts to 0.06 kt CO_2-e.

Methodological issues

Activity data

Animal population figures were obtained from the Tokelau Census data (see table 8.1.2). The animal population between the census years is calculated by equal increments between the data collection points, to obtain the average animal population (AAP) per year.

An average pig weight of 80 kilograms is used.

Methods and emission factors

Tier 1 methodology with a default emission factor of 1.5 kg CH_4/head/year from table 10.10, volume 4 of the 2006 IPCC Guidelines was used for calculating emissions from this category (IPCC, 2006c). Tokelau's allocation by climate zone is 100 per cent to a warm climate.

The following equation was used for calculating emissions from swine (pigs).

$$\text{Emissions (kt } CH_4\text{)} = \text{AAP (Swine)}*1.5\ [\text{kg } CH_4 \text{ head}^{-1}\text{year}^{-1}]/10^6[\text{kg/kt}]$$

Uncertainty

Section 10.2.3 (volume 4) of the 2006 IPCC Guidelines states that the uncertainty associated with animal populations will vary widely depending on the source, but should be known within ±20 per cent (IPCC, 2006c). The default emission factor uncertainty is ±30 per cent to 50 per cent (default mid-range is ±40 per cent).

For this category, the default uncertainty value of ±20 per cent for activity data and an upper range default emission factor uncertainty of ±50 per cent were used.

8.4.2 Emissions from Manure management in Tokelau

The 2006 IPCC Guidelines provide default emission factors for *Manure management* (3.B.1) for both swine and poultry, therefore, both animal types are included in reporting from this category (IPCC, 2006c).

Manure management – Swine contributes 92.4 per cent to the total agriculture emissions in Tokelau, and amounts to 0.76 kt CO_2-e. *Manure management – poultry* is negligible (0.0005 kt CO_2-e).

Methodological issues

Activity data

The activity data entries for *Manure management* are exactly the same as for *Enteric fermentation* (see section 8.4.1).

The assumption is that all poultry are dry layers.

Methods and emission factors

A Tier 1 methodology with default emission factors provided in table 10.15, volume 4 of the 2006 IPCC Guidelines were used for estimating emissions from the *Manure management* category. The Tier 1 method is based on animal population data and does not require distinguishing between different manure management systems. Equation 10.22 from volume 4 of the 2006 IPCC Guidelines was applied in conjunction with the default emission factors from table 10.14, volume 4 of 2006 IPCC Guidelines for Oceania/warm climate. These are 18.5 kg CH_4/head/year for swine and 0.03 kg CH_4/head/year for poultry (IPCC, 2006c).

Uncertainty

Default uncertainty values for activity data and emission factors were used for this category. Section 10.2.3 in volume 4 of the 2006 IPCC Guidelines states that the uncertainty associated with populations will vary widely depending on the source, but should be known within $\pm$20 per cent (IPCC, 2006c). The default emissions factor uncertainty for *Manure management* is $\pm$30 per cent.

8.5 Emissions from the Waste sector in Tokelau (CRF 6 Tokelau_5)

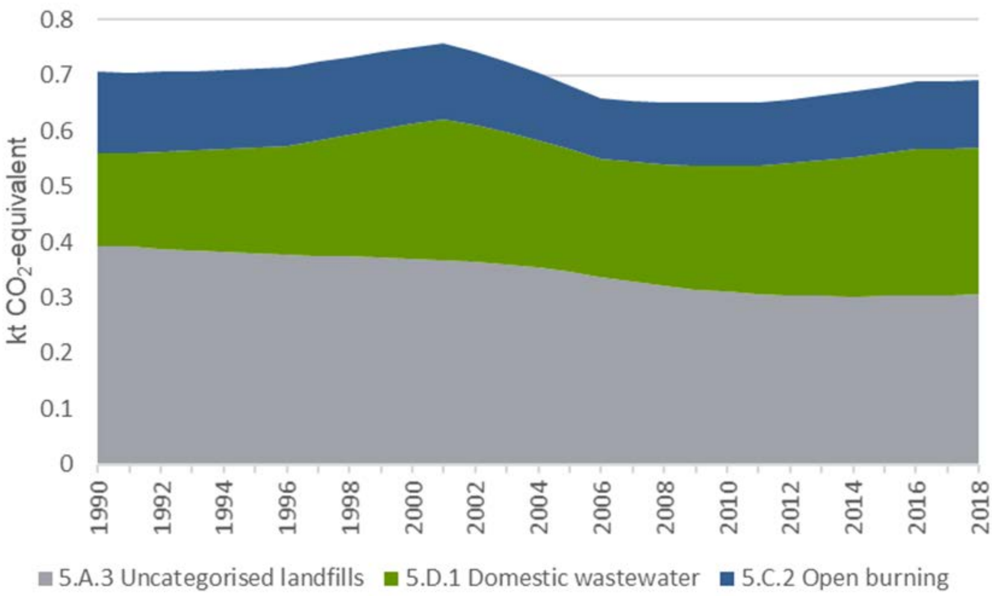
The total amount of all Waste sector emissions in Tokelau in 2018 was 0.69 kt CO_2-e, making the Waste sector the third-biggest emitter in Tokelau. The Waste sector contributed 19.1 per cent to the total emissions from Tokelau and 0.0009 per cent to New Zealand's gross emissions including Tokelau. The sources of emissions in the Waste sector in Tokelau are the *Solid waste disposal*, *Wastewater treatment and discharge*, and *Incineration and open burning of waste* contributing 44.2 per cent, 38.2 per cent and 17.6 per cent, respectively, to the total emissions from the Waste sector in Tokelau.

The raw data related to the Waste sector were obtained from multiple sources (see items 1 to 5, 11 and 13 to 16 in table 8.1.2). The data were compiled, analysed and processed by the Tokelau National Statistics Office to produce activity data. The human population data are used as a driver for estimates in all of the Waste categories.

Emissions from all categories reported in the Waste sector for Tokelau were estimated using a Tier 1 methodological approach (IPCC, 2006d).

Figure 8.5.1 shows emission trends in the Waste sector by category for Tokelau.

Figure 8.5.1 Waste sector emissions by category for Tokelau (kt CO_2-e) from 1990 to 2018



Source-specific recalculations

A correction has been made to the original, now outdated, assumption about the ratio of septic tank–sea discharge for the *Domestic wastewater* category. For this, 5 yearly Census data was used and interpolated linearly between the data points. Instead of the *de jure* residential population (which includes Tokelauan public servants and their families working and living in Apia), the *de facto* Census night population is used as a more accurate indicator of contributors to waste production on-atoll.

Source-specific planned improvements

There are no planned improvements for the waste sector. Possible improvements in the Waste sector will focus on ongoing data refinement as far as resources allow.

8.5.1 Emissions from Solid waste disposal in Tokelau

According to the 2016 Tokelau Census, most household rubbish is collected by village workers. 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. Most of the collected rubbish is either burned on the reef or buried in centralised areas of the islands. Exceptions are the 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 Apia under a memorandum of understanding with a Samoan company.[72]

[72] 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).

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. There are no dedicated categorised landfills in Tokelau, therefore, solid waste disposal is reported for uncategorised landfills only.

The *Solid waste disposal* category contributes 44.2 per cent to the total Waste emissions in Tokelau, which amounts to 0.31 kt CO_2-e.

Methodological issues

Activity data

- The total amount of solid waste is based on the 2006 IPCC default 690 kg/person/year for Oceania (IPCC, 2006d). This is likely to be an overestimate, however, a country-specific value is not available.
- Solid waste is assumed to be half buried and the other half burned. As above, this does not account for exported solid waste or organic waste fed to pigs and will be an overestimate.
- The composition of solid waste for the landfill calculations is based on the 2006 IPCC default (67.5 per cent food, 6 per cent paper/cardboard, 2.5 per cent wood, and the remaining 24 per cent is 'inert') (IPCC, 2006d). This does not take into account the food waste that is fed to animals or used for composting and gardens, nor data on waste composition, such as disposable nappies, and will likely be an overestimate overall.

Methods and emission factors

A Tier 1 methodology has been applied to estimate emissions from this category. The Tier 1 approach is to use all default values. It is assumed that 50 per cent of waste is buried (landfilled) and the other 50 per cent is burned. Any amounts of waste shipped offshore are additional and are not counted. Table 8.5.1 sums up the information about parameters used for calculating emissions from this category.

Table 8.5.1 Summary of parameters for uncategorised landfills in Tokelau

Parameter	Values	Source	Reference
Bulk MSW DOC(kt C/kt waste)	0.14	IPCC default	IPCC, 2006d (worksheets for SWDS)
k-value	0.17	IPCC default	Table 3.2, IPCC, 2006d
Methane correction factor	0.6	IPCC default	Table 3.1, IPCC, 2006d
Oxidation factor	0 per cent	IPCC default	Table 3.2, IPCC, 2006d
Starting year	1950	IPCC default	Section 3.6, p 3.24, IPCC, 2006d
Delay time	6 months	IPCC default	Section 3.2.3, p 3.19, IPCC, 2006d
Fraction of DOC that decomposes	0.5	IPCC default	Section 3.2.3, p 3.13, IPCC, 2006d
Fraction of CH_4 in gas	0.5	IPCC default	Section 3.2.3, p 3.15, IPCC, 2006d
Amount of waste per person per year	690 kg	IPCC default for Oceania	Annex 2A.1, IPCC, 2006d
Amount of waste landfilled	50 per cent	Assumption	

Note: MSW = municipal waste disposal; DOC = degradable organic carbon; SWDS = solid waste disposable sites.

Uncertainty

The same uncertainty data for uncategorised landfills were used for Tokelau and New Zealand (table 7.2.9, chapter 7 of the NIR; for methodological notes, refer to the uncertainties for the *Solid waste* category, section 7.2.3, chapter 7 of the NIR and table 8.5.2).

Table 8.5.2 Uncertainty in emissions from the Solid waste disposal category

Emissions category	Uncertainty in activity data (%)	Uncertainty in emission factors (%)
Uncategorised landfills	±140	±40

8.5.2 Emissions from Open burning and incineration in Tokelau

Because there are no major incineration facilities in Tokelau, all emissions associated with waste burning are reported under the *Open burning* category. Carbon dioxide, CH_4 and N_2O are reported in this category.

The composition of solid waste for CO_2 from open burning is the same as for landfills, except that the 24 per cent 'inert' is considered to be 'other inert' for open burning purposes (and not disaggregated into glass, metal, plastic and so on). Keeping the 24 per cent in 'other inert' is likely to result in an overestimate.

The emission factors for open burning of solid waste for CH_4 and N_2O are the IPCC defaults for municipal solid waste and are based on a generic waste composition. It is not clear if this will over- or under-estimate emissions.

The category *Open burning and incineration* contributes 17.6 per cent to the total Waste sector emissions in Tokelau, which amounts to 0.12 kt CO_2-e.

Methodological issues

Activity data

The calculations are based on Tokelau's population data and assume that 50 per cent of the waste is landfilled and the other 50 per cent is burned. This information is reported as 'non-biogenic' open burning, because only fossil carbon is reported, and the emission factors for CH_4 and N_2O are for municipal solid waste, which does not distinguish biogenic and non-biogenic wastes.

Methods and emission factors

A Tier 1 methodology with default 2006 IPCC parameters was used for calculating emissions from this category.

The emission factor for CO_2 was the weighted average of calculated factors from table 8.5.3 and a 58 per cent oxidation factor for open burning. For other gases, the following 2006 IPCC default emission factors were used: for CH_4, the default emission factor for municipal solid waste in section 5.4.2 (6,500 kg CH_4/gigagrams (Gg) wet waste); for N_2O, the default emission factor for open burning of municipal solid waste from table 5.6 (150 kg N_2O/Gg dry waste) (IPCC, 2006d). Converted waste volume to dry weight by using dry matter conversion was calculated for CO_2 (56.1 per cent). Table 8.5.3 shows waste type and the composition data based on default 2006 IPCC parameters used in estimating emissions from 5.C.2.

Table 8.5.3 Composition data and carbon content used for estimating emissions from 5.C.2

<table>
<tr><th>Waste type</th><th>Landfill composition (%)</th><th>CO2 incineration composition (%)</th><th>Dry matter (%)</th><th>Total carbon (%)</th><th>Fossil carbon (%)</th></tr>
<tr><td>Paper/card</td><td colspan="2">6.0</td><td>90</td><td>43</td><td>1</td></tr>
<tr><td>Textiles</td><td colspan="2">0</td><td>80</td><td>50</td><td>20</td></tr>
<tr><td>Food waste</td><td colspan="2">67.5</td><td>40</td><td>38</td><td>0</td></tr>
<tr><td>Wood</td><td colspan="2">2.5</td><td>85</td><td>50</td><td>0</td></tr>
<tr><td>Garden and park waste</td><td colspan="2">0</td><td>40</td><td>49</td><td>0</td></tr>
<tr><td>Nappies</td><td colspan="2">0</td><td>40</td><td>70</td><td>10</td></tr>
<tr><td>Rubber and leather</td><td rowspan="5">24.0 (‘inert’)</td><td>0</td><td>84</td><td>67</td><td>20</td></tr>
<tr><td>Plastics</td><td>0</td><td>100</td><td>75</td><td>100</td></tr>
<tr><td>Metal</td><td>0</td><td>100</td><td>NA</td><td>NA</td></tr>
<tr><td>Glass</td><td>0</td><td>100</td><td>NA</td><td>NA</td></tr>
<tr><td>Other, inert</td><td>24.0</td><td>90</td><td>3</td><td>100</td></tr>
<tr><td colspan="3">Calculated weighted average</td><td>56.13</td><td>30.20</td><td>24.06</td></tr>
</table>

Percentages in table 8.5.3 are defaults from table 2.3 and table 2.4 of volume 5, 2006 IPCC Guidelines (IPCC, 2006d).

An assumption was made that ‘inert’ waste for landfills is classified entirely as ‘other inert’ waste for incineration (the impact of this assumption is that emissions are slightly higher than distributing the 24 per cent over the various inert types due to the high fossil carbon percentage).

Uncertainty

The same uncertainty data for open burning of waste were used for Tokelau and New Zealand (table 7.4.6, chapter 7; for methodological notes, refer to uncertainties in emissions from incineration and open burning, section 7.4.3, chapter 7).

Table 8.5.4 Uncertainty in emissions from open burning for Tokelau.

Emissions category	Uncertainty in activity data (%)	Uncertainty in emission factors (%)
Waste open burning (CO_2)	±50	±40
Waste open burning (CH_4)	±50	±100
Waste open burning (N_2O)	±50	±100

8.5.3 Emissions from Wastewater treatment and discharge in Tokelau

In the absence of industrial plants in Tokelau, all emissions associated with wastewater treatment and discharge are reported under the *Domestic wastewater* category (5.D.1). The category uses the same population values as in the *Solid waste disposal* and *Open burning of Waste categories* (see above). The category includes emissions of CH_4 and N_2O.

The *Domestic wastewater* category contributes 38.2 per cent to the total of Waste sector emissions from Tokelau, which amounts to 0.26 kt CO_2-e.

Methodological issues

A Tier 1 methodology with the 2006 IPCC default emission factors (except the protein consumption value) for all gases was applied for estimating emissions from this category.

Assumptions for estimating CH_4 emissions from wastewater:

- 60 grams biochemical oxygen demand (BOD) per person per day (as for Canada, Europe, Russia and Oceania), which calculates as 21.9 kg/person/year
- for population, the same time series as in categories 5.A.3 and 5.C was used
- despite having no wastewater collection system, a correction factor for industrial BOD discharged in sewers of 1.25 is used (default for collected systems) to account for any industrial and commercial activity in Tokelau, such as fishing. No other estimates of industrial wastewater are made (effectively 5.D.2 *Industrial wastewater* is 'IE' (included elsewhere) and included in 5.D.1 *Domestic wastewater*)
- in 2016, most Tokelauans had access to a private toilet in their homes using septic tanks: 72.9 per cent of private occupied dwellings had an indoor flush toilet, and 21.6 per cent of dwellings had an outdoor flush toilet. Atafu had the highest proportion of dwellings with an indoor toilet (87.4 per cent), and Nukunonu had the highest proportion of households with an outdoor toilet (34.9 per cent) (Census 2016, similar to values for 2011 and 2006). The percentage of open water toilets gradually reduced from 65 per cent of dwellings in 1991 to nil by 2016.

Table 8.5.5 sums up default parameters used for estimating CH_4 emissions for Tokelau wastewater treatment. The default BOD correction factor for collected systems is used to account for industrial and commercial water, because there is no separate estimate.

Table 8.5.5 Parameters for estimating methane emissions for Tokelau wastewater treatment

Parameter	Value	Source	Reference
Methane correction factors			
Septic system	0.5	IPCC default	Table 6.3, section 6.2.2.2, IPCC, 2006d
Sea, river and lake discharge	0.1	IPCC default	Table 6.3, section 6.2.2.2, IPCC, 2006d
Weighted average methane correction factor	0.233	Calculated	
Maximum methane producing capacity ($kg\ CH_4/kg$ BOD)	0.6	IPCC default	Table 6.2, section 6.2.2.2, IPCC, 2006d
Biochemical oxygen demand (BOD) (kg BOD/person/year)	21.9	IPCC default for Oceania	IPCC, 2006d (worksheets for SWDS)
Correction factor for BOD	1.25	IPCC default for collected systems	Section 6.2.2.3, p 6.14, IPCC, 2006d

Note: SWDS = solid waste disposable sites.

Assumptions for estimating nitrous oxide emissions from wastewater

Table 8.5.6 shows the parameters used to calculate N_2O emissions from wastewater. It is assumed that septic tanks do not discharge to the sea and that only the population using open water toilets contributes to the nitrogen in effluent calculation.

Protein consumption of 32.45 kg/person/year has been calculated based on known consumption compiled by the Tokelau National Statistics Office. The fraction of industrial and commercial co-discharged protein accounts for any commercial and industrial activities because there is no separate estimate.

Table 8.5.6 Parameter values applied for estimating nitrous oxide emissions for Tokelau wastewater treatment

Parameter	Value	Source	Reference
Per capita protein consumption (kg/person/year)	32.448	Tokelau specific	Developed by Tokelau's National Statistics Office using imports data (see table 8.1.2)
Fraction of nitrogen in protein	0.16	IPCC default	Section 6.3.1.3, p 6.25, IPCC, 2006d
Fraction of non-consumed protein	1.1	IPCC default for developing countries	Table 6.11, section 6.3.3, IPCC, 2006d
Fraction of industrial and commercial co-discharged protein	1.25	IPCC default	Table 6.11, section 6.3.3, IPCC, 2006d
Nitrogen removed with sludge (kg)	0	IPCC default	Section 6.3.1.3, p 6.25, IPCC, 2006d
Emission factor	0.005	IPCC default	Table 6.11, section 6.3.3, IPCC, 2006d
Emissions from wastewater treatment plants	0	IPCC default	IPCC (2006d)

Uncertainty

The same uncertainty data for domestic wastewater were used for Tokelau and New Zealand (table 7.5.16, chapter 7; for methodological notes, refer to uncertainties in emissions from domestic wastewater in section 7.5.3, chapter 7). Table 8.5.7 shows uncertainties for activity data and emission factors used by Tokelau for domestic wastewater.

Table 8.5.7 Uncertainty in emissions from domestic wastewater

Emissions category	Uncertainty in activity data (%)	Uncertainty in emission factors (%)
Domestic and industrial wastewater (CH_4)	±10	±40
Domestic and industrial wastewater (N_2O)	±10	±90

Chapter 8: References

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).

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Chapter 9: Indirect carbon dioxide and nitrous oxide emissions

New Zealand elected not to report indirect carbon dioxide emissions in its 2020 Inventory submission. Indirect nitrous oxide emissions are reported in the Agriculture sector (chapter 5) and the Land Use, Land-Use Change and Forestry sector (chapter 6).

Chapter 10: Recalculations and improvements

This chapter summarises the recalculations and improvements made to the inventory following the 2019 submission. Further details on the recalculations and improvements for each sector are provided in chapters 3 to 8 and 11.

Recalculations of estimates reported in the previous submission of the inventory are due to improvements in:

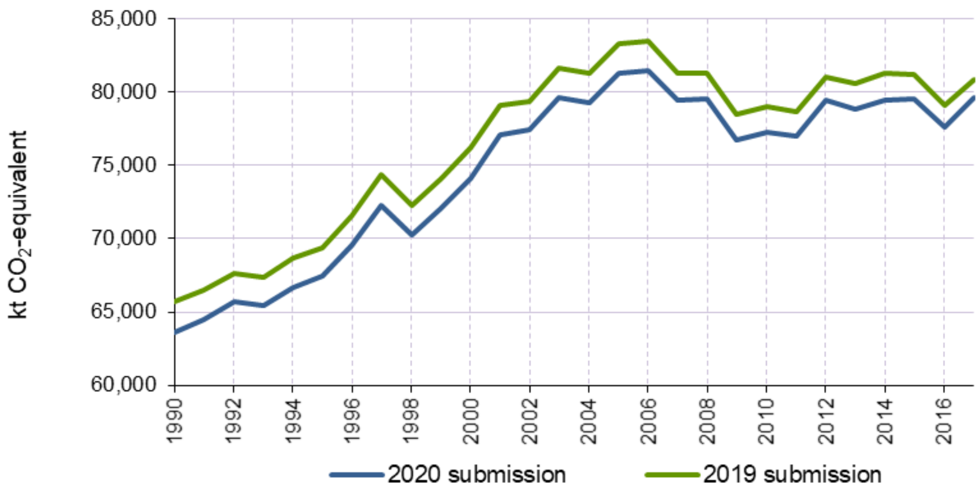
- activity data
- parameters for estimating emissions including emission factors
- methodology, including correcting errors
- activity data and emission factors that became available for certain sources that were previously reported as 'NE' (not estimated) because of insufficient data.

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 3.2 per cent (2,077.3 kilotonnes carbon dioxide equivalent (kt CO_2-e) decrease in gross emissions in 1990 and a 1.5 per cent (1,212.6 kt CO_2-e) decrease for the 2017 year. The greatest contribution to the decrease in estimates for gross emissions across the time series came from the Agriculture sector. This decrease is mainly the result of new nitrous oxide (N_2O) emission factors in the Agriculture sector for livestock excreta, to more accurately reflect emissions resulting from different kinds of livestock grazed on flat land and sloped land.

Figure 10.1.1 Effect of recalculations on New Zealand's gross greenhouse gas emissions from 1990 to 2017



The effect of recalculations on net emissions, which includes the Land Use, Land-Use Change and Forestry (LULUCF) sector, was an increase of 2.3 per cent (787.4 kt CO_2-e) in net emissions in 1990 and an increase of 0.1 per cent (35.7 kt CO_2-e) in net emissions in 2017. This is the combined effect of a number of changes made to gross emissions and changes in LULUCF sector emissions mainly due to a revised analysis of the pre-1990 natural forest plot data.

The following tables show for each sector the category that had the largest recalculations across the time series. Table 10.1.1 shows the recalculations that increased emissions estimates the most for each sector.

Table 10.1.1 Largest recalculations in each sector that increase emissions estimates

Sector	Category with the largest increase in estimated emissions across the entire time series	Largest single increase in emissions estimates for the category (kt CO_2-e)	Year of the largest increase in estimated emissions
Energy	1.A.3.b.ii Road transportation – Diesel oil	152.7	2017
IPPU	2.F.1.a Commercial refrigeration – HFC-143a	69.7	2017
Agriculture	3.A.2 Enteric fermentation – Sheep	103.1	2017
LULUCF	4.A.1.i Forest land remaining forest land – Pre-1990 planted forest	4,590.5	2013
Waste	5.D.1 Domestic Wastewater	6.2	1990
Tokelau	6.Tokelau_3 – Agriculture	1.3	2001

Table 10.1.2 shows the recalculations that reduced emissions estimates the most for each sector.

Table 10.1.2 Largest recalculations in each sector that reduce emissions estimates

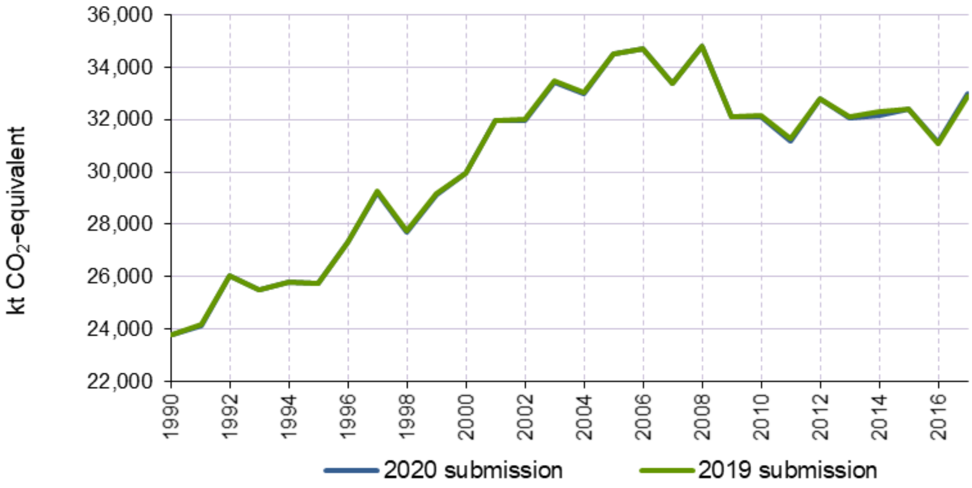
Sector	Category with the largest reduction in estimated emissions across the entire time series	Largest single reduction in emissions estimates for the category (kt CO_2-e)	Year of the largest decrease in estimated emissions
Energy	1.A.4.a Other sectors – Commercial/institutional	–320.8	2017
IPPU	2.F.1.a Commercial refrigeration – HFC-143a	–46.5	2015
Agriculture	3.D.1.3 Direct N_2O emissions from managed soils – Urine and dung deposited by grazing animals	–2,211.6	1990
LULUCF	4.A.1.i Forest land remaining forest land – Pre-1990 natural forest converted to pre-1990 planted forest	–2,888.0	1996
Waste	5.A.2 Solid waste disposal – Unmanaged waste disposal sites	–31.5	2016
Tokelau	6.Tokelau_1 – Energy	–1.6	1991

The following sections detail the effect of and reasons for recalculations for each sector and summarise the improvements that resulted in the recalculations.

10.1.1 Energy

Changes to activity data in the Energy sector have resulted in a 0.03 per cent (7.3 kt CO_2-e) decrease in energy emissions in 1990 and a 0.4 per cent (128.0 kt CO_2-e) increase in energy emissions in 2017 (figure 10.1.2). No significant improvements or methodological changes have occurred for the Energy sector. However, changes in the level of emissions estimates have occurred due to small changes in the activity data. Energy activity data for the years 1990–2017 have been updated according to the latest energy statistics published by the Ministry of Business, Innovation and Employment.

Figure 10.1.2 Effect of changes to activity data on New Zealand's Energy sector from 1990 to 2017



10.1.2 Industrial Processes and Product Use

Improvements and recalculations made in the Industrial Processes and Product Use (IPPU) sector have resulted in no change for 1990 and a 3.1 per cent increase in emissions for 2017 (152.8 kt CO_2-e) (figure 10.1.3). The increase in 2017 is due to a recalculation of emissions from the *Refrigeration and air conditioning* category. The increase in reported emissions for 2017 is almost entirely due to a reassessment of the annual amounts of refrigerant gases imported, stockpiled by importers, sold and used. This changed the timing of these emissions.

Other recalculations and improvements, as detailed in table 10.1.3, have had only a minor effect.

Figure 10.1.3 Effect of recalculations on the IPPU sector from 1990 to 2017

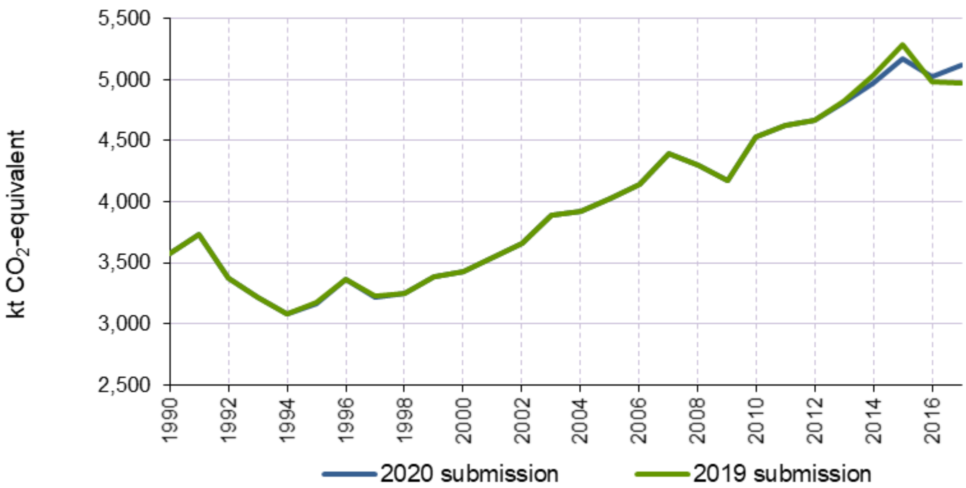


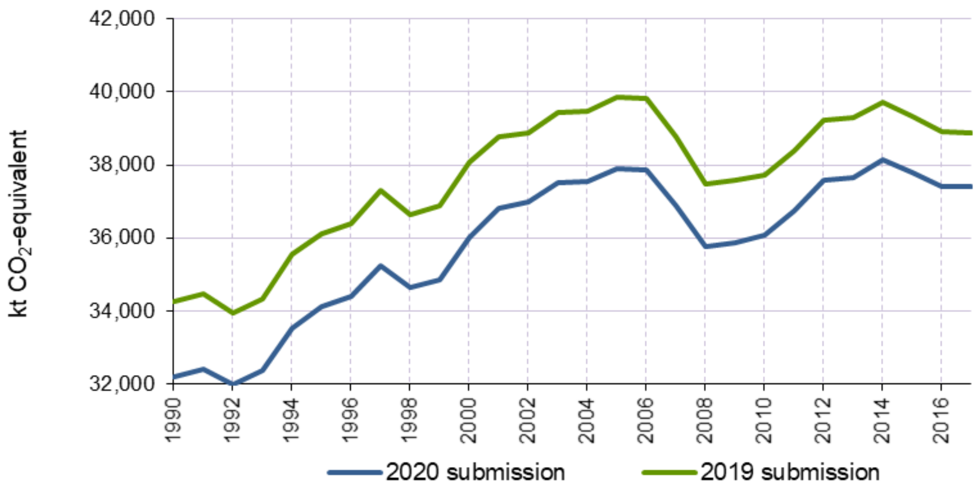
Table 10.1.3 Explanations and justifications for recalculations in the IPPU sector

Explanation of recalculation	Underpinning UNFCCC principle	Additional justification
A minor error was corrected in the *Foam blowing agents* category, adding a small amount to 2017 emissions.	Accuracy	Correction of an error.
Emissions in the *Refrigeration and air conditioning* category for 2013–17 have been recalculated because of a reassessment of stockpiling by importers and users from time to time, and because of a reassessment of some import data by Statistics New Zealand.	Accuracy	Stockpiling of hydrofluorocarbons (HFCs) in response to price changes and simply because of single large shipments from time to time can create an issue for accurate allocation of emissions over time.
Import data on vehicles for 2017 have been revised by Statistics New Zealand but the effect on emissions from mobile air conditioning has been insignificant.	Accuracy	
Emissions of sulphur hexafluoride used in electrical equipment have been recalculated for 2011 on the basis of improved data provided by users.	Accuracy	

10.1.3 Agriculture

Improvements and recalculations made to the Agriculture sector in the 2020 inventory submission have resulted in a 6.1 per cent (2,075.3 kt CO_2-e) decrease in estimated agricultural emissions in 1990 and a 3.8 per cent (1,462.0 kt CO_2-e) decrease in agricultural emissions in 2018, as shown in figure 10.1.4.

Figure 10.1.4 Effect of recalculations on New Zealand's Agriculture sector from 1990 to 2017



The improvements that have been implemented in the 2020 Agriculture inventory are:

- use of new N_2O emission factors from animal excreta ($EF_{3,PRP}$) split by stock type and hill slope. These are applied using a nutrient transfer model (described in annex 3, section 3.1.3), which calculates the amount of livestock excreta deposited onto different slopes (low, medium and steep)
- use of revised activity data for the proportion of dairy goats in the overall farmed goat population
- minor improvements to the equations used to estimate energy required for maintenance (k_m) for beef cattle, sheep and deer, including the specification of a constant to more significant figures and reverting to the Intergovernmental Panel on Climate Change (IPCC) default value for the gross energy content of feed of 18.45 megajoules per kilogram of dry matter (MJ/kg DM), following recommendations from the Agriculture Inventory Advisory Panel in 2019.

Emissions estimates from livestock have also been updated using the latest available activity data from the sources described in chapter 5, section 5.1.4.

New EF_3 emission factor values for cattle, sheep and deer, and new methodology to allocate nitrogen excretion to different hill slopes

For the 2020 inventory submission, a new set of emission factors to calculate N_2O emissions for sheep, deer, beef cattle and dairy cattle from dung and urine deposited directly onto pasture ($EF_{3,PRP}$) has been adopted based on meta-analysis on current research by van der Weerden et al. (2019). More information on the body of research presented by the meta-analysis and the new emission factors are in chapter 5, section 5.5.2, under *Urine and dung deposited by grazing animals (CRF 3.D.1.3)*.

As part of this inventory improvement, a nutrient transfer model developed by Saggar et al. (2015) is used to allocate total urine and dung N_{ex} (calculated using the methods described in chapter 5, section 5.3) to the different hill slope categories. The nutrient transfer model uses data on the area of farm land under different slope classes, and accounts for animal behaviour where livestock spend more time on lower slopes relative to steeper slopes. For more information on this model, please refer to annex 3, section 3.1.3.

In the previous inventory submissions, an $EF_{3,PRP}$ emission factor of 0.01 was used for urine from cattle, sheep and deer, and an $EF_{3,PRP}$ emission factor of 0.0025 was used for dung from cattle, sheep and deer.

The implementation of the updated emission factors and associated methodology change caused estimated emissions from the Agriculture sector to decrease by 6.5 per cent in 1990 and 4.3 per cent in 2018 (see table 10.1.4).

Table 10.1.4 Effect of revised $EF_{3,PRP}$ values for cattle, sheep and deer, and new methodology to allocate N_{ex} to different hill slopes on agricultural emissions estimates, 1990 to 2018

		1990	2018	Change in emission outputs between 1990 and 2018 (kt CO_2-e)	Percentage change in emission outputs between 1990 and 2018
Total emissions from Agriculture category (kt CO_2-e)	2020 (1990–2018) emissions estimate *with previous* emission factors and methodology	34,425.4	39,370.4	4,945.1	14.4
	2020 (1990–2018) emissions estimate *with new* emission factors and methodology	32,182.0	37,697.0	5,515.0	17.1
	Difference in emissions estimates compared with previous inventory	–2,243.4	–1,673.5	569.9	
	Percentage difference in emissions estimates	–6.5	–4.3		

Revised activity data on dairy goats

A revised set of estimates on the dairy goat population from 1990 to 2018 has been used for the 2020 submission. This activity data improvement has a small effect on estimated emissions from the Agriculture sector as detailed in table 10.1.5.

Emissions from goats are currently estimated using a Tier 1 methodological approach, with country-specific emission factors and parameters developed by Lassey (2011). Activity data on the total goat population are sourced from Statistics New Zealand (Stats NZ), and until this inventory submission, research provided for the Ministry for Primary Industries by Lassey (2011) was used to estimate the population of dairy goats.

In the current inventory, a weighted emission factor for enteric fermentation (kg methane (CH_4) per goat per year, EF_{Goats}) is calculated based on the estimated proportion of dairy goats in the overall population. A similar calculation is used to estimate N_{ex} (kg nitrogen (N) excreted per goat per year). While EF_{Goats} and N_{ex} per goat are based on the estimated proportion of dairy goats, there is no explicit separation between dairy and other goats.

Recent research from Burggraaf et al. (2019), has been used in this inventory submission to update our assumptions on the number of dairy goats in New Zealand. It is now assumed that dairy goats comprised 3 per cent of total goat population in 1990, with this proportion increasing linearly to 67 per cent by 2017. The remaining population has been assumed to be split equally between meat and fibre goats. In late 2019, the Agricultural Inventory Advisory Panel recommended that the updated dairy goat population estimates from Burggraaf et al. (2019) be used in the inventory. Table 10.1.5 shows the change in estimated goat population numbers from the updated research.

Table 10.1.5 Comparison of previous and new dairy goat population estimates

	Dairy goat population		
Year	Using previous methodology in Lassey (2011)	Using new methodology in Burggraaf et al. (2019)	Total goat population
1990	37,426	31,887	1,062,900
2005	30,738	52,482	136,120
2018	24,941	59,486	88,785

After the adoption of these new population estimates, estimated emissions from the Agriculture sector were unchanged in 1990 and increased slightly by 0.0 per cent (2.0 kt CO_2-e) in 2018.

Table 10.1.6 Effect of revised dairy goat population estimates on agricultural emissions estimates, 1990 to 2018

		1990	2018	Change in emission outputs between 1990 and 2018 (kt CO_2-e)	Percentage change in emission outputs between 1990 and 2018
Total emissions from Agriculture category (kt CO_2-e)	2020 (1990–2018) emissions estimate *using previous* dairy goat population estimates	32,182.0	37,694.9	5,513.0	17.1
	2020 (1990–2018) emissions estimate *using new* dairy goat population estimates	32,182.0	37,697.0	5,515.0	17.1
	Difference in emissions estimates compared with previous inventory	0.0	2.0	2.0	
	Percentage difference in emissions estimates	0.0	0.0		

More significant improvements were proposed for the goat sector, particularly the manure management component of the goat inventory. However, these additional changes were not recommended for inclusion by the Agricultural Inventory Advisory Panel. The Panel considered that the proposed emission calculation methodology was based on insufficient activity data, which increased the likelihood of errors in the estimates. These improvements will be revisited with updated evidence and data at a future Advisory Panel meeting.

Minor improvements to the equations used to estimate energy efficiency for maintenance (k_m)

The variable k_m estimates the efficiency of energy used for maintenance activities for cattle, sheep and deer, which is used to help calculate energy requirements, intake, and nitrogen excretion. For the 2020 submission, minor improvements were made to this equation for beef cattle, sheep and deer (not dairy cattle), so that it is consistent with the Commonwealth Scientific and Industrial Research Organisation (CSIRO) (1990) ruminant feeding standards methodology and the 2006 IPCC Guidelines (IPCC, 2006). These improvements included:

- specifying the values of constants and variables in the k_m equation to more significant figures, to be consistent with CSIRO (1990) methodological guidelines
- adopting the IPCC default value for the gross energy content of feed – 18.45 MJ/kg dry matter (the value previously used in the inventory was 18.4 for cattle and deer and 18.5 for sheep).

After these improvements, estimated emissions from the Agriculture sector decreased by 0.1 per cent (24.0 kt CO_2-e) in 1990 and 0.0 per cent (11.7 kt CO_2-e) in 2018 (table 10.1.7).

Table 10.1.7 Effect of changes to energy efficiency for maintenance (k_m) equations on agricultural emissions estimates, 1990 to 2018

		1990	2018	Change in emission outputs between 1990 and 2018 (kt CO_2-e)	Percentage change in emission outputs between 1990 and 2018
Total emissions from Agriculture category (kt CO_2-e)	2020 (1990–2018) emissions estimate *using previous* k_m equation specification	32,205.9	37,708.7	5,502.7	17.1
	2020 (1990–2018) emissions estimate *using new* k_m equation specification	32,182.0	37,697.0	5,515.0	17.1
	Difference in emissions estimates compared with previous inventory	–24.0	–11.7	12.3	
	Percentage difference in emissions estimates	–0.1	0.0		

Revision of agricultural statistics

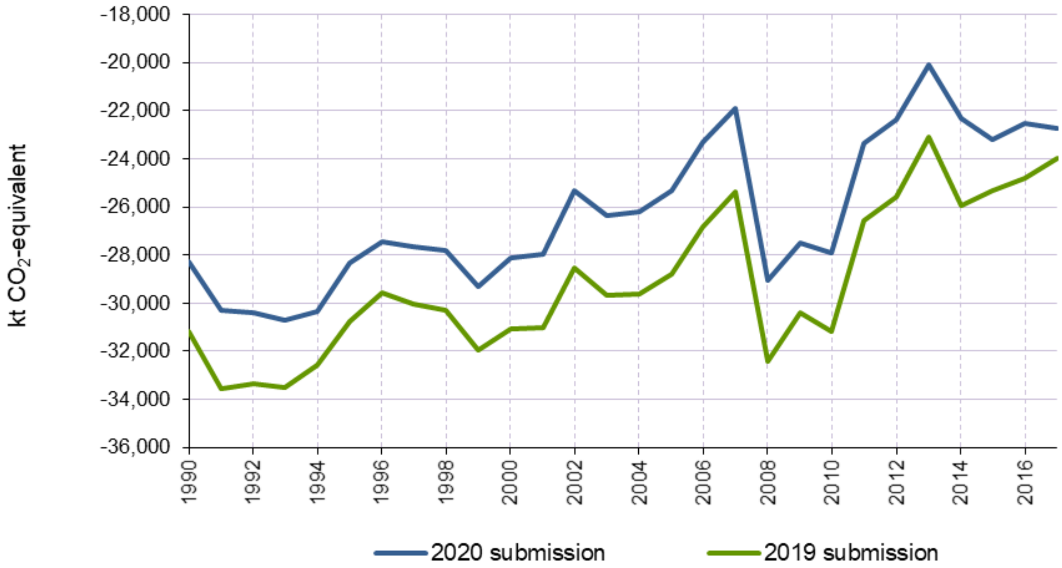
Revision and finalisation of agricultural data from Stats NZ can mean emissions estimates for the latest two years vary from the previous submission for certain source categories.

The calculation of emissions for the most recent year requires data from Stats NZ that are only provisional at the time the inventory is compiled. These figures can change after receiving final animal numbers and data. The final figures will be taken account of in the 2021 (1990–2019) submission.

10.1.4 Land use, land-use change and forestry

Improvements made to the LULUCF sector have resulted in a 9.2 per cent (2,864.7 kt CO_2-e) decrease in net LULUCF removals in 1990 and a 5.2 per cent (1,248.3 kt CO_2-e) decrease in net LULUCF removals in 2017 (figure 10.1.5).

Figure 10.1.5 Effect of recalculations on net emissions from New Zealand's LULUCF sector from 1990 to 2017



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 2020 inventory submission are summarised in table 10.1.8. Further details on these changes are given in chapter 6.

Table 10.1.8 Explanations and justifications for recalculations in the LULUCF sector

Explanation of recalculation	Underpinning UNFCCC principle	Additional justification
A revised analysis of the pre-1990 natural forest plot data was undertaken for the 2020 submission (Paul et al., unpublished). This resulted in a significant reduction in the estimate for carbon stock change in the regenerating component of pre-1990 natural forest, compared with the previous submission. Details of the revised analysis and the drivers of this reduction can be found in chapter 6, section 6.4.5, under Forest land.	Accuracy	Key category improvement (*Forest land remaining forest land*)
The post-1989 planted forest yield table has been revised for the 2020 submission. The revised yield table uses data from the annual national forest inventories of 2016, 2017 and 2018 and previous periodic national forest inventories between 2007 and 2015. The analysis of the data collected has provided a plot-based estimate of carbon stock and mean carbon density within this forest type, which leads to more accurate estimates.	Accuracy	Key category improvement (*Forest land remaining forest land*; *Land converted to forest land*; *Land converted to grassland*)

10.1.5 Waste

Improvements and recalculations made in the Waste sector have resulted in a 0.1 per cent (5.8 kt CO_2-e) increase in emissions in 1990 and a 0.8 per cent (32.1 kt CO_2-e) decrease in emissions in 2017 (figure 10.1.6). Minor improvements and corrections have been made to the Waste sector in the 2020 submission, including responses to findings resulting from expert review team reviews. The most significant changes to emissions are in the *Unmanaged waste disposal sites* and *Domestic wastewater* source categories.

A full list of recalculations is made in table 10.1.9.

Figure 10.1.6 Effect of recalculations on New Zealand's Waste sector from 1990 to 2017

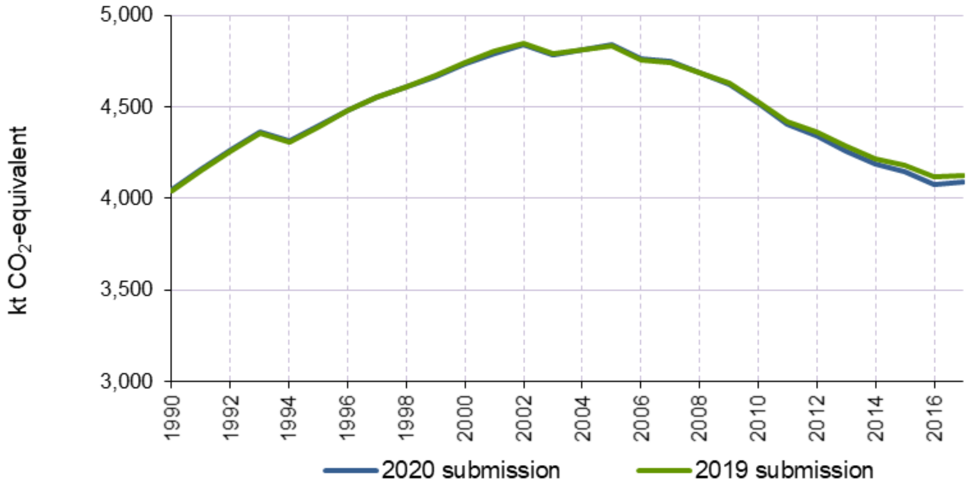


Table 10.1.9 Explanations and justifications for recalculations in the Waste sector

Explanation of recalculation	Underpinning UNFCCC principle	Additional justification
One landfill site that is closed to municipal waste but now conducts landfill gas recovery has been updated in the model accordingly.	Accuracy	*Solid waste disposal* is a key category
Changes in the emission calculations for *Domestic wastewater* (5.D.1) have increased emissions by 6.2 kt CO_2-e (3.0 per cent) in 1990 and reduced emissions by 3.4 kt CO_2-e (1.3 per cent) in 2017. The main change was driven by an update to the population growth rate based on revised data released by Stats NZ.	Accuracy	*Wastewater treatment and discharge* is a key category
Activity data for meat and poultry (within *Industrial wastewater* 5.D.2) have been adjusted for all emission calculations based on revised data released by the Ministry for Primary Industries, Deer Industry New Zealand and the Poultry Industry Association of New Zealand.	Accuracy	*Wastewater treatment and discharge* is a key category
Corrections to methods for non-municipal solid waste disposal sites within the *Unmanaged waste disposal sites* category have decreased emissions from this category by 0.3 kt CO_2-e (0.0 per cent) in 1990 and decreased emissions by 25.2 kt CO_2-e (1.1 per cent) in 2017. This change is the result of corrections made to the calculations.	Accuracy	*Solid waste disposal* is a key category

10.1.6 Other sector (Tokelau)

The improvements to the Other (Tokelau) sector are a combination of refinements as a result of historical information coming to hand (electricity: 2004; transport 1990–2014); improved fuel calculations (based on a full year rather than 9 months, upscaled; estimated number of roundtrips Apia–Tokelau during 1990–2014; average fuel use per trip); and the correction of a major error (number of pigs).

Improvements and recalculations made for the Tokelau sector have resulted in a 13 per cent (–0.5 kt CO_2-e) decrease in emissions in 1990 and a 22.9 per cent (0.7 kt CO_2-e) increase in emissions in 2017 (figure 10.1.7).

Several other improvements and minor corrections have been made to all categories, in the process of automating the calculation of Tokelau's emissions using a model developed in an Excel spreadsheet, based on the IPPC reporting framework. It requires only annual updates of fuel purchases, number of voyages (roundtrips Apia–Tokelau, inter-island trips) and 5-yearly Census data to be input into a single worksheet.

A full list of recalculations is made in table 10.1.10.

Figure 10.1.7 Explanations and justifications for recalculations in the Tokelau sector

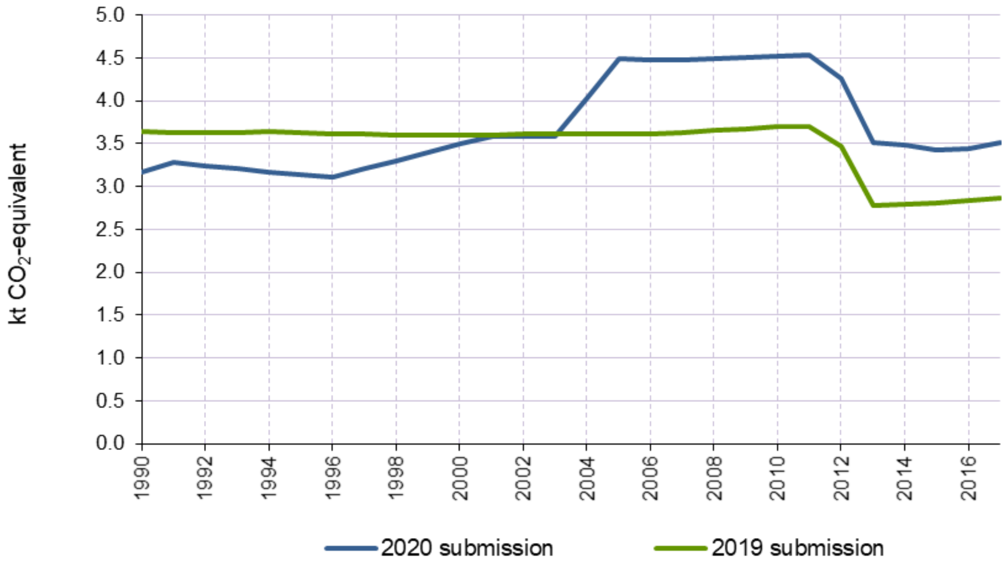


Table 10.1.10 Explanation and justifications for recalculating Energy, Agriculture and Waste water sectors

Explanation of recalculation	Underpinning UNFCCC principle	Additional justification
The **Energy sector** was split into **electricity** and **transport**, to bring out more clearly the changes that have taken place over time. Transport showed a gradual increase, but electricity had two key events, in 2004 and 2012. These are explained in chapter 8, section 8.1.3.	Accuracy, transparency	
This submission reflects that, during 2004, Tokelau achieved 24 hours, 7 days a week availability of electricity to households and the public sector: up from 6–10 pm daily availability until then. This reputedly led to a five-fold increase in diesel consumption for power generation nationally. The previous submission had assumed constant diesel use up to the point where solar power was introduced in 2012. This time, the emissions from power generation were kept constant between 1990–2003 and between 2005–11.	Accuracy, consistency, transparency	
Diesel consumption for electricity was previously assumed to be constant since the introduction of solar power during 2012, using the value for 2015. We have now incorporated a 10 per cent increase between 2015 and 2018.	Accuracy	
Almost all the diesel used on-atoll for machinery (such as trucks, tractors, cranes) is sourced from the fuel supply for electricity. It was therefore not possible to clearly separate emissions from the two types of sources. Given the relatively small number of diesel-powered vehicles in Tokelau, we lumped their fraction with that of electricity.	Accuracy, transparency	
We therefore limit the calculation of emissions from local transport to the use of petrol and lubricating oil used by petrol cars and outboard motors around the atolls.	Accuracy, transparency	
To estimate annual fuel purchases, the full financial data for 2018 were available this time. Our first calculations used fuel purchases during the first 9 months of 2018, upscaled to one year. (Note that fuel volumes in prior years would be incomplete because much use was made of chartered boats then.)	Accuracy, transparency	
Using data on fuel purchases during 2018, we were able to determine the average diesel use per roundtrip Apia–Tokelau by the ferries and cargo ships: around 16,000 litres each.	Accuracy, transparency	

Explanation of recalculation	Underpinning UNFCCC principle	Additional justification
We estimated the number of round trips increased from about two a month in the 1990s, to actual values known from 2014–18. Then we calculated total diesel use for shipping accordingly, rather than using the 2014 value as a constant back to 1990. We continued to allocate a fraction of 300/1300 to Tokelau, ignoring emissions from international shipping (1000/1300) between Tokelau and its nearest port, Apia.	Accuracy, transparency	
A minor change was made to how the numbers of refrigerators, freezers and air conditioning units in Tokelau were calculated. In Tokelau's first submission, the data from a smoothed regression line were used. In this submission, the actual census year data and interpolated intervening years were used.	Accuracy, transparency	
To account for the phase in of hydrofluorocarbons (HFCs), it has been assumed that the proportion of appliances using HFCs increased 10 per cent per year, starting at 10 per cent of appliances in 1994 and reaching 100 per cent of appliances in 2003.	Accuracy, transparency	
Agriculture did not feature strongly in Tokelau's first estimates for 1990–2017, as a result of an error in the pig population size. The IPCC methodology (3.A.3 and 3.B.1.3) requires the swine population to be reported in 1000s, and the resulting per milli fraction was used to calculate emissions from pigs, which were hence a factor 1,000 too small. The current submission corrects this.	Accuracy, consistency, transparency	
For our calculations of waste, we are now using the *de facto* census night population, instead of the official, *de jure* usually resident population of Tokelau. The distinction was first made in Census 1991 to include travellers, plus Tokelau public servants and their families who live and work in Apia, Samoa (and hence do not contribute to Tokelau waste). The *de jure* population also includes residents who are away from Tokelau for less than 6 months for education, health or holiday, hence are also not contributing to waste production.	Accuracy, transparency	
A more accurate time series in waste water was developed by using 5-yearly Census data to calculate a reduction of open water toilets from 65 per cent in 1991, to 0 per cent in 2016. Previously, 66 per cent was assumed as a constant. The percentage of septic tanks, that is, the complement to open water toilets, was increased accordingly from 35 per cent to 100 per cent. This change increases emissions from methane and reduces emissions from nitrous oxide.	Accuracy, transparency	
The above refinements led to somewhat lower emissions for 1990 and to higher emissions for 2018 than in our previous estimate. Hence, our overall emissions appear to have increased by 14.2 per cent over that period (whereas our previous submission reported a decrease of 21 per cent). While the change to solar power in 2012 meant a positive and deliberately drastic reduction in emissions, it appears to have merely negated the developmental increase in 2004. For Tokelau, 2005 would be a more realistic baseline to set its reduction target from, than 1990 as used for developed countries.	Accuracy, consistency, transparency	

10.1.7 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 2019 inventory submission (tables 10.1.12, 10.1.13 and 10.1.14). The recalculations incorporate improved activity data and emission factors (see chapter 11 and table 10.2.1). Table 10.1.11 lists the recalculations in order of decreasing magnitude.

Table 10.1.11 Explanations and justifications for recalculations of New Zealand's previous Kyoto Protocol estimates

Explanation of recalculation	Underpinning UNFCCC principle	Additional justification
A revised analysis of the pre-1990 natural forest plot data was undertaken for the 2020 submission (Paul et al., unpublished). This resulted in a significant reduction in the estimate for carbon stock change in the regenerating component of pre-1990 natural forest, compared with the previous submission. Details of the revised analysis and the drivers of this reduction can be found in chapter 6, section 6.4.5, under Forest land.	Accuracy,	Key category improvement (*Forest land remaining forest land*)
The post-1989 planted forest yield table has been revised for the 2020 submission. The revised yield table uses data from the annual national forest inventories of 2016, 2017 and 2018 and previous periodic national forest inventories between 2007 and 2015. The analysis of the data collected has provided a plot-based estimate of carbon stock and mean carbon density within this forest type, which leads to more accurate estimates.	Accuracy	Key category improvement (*Forest land remaining forest land*; *Land converted to forest land*; *Land converted to grassland*)

Improvements in activity data (table 10.1.13) have affected emissions recalculations for all three Kyoto Protocol activities (table 10.1.12).

Table 10.1.12 Impact of the recalculations of New Zealand's net emissions under Article 3.3 and Article 3.4 of the Kyoto Protocol in 2017

	2017 net emissions (kt CO_2-e)		
Activities under the Kyoto Protocol	2019 submission	2020 submission	Change from 2019 submission (%)
Afforestation/reforestation	–17,610.0	–17,790.2	–1.0%
Deforestation	1,657.0	1,977.1	–19.3%
Forest management	–14,553.9	–13,136.0	9.7%
Total	**–30,506.9**	**–28,949.2**	**5.1%**

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 10.1.13 Recalculations to New Zealand's 2017 activity data under the Kyoto Protocol

	Area as at 2017 (ha)		
Activities under the Kyoto Protocol	2019 submission	2020 submission	Change from 2019 submission (%)
Afforestation/reforestation	680,086	689,747	1.4
Deforestation	200,161	197,466	–1.3
Forest management	9,245,248	9,210,186	–0.4
Activities occurring in 2017			
New planting	4,979	6,461	29.8
Deforestation			
Pre-1990 natural forest	772	740	–4.1
Pre-1990 planted forest	1,713	2,117	23.6
Post-1989 forest	462	635	37.6

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. There was an in-country review of the 2019 submission, however, the assessment review report (ARR) was not published in time to respond to the recommendations in this submission. Where possible, improvements have been made in response to some of the preliminary findings from the in-country review of the 2019 submission.

The most recent ARR available at the time of writing was the 2017 report published in April 2018 (UNFCCC, 2018), which is responded to in this submission. The 2017 ARR includes findings from reviews of the 2017 and earlier submissions of New Zealand's inventory. New Zealand has endeavoured to address as many recommendations as practicable in the 2018, 2019 and 2020 submissions. Further improvements will be implemented in future submissions.

Table 3 and table 4 of the 2017 ARR contain assessment of progress in addressing recommendations provided by the expert review teams (ERTs) during the reviews of the 2016 and earlier inventory submissions. These recommendations are detailed in table 10.2.1 along with New Zealand's latest responses to those recommendations.

Table 5 of the 2017 ARR contains new recommendations related to the review of the 2017 inventory submission. These recommendations, along with New Zealand's latest 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 2017 assessment review report for issues raised in earlier reviews

Sector	ID number	Expert review team recommendation	New Zealand response
General	G.1, 2017	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 efforts of the inventory staff have been prioritised to improve inventory transparency. This includes providing transparent explanations for the methodological issues associated with activity data, emission factors and methods. As a result of these efforts, the NIR 2019 contains a substantial amount of new information and shows improved organisation of the previously included sections. For example, the inventory also includes additional tables (e.g., table 3.2.1 in chapter 3 to show energy use and non-energy use for natural gas, table 7.2.2 in chapter 7 to provide a more transparent account on activity data for solid waste deposited to municipal and uncategorised landfills), notes on the use of the New Zealand Emissions Trading Scheme (NZ ETS) data and a note on the cement and glass production in the Industrial Processes and Product Use (IPPU) sector, as well as dedicated sections to categories 2.F and 2.G. Similar progress in overall transparency improvement has been achieved across other inventory sectors as far as resources allowed.

Sector	ID number	Expert review team recommendation	New Zealand response
General	G.2 2017	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 quality assessment/ quality control (QA/QC) process has been significantly improved in 2018/19, which included completion of the automated QC tools applied to all inventory sectors; ensuring that QC deliverables are well understood by all sector leads and are fit for purpose; changing the inventory approval process at the sectoral level by including mandatory checks for common reporting format (CRF) data integrity performed at the sectoral level and by the central inventory agency using custom-made QC tools prior to sectoral submissions. The checks for consistency between NIR and CRF have also been integrated in the inventory QC process.
Energy – Reference approach	E.1, 2017	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**. Preliminary disaggregated data for the production of naphtha and crude oil have been identified. The necessary changes to the energy greenhouse gas data system have been included in the 2020 workplan and this improvement is expected to be implemented in the reference approach for the 2021 submission.
Energy – Stationary combustion: solid fuels – CO_2	E.8, 2017	Critically assess whether the New Zealand Emissions Trading Scheme 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.2, 2017	Report in the NIR on progress in addressing the recommendation on reporting naphtha and crude oil using aggregate values (see ID# E.1 above).	**Resolved.** Progress has been reported in NIR section A4.5.
Energy – Reference approach – CO_2	E.3, 2017	Endeavour to incorporate disaggregated data for lubricants, petroleum coke and bitumen in the submission or, if this is not possible, report on progress in addressing the recommendation.	**Addressing.** Disaggregated data for the imports of petroleum coke and bitumen have been identified. The necessary changes to the energy greenhouse gas data system have been included in the 2020 workplan and the improvement is expected to be implemented in the reference approach for the 2021 submission.
Energy – Feedstocks, reductants and other non-energy uses of fuels – CO_2	E.4, 2017	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 and table showing natural gas energy and non-energy use were included in the 2018 submission.
Energy – Feedstocks, reductants and other non-energy uses of fuels – CO_2	E.5, 2017	Review the notation keys reported for emissions from the different categories.	**Resolved.** The notation keys have been reviewed, and we are satisfied with the status quo.
Energy – Manufacture of solid fuels and other energy industries: solid fuels – CO_2, CH_4 and N_2O	E. 7, 2017	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 United Nations Framework Convention on	**Resolved.** The NIR has been updated to clarify that this activity is ‘not occurring’ for the entire time series.

Sector	ID number	Expert review team recommendation	New Zealand response
		Climate Change (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 GHG emissions.	
Energy – Domestic aviation: liquid fuels – CO_2	E.9, 2017	Estimate CO_2 emissions from domestic aviation using a tier 2 or 3 methodology, in accordance with the 2006 IPCC Guidelines.	**Resolved.** For estimating emissions from domestic aviation, a country-specific carbon dioxide (CO_2) emissions factor is used for jet kerosene and an IPCC default for gasoline. Carbon dioxide emissions are estimated based on fuel consumption and origin and destination. Estimating CO_2 emissions based on landing and take-off cycles would not improve accuracy.
Energy – Road transportation: liquid and gaseous fuels – CO_2	E.10, 2017	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 are unavailable.
Energy – Coal mining and handling – CH_4	E.14, 2017	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 remain below 0.1 per cent of the national total GHG emissions.	**Addressing.** An update has been provided in the NIR.
Energy – Natural gas processing – CO_2 and CH_4	E.17, 2017	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 Kapuni gas treatment plant in the NIR.	**Resolved.** The CRF tables have been revised.
Energy – 1.A.3.b Road transportation – liquid fuels – CH_4 and N_2O	E.11, 2017	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.** The procedure for validating vehicle-kilometres travelled with fuel statistics has been described in the NIR
Energy – 1.A.4.c Agriculture/forestry/ fishing – liquid fuels – CH_4 and N_2O	E.13, 2017	Collect separate AD 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 EFs for mobile combustion and stationary combustion.	**Resolved.** The emissions estimates have been disaggregated and reported in the CRF tables.
Energy – 1.B.1.a Coal mining and handling – CH_4	E.16, 2017	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	**Resolved.** Further explanation has been included in the 2018 submission. (Note this activity is not occurring).

Sector	ID number	Expert review team recommendation	New Zealand response
		description of the number and types of coal mines active in New Zealand.	
Energy – 1.B.2.b Natural gas – CO_2	E.18, 2017	Improve comparability by reporting CO_2 venting from natural gas processing in category 1.B.2.c.2 (gas venting).	**Resolved.** Information has been added to the NIR.
Energy – 1.B.2.b Natural gas – CO_2	E.19, 2017	The ERT, noting its recommendation in ID#E.17 (2017), recommends that, if it chooses not to report CH_4 emissions from the Kapuni gas treatment plant, New Zealand change the notation key used for fugitive CH_4 emissions from natural gas processing (category 1.B.2.b.3) from "NO" to "NE" and describe these emissions in the NIR, as well as provide a justification for their insignificance in accordance with decision 24/CP.19, annex, paragraph 37(b).	**Resolved.** The CRF tables and the NIR have been updated.
IPPU – General	I.1, 2017	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 – General	I.2, 2017	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 – Cement production	I.3, 2017	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.	**Resolved.** The activity data for this category are confidential and, therefore, cannot be included in submissions. To follow good practice, these data can be provided to the ERT on request during the review.
IPPU – Glass production – CO_2	I.5, 2017	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 and 2018 NIR.
IPPU – 2.B.5 Carbide production – CO_2	I.11, 2017	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.D Non-energy products from fuels and solvents use – CO_2	I.15, 2017	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 – Electronics industry (2.D) Product uses as substitutes for ozone-depleting substances (2.F) Other product manufacture and use (2.G) – hydrofluorocarbons (HFCs), perfluorocarbons	I.16, 2017	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 to 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 by adding information about sources, and survey details can be made available to reviewers as required. The description in the NIR will be further reviewed and improved for future submissions.

Sector	ID number	Expert review team recommendation	New Zealand response
(PFCs), sulfur hexafluoride (SF_6) and nitrogen trifluoride (NF_3)			
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.17, 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.
IPPU – Other product manufacture and use (2.G) – SF_6	I.21, 2017	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.	**Resolved.** This information is included.
Agriculture – 3.B.1 Cattle – CH_4	A.1, 2017	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).	**Resolved.** New Zealand has provided more comprehensive information on the causes of inter-annual changes in the CH_4 implied emission factor in the 2019 NIR. See chapter 5, section 5.1.1, Effect of productivity improvements and climatic events on implied emissions.
Agriculture – 3.D.a.1 Inorganic N fertilisers – N_2O	A.2, 2017	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.	**Resolved.** Updated information on synthetic nitrogen fertiliser use is provided in the 2019 NIR.
Agriculture – 3.F Field burning of agricultural residues – CH_4, and N_2O	A.3, 2017	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.	**Resolved.** Updated information on the burning of agricultural residues is provided in the 2019 NIR.
LULUCF – General – CO_2, CH_4 and N_2O	L.1, 2017	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, 2017	Provide in the NIR tables 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 all categories are provided in the NIR since the 2019 submission.
Waste – 5. General (waste) – CH_4, N_2O and CO_2	W.2, 2017	Noting the general recommendation in ID#W.1 in table 3, provide, in the NIR, tables with information on waste generation and various treatment options (with the full time series).	**Resolved.** Aggregate activity data for all categories are provided in the NIR since the 2019 submission.
Waste – Solid waste disposal (5.A) – CH_4	W.4, 2017	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 all categories is provided in the NIR since the 2019 submission.

Sector	ID number	Expert review team recommendation	New Zealand response
Waste – Solid waste disposal (5.A) – CH_4	W.5, 2017	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 revises 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 since the 2018 submission, under gas recovery in chapter 7, section 7.2.2.
Waste – Solid waste disposal (5.A) – CH_4	W.6, 2017	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 improved data on landfill gas collection rates by incorporating data from the NZ ETS in the NIR since the 2019 submission. There is detailed explanation of the data used under gas recovery in chapter 7, section 7.2.2.
Waste – Solid waste disposal (5.A) – CH_4	W.7, 2017	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 are 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 since the 2018 submission, under gas recovery in chapter 7, section 7.2.2, including table 7.2.6, which reports data on CH_4 recovery at landfills.
Waste – Solid waste disposal (5.A) – CH_4	W.8, 2017	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. 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 reasons why different parameters are used.	**Resolved.** New Zealand has provided more detail on the methods applied to estimate emissions from SWDS in the NIR since the 2018 submission, under CH_4 generation rates in section 7.2.2.
Waste – 5.A.1 Managed waste disposal sites – CH_4	W.9, 2017	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 since the NIR for the 2018 submission, under CH_4 generation rates in chapter 7, section 7.2.2. In addition, an additional summary from a key report was included for the 2020 submission to explain the choice of k values.
Waste – 5.A.2 Unmanaged waste disposal sites – CH_4	W.10, 2017	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 since the 2018 submission and has also derived degradable organic carbon values based on the composition of waste for each specific farm type. An additional summary from a key report was also included for the 2020 submission to explain the degradable organic carbon values for farm waste .

Sector	ID number	Expert review team recommendation	New Zealand response
Waste – 5.D.1 Domestic wastewater – CH_4	W.13, 2017	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 2019 submission.
KP-LULUCF – Forest management – CO_2, CH_4 and N_2O	KL.1, 2017	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.2, 2017	Report consistently across the NIR and the CRF tables by correcting the values of the "total technical corrections" in table 11.3.3 of the NIR (–17.26) and the corresponding value in annex 5.1 to the NIR and the CRF table "Accounting" (–17.25).	**Resolved:** Reporting of 'total technical corrections' has been revised in the NIR and CRF tables of the 2018 submission.

Table 10.2.2 New Zealand's response to recommendations as reported in table 5 of the 2017 assessment review report from the review of New Zealand's 2017 inventory submission

Sector	ID number	Expert review team recommendation	New Zealand response
Energy – General	E.22, 2017	The ERT recommends that New Zealand correct a number of inconsistencies in the 2017 annual submission.	**Resolved.** These inconsistencies have been corrected.
Energy – Reference approach	E.23, 2017	The ERT recommends that New Zealand clarify whether AD for other oil occur in the country and, if so, report the notation key "IE" in CRF table 1.A(b); or correct the information in the documentation box by excluding the mention that emissions from other oil are grouped under bitumen, since these emissions are not occurring.	**Resolved.** The notation key 'IE' has been used in table 1.A(b).
Energy – Reference approach	E.24, 2017	The ERT recommends that New Zealand provide in the NIR a comparison of the allocation of fuel consumption data used in the inventory (CRF table 1.A(b)) and in the energy balance.	**Not resolved.** This will be considered as resources allow.
Energy – International aviation	E.25, 2017	The ERT recommends that New Zealand evaluate these differences between AD reported in CRF table 1.D and CRF table 1.A(b) for jet kerosene (international aviation bunkers) for all years and correct the identified discrepancies.	**Resolved.** There are no differences for most years (e.g., 2008–12 and 2015–17) and for the remaining years, the differences are insignificant (less than 0.03 per cent).
Energy – Coal mining and handling	E.26, 2017	The ERT recommends that New Zealand clarify in the NIR whether there are any emissions relating to CH_4 recovery/flaring under category 1.B.1.a.i (abandoned underground mines) that are not estimated. If emissions from recovery/flaring do occur, estimate the amount of CH_4 recovered in accordance with the 2006 IPCC Guidelines (volume 2, chapter 4.1.5.3, p.4.28). And if such emissions do not occur, change the notation key in CRF table 1.B.1 from "NE" to "NO".	**Resolved.** The NIR has been updated to clarify that recovery/flaring does not occur.
IPPU – 2.A Mineral industry – CO_2	I.22, 2017	Review the calculation of the uncertainty for category 2.A and correct the values in NIR table 4.2.1 and A2.1.1, annex 2, if needed.	**Resolved.** This has been reviewed.
IPPU – 2.A.2 Lime production – CO_2	I.23, 2017	Report in CRF table 2(I).A-Hs1 a consistent type of AD for lime production for all years (e.g. by converting "pure CaO" to "burnt lime" using an appropriate conversion factor) and apply the default EF from the 2006 IPCC Guidelines for 1990–2013 accordingly. In addition, the ERT recommends that the Party update the description in the NIR to correctly reflect the AD and EFs used and to clarify the assumptions and methods applied for 1990–2013 and 2014 onwards.	**Resolved.** The amounts of impure burnt lime are now used consistently for the entire time series.

Sector	ID number	Expert review team recommendation	New Zealand response
IPPU – 2.B.1 Ammonia production – CO_2	I.24, 2017	Clarify in the NIR (section 4.3.2) that urea used as fertilizer is reported under category 3.H. The ERT also recommends that New Zealand either: (a) provide an estimate for urea use in selective catalytic reduction (under category 2.D.3) in line with the 2006 IPCC Guidelines; or (b) provide a justification for its exclusion in terms of the likely level of emissions, in accordance with the requirements in paragraph 37(b) of the UNFCCC Annex I inventory reporting guidelines.	**Resolved.** The use of urea as a catalyst is now reported.
IPPU – 2.B Chemical industry – CO_2	I.25, 2017	Review the calculation of the uncertainties for category 2.B and correct the values given in the NIR (annex 2, table A2.1.1) if necessary.	**Resolved.** This has been reviewed.
IPPU – 2.C.1 Iron and steel production – CO_2	I.26, 2017	Estimate CO_2 emissions from electric steel production at the Pacific Steel plant, either by using a carbon balance or by applying an appropriate EF, and report these emissions under category 2.C.1.	**Resolved.** The electric arc steel plant was closed in 2015. The relevant data became unavailable.
IPPU – 2.B.1 Aluminium production – PFCs	I.27, 2017	Improve the description in the NIR of the reasons for the choice for using a tier 1 method for 1990 and 1991, including the information provided to the ERT during the review … which reduced the occurrence of anode effects and which explains the decrease in emissions and in the EF between the years 1990–1991 and later years.	**Resolved.** This explanation has been included in the NIR.
IPPU – 2.C.4 Magnesium production – SF_6	I.28, 2017	Correct NIR table 4.4.2 (p.119) to reflect that AD uncertainty is 100 per cent and EF uncertainty is reported as “zero”; and state in the NIR that for SF_6 emissions from magnesium casting, a country-specific uncertainty is used rather than the IPCC default uncertainty and explain the reason for it.	**Resolved.** This table has been corrected.
IPPU – 2.D.1 Lubricant use – CO_2	I.29, 2017	If an outlier is found in the estimates of lubricant use, the Party consider averaging the AD before estimating emissions, rather than averaging the emission data. The ERT also recommends that the Party revise its estimates for 2011–2014 to improve consistency of the time series and include 2015 data in the assumption to avoid significant changes in the CO_2 IEF.	**Resolved.** The data used have been reviewed and a different selection made for the 2019 submission, due to variance in reported import volumes.
IPPU – 2.F Product uses as substitutes for ozone depleting substances – HFCs	I.30, 2017	Explain, in section 4.7.3 of the NIR, which approach (other than a combination of uncertainties) was used to derive the uncertainty of ±35 per cent, presented in NIR table A.2.1.1.	**Resolved.** This explanation has been provided, and details are available to the ERT on request.
IPPU – 2.F.1 Refrigeration and air conditioning – HFCs	I.31, 2017	Review the data underlying the estimation of HFC emissions from commercial and industrial refrigeration, in particular the development of average annual stocks in recent years. The ERT also recommends that New Zealand provide, in section 4.7.2 of the NIR, a brief explanation for the exceptionally high product life factors of HFC143a and HFC-134a, respectively, in these categories.	**Resolved.** This explanation has been provided, and details are available to the ERT on request.
IPPU – 2.F.1 Refrigeration and air conditioning – HFCs	I.32, 2017	Update the average charge of HFC-134a for the years from 2010 onwards by taking into consideration the cars added to the fleet in recent years, based on data available from importers and/or from fleet statistics.	**Resolved.** This has been reassessed and a brief explanation provided in the NIR.
Agriculture – General – CH_4	A.4, 2017	Provide in its NIR the list of livestock species included in the category other poultry and provide explanations regarding the methodology it uses to estimate emissions and EFs for ostriches and emus.	**Resolved.** Additional information on the species included in ‘other poultry’ is in the 2019 NIR.
Agriculture – 3.A.4 Other livestock – CH_4	A.5, 2017	Provide information on the breeding of rabbits and fur-bearing animals in its NIR.	**Addressing.** The Ministry for Primary Industries has investigated this issue. Rabbits are considered an agricultural pest and only a very small number are farmed rabbits.

Sector	ID number	Expert review team recommendation	New Zealand response
			There is no farming of other fur-bearing animals. This explanation has been included in chapter 1, section 1.4 and chapter 5, section 5.1.4.
LULUCF – Forest land – CO_2	L.3, 2017	New Zealand re-analyse the harvesting age assumption on the average harvest age and recalculate the emissions if it cannot provide a justification that emissions are not overestimated or underestimated; and report the outcomes of this exercise in the NIR.	**Addressing.** Analysis is scheduled for 2019/20.
LULUCF – Forest land – CO_2	L.4, 2017	Consider ways to reduce uncertainties in the stock change estimates when further designing the systems to estimate carbon stock change in pre-1990 natural forests.	**Resolved.** Uncertainty of the pre-1990 natural forest carbon stock change has been reduced through applying different methods, as described in the NIR.
LULUCF – Forest land remaining forest land – CO_2	L.5, 2017	Update the below-ground biomass ratios, or, while that update is not possible, report in the NIR on the progress on the ongoing work to update the below-ground biomass ratios.	**Resolved.** Below ground biomass ratios have been updated in the 2020 submission.
LULUCF – Land converted to forest land – CO_2	L.6, 2017	Include information on the reasons for the inter-annual changes in the net carbon stock change in dead wood per area for category 4.A.2.4 (settlements converted to forest land), in particular the inter-annual changes observed for 2011 onwards.	**Resolved.** An explanation was provided in the 2019 NIR describing how active management affects dead wood stocks.
LULUCF – Wetlands – CO_2	L.7, 2017	Continue the ongoing work to improve its estimates for wetlands and report the emissions for categories 4.D.1.1 and 4.D.2.1.	**Resolved.** New Zealand is now reporting on these two categories since the 2018 submission.
LULUCF – Direct N_2O emissions from N mineralization/ immobilization – N_2O	L.9, 2017	The ERT recommends that New Zealand correct the C/N ratio to 15:1 in the NIR (p.300).	**Resolved.** This has been correctly reported since the 2018 submission.
Waste – 5.A.1.a Anaerobic– General	W.14, 2017	Update the NIR and make reference to category 5.A.1.a in the subheading 'Municipal landfills' under NIR section 7.2.2.	**Resolved.** The NIR was corrected for the 2018 submission.
Waste – 5.B.1 Composting – CH_4 and N_2O	W.15, 2017	Improve the consistency of its reporting in NIR sections 7.1.2 and 7.3, including figure 7.1.2 (p.314), to reflect that category 5.B.1 is 'NE' (not estimated). The ERT also recommends that the Party includes information on the exclusion of category 5.B.1 in terms of the likely level of emissions in the waste chapter (under the relevant section) and includes a cross reference to annex A6.2.1.	**Resolved.** The NIR was corrected for the 2018 submission. Emissions for composting are reported since the 2019 submission.
Waste – 5.B.1 Composting – CH_4 and N_2O	W.16, 2017	Update its calculation provided in the NIR to justify the use of 'NE' (not estimated) for CH_4 and nitrous oxide (N_2O) emissions from category 5.B.1 (composting) in the NIR (annex A6.2.1, p.499).	**Resolved.** The NIR was corrected for the 2018 submission. Emissions for composting are reported since the 2019 submission.
Waste – 5.C.1 Waste incineration – CH_4 and N_2O	W.17, 2017	Explain the assumptions and how the EFs were obtained. The ERT further recommends that the Party checks the value of the CH_4 EF for clinical waste in NIR table 7.4.1 (1.79 kg/kt) and in the spreadsheet (17.86 kg/kt) and correct it, as appropriate.	**Resolved.** The sources of the emission factors were clarified in table 7.4.4 in the 2019 NIR.
Waste – 5.D.1 Domestic wastewater – CH_4 and N_2O	W.18, 2017	Apply an average population inflation factor to all known populations served by wastewater treatment plants to estimate emissions for category 5.D.1 and provide the associated justification of methods and assumptions in the NIR.	**Resolved.** The full population has been accounted for since the 2018 submission and the NIR updated to explain the methods.

Sector	ID number	Expert review team recommendation	New Zealand response
Waste – 5.D.1 Domestic wastewater – N_2O	W.19, 2017	Report a value of 1.25 for the industrial and commercial co-discharged protein parameter and 1.40 for the fraction of non-consumed protein in CRF table 5.D.	**Resolved.** The correct parameters were included in the CRF for the 2018 submission.
KP-LULUCF – General – CO_2, CH_4 and N_2O	KL.3, 2017	The ERT recommends that New Zealand enhance the internal coherence of the NIR and its adherence to the reporting guidelines under Article 7, paragraph 1, of the Kyoto Protocol, by including the correct approaches and methods used.	**Resolved.** New Zealand has improved explanations of the approaches and methods used in chapter 11, section 11.2.3.
KP-LULUCF – Forest management – CO_2	KL.4, 2017	Include relevant information in the NIR in support of the mandatory requirement to demonstrate that the mineral soil pool under FM activity is not a source, following the guidance in section 2.3.1 in the Kyoto Protocol Supplement.	**Resolved.** New Zealand has added the information requested here in chapter 11, section 11.3.4.
KP-LULUCF – Afforestation and reforestation – CO_2	KL.5, 2017	Include in the NIR synthesized information on the correspondence between forest land (i.e. the area of planted forest versus natural forest as presented in CRF table 4.A) and AR areas reported in CRF table 4(KP-1)A.1.	**Resolved.** New Zealand has added table 11.3.1a to section 11.3.2 in chapter 11, providing this information.
KP-LULUCF – Afforestation and reforestation – CO_2	KL.6, 2017	Include in the NIR the information provided to the ERT during the review on how surrogate data sets on AR used for the periods 1990–2007 and 2008–2012 are applied in order to demonstrate that: (a) the AR areas meet the forest definition; (b) AR is directly human induced and differentiated from natural expansion and/or restocking; and (c) the geographical location of the boundaries of the areas that encompass lands subject to AR activities are identifiable.	**Resolved.** New Zealand has included this information in chapter 11, sections 11.5.1 and 11.5.3. Additionally, these sections have been updated since the 2019 in-country review of the 2019 submission.
KP-LULUCF – Deforestation – CO_2, CH_4 and N_2O	KL.7, 2017	Include in the NIR the additional information provided to the ERT during the review, explaining (a) how the forest definition is distinguishable from, for example, the subcategory grassland with up to 30 per cent woody biomass; and (b) the geographical location of the boundaries of the areas that encompass lands subject to deforestation activities. In addition, the ERT recommends that the Party include in the NIR the information contained in the spreadsheet provided to the ERT during the review on the split of the areas for deforestation.	**Resolved.** New Zealand has included this information in chapter 11, section 11.5.3.
KP-LULUCF – Forest management – CO_2	KL.8, 2017	Include information in the NIR on which areas/categories of forest land (as in CRF table 4.A) are related to the areas of forest management in CRF table 4(KP-I)B.1.	**Resolved.** New Zealand has included this information in chapter 11, table 11.3.3, of the 2020 submission.
KP-LULUCF – Forest management – CO_2	KL.9, 2017	Report on the area subject to the carbon equivalent forest provision and associated emissions in CRF table 4(KP-1)B.1.2, starting with the next submission, and provide additional information on the difference between the assumptions on carbon equivalent forest AD made in the original/revised FMRL submissions and the actual AD in the GHG inventory.	**Resolved.** New Zealand has begun reporting on carbon equivalent forests since its 2018 submission.

Chapter 10: References

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Chapter 11: KP-LULUCF

11.1 General information

Emissions summary

2018

In 2018, net emissions from land subject to Article 3.3 and Article 3.4 activities under the Kyoto Protocol were –29,346.0 kilotonnes carbon dioxide equivalent (kt CO_2-e) (table 11.1.1). This is comparable to net emissions in the previous five years.

In 2018, net emissions from *Afforestation and reforestation* and *Deforestation* activities were –15,447.0 kt CO_2-e. This value is the total of all emissions and removals from activities under Decision 2/CMP.7, Article 3.3 of the Kyoto Protocol. It includes removals from growth, emissions from harvesting, and emissions and removals from harvested wood products in post-1989 forests; emissions from the conversion of land to post-1989 forest; and emissions from deforestation of all forest land and emissions from biomass burning and mineralisation of soil nitrogen associated with afforestation, reforestation or deforestation activities since 1990.

In 2018, net emissions from *Forest management* were –13,898.9 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	2017[P]	2018[P]
Afforestation and reforestation						
Net cumulative area since 1990 (ha)	677,229	679,128	680,963	683,921	689,747	698,497
Area in calendar year (ha)	4,530	3,447	3,502	4,281	6,461	9,443
Net emissions in calendar year (kt CO_2-e)	–17,542.2	–17,824.5	–18,066.9	–17,790.2	–17,790.2	–17,593.2
Deforestation						
Net cumulative area since 1990 (ha)	176,101	184,637	190,560	193,974	197,466	201,206
Area in calendar year (ha)	14,232	8,536	5,923	3,414	3,493	3,740
Net emissions in calendar year (kt CO_2-e)	9,525.6	5,667.4	3,640.3	1,821.5	1,977.1	2,146.2
Forest management						
Area included (ha)	9,224,080	9,217,093	9,212,837	9,211,357	9,210,186	9,208,933
Net emissions in calendar year (kt CO_2-e)	–18,487.6	–16,962.0	–15,470.4	–13,119.5	–13,136.0	–13,898.9
Total area included (ha)	**10,077,410**	**10,080,857**	**10,084,359**	**10,089,252**	**10,097,399**	**10,108,636**
Net emissions in calendar year (kt CO_2-e)	**–26,504.2**	**–29,119.1**	**–29,897.0**	**–29,088.2**	**–28,949.2**	**–29,346.0**
Accounting quantity (kt CO_2-e)	**–8,016.6**	**–12,157.1**	**–14,426.6**	**–15,968.7**	**–15,813.2**	**–15,447.0**

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 because 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 (all figures for 2017 and 2018 are provisional). Afforestation and deforestation differs from that in chapter 6 due to carbon equivalent forests being reported separately.

1990–2018

Between 1 January 1990 and 31 December 2018, 726,858 hectares of new forest (post-1989 forest) were established as a result of afforestation and reforestation activities – an average of 25,064 hectares per year. This figure is 28,361 hectares greater than the Kyoto Protocol defined area of afforestation and reforestation, due to subsequent deforestation activity that has occurred in these forests. During 2018, an estimated 9,443 hectares of new forest were planted, which is greater than the area planted in 2017 (6,461 hectares) (table 11.1.1).

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).

Deforestation of all subcategories of *Forest land* (post-1989, pre-1990 planted and pre-1990 natural forest) during 2018 was estimated at 3,740 hectares. Since 1990, the area of deforestation of all subcategories of *Forest land* is estimated as 201,206 hectares.

Between 1 January 1990 and 31 December 2018, the total area of *Forest management* land deforested was 173,356 hectares. However, due to the application of the carbon equivalent forest provision (Kyoto Protocol Supplement, IPCC, 2014a, section 2.7.2) the net area under *Forest management* only decreased by 165,841 hectares, or 1.8 per cent. This is the result of:

- 165,841 hectares of land being transferred from Article 3.4 – *Forest management* reporting to Article 3.3 – *Deforestation* reporting due to deforestation
- 3,422 hectares of land converted to a non-forest land use (*Carbon equivalent forest – harvested and converted (CEF_{HC})*) included in Article 3.4 – *Forest managemen*t reporting as a result of applying the carbon equivalent forest provision (Kyoto Protocol Supplement, IPCC, 2014a, section 2.7.2)
- 4,093 hectares of newly established forest (*Carbon equivalent forest – newly established (CEF_{NE})*) added to Article 3.4 – *Forest management* under the Kyoto Protocol as a result of applying the carbon equivalent forest provision (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 five 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	Net emissions for 2013–18 (kt) Source form	Source emission	CO_2-equivalent
Emissions from afforestation and reforestation	CO_2	–107,090.2	–107,090.2
Emissions from deforestation	CO_2	24,607.0	24,607.0
Emissions from forest management activities	CO_2	–91,166.8	–91,166.8
Mineralisation of soil nitrogen associated with land-use change	N_2O	1.5	457.7
Biomass burning	CH_4	7.8	194.1
Biomass burning	N_2O	0.32	94.5
Net emissions			**–172,903.7**

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, chapter 1).

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*[73] and *Deforestation* activities are reported under Article 3.3, along with emissions from *Deforestation* activities in pre-1990 natural and pre-1990 planted

[73] Including emissions from harvesting of post-1989 forest.

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.

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 2018, this covered 10,149,356 hectares, or 37.7 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 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, 2012 and 2016 land use maps
- an estimate of total afforestation for the period 2013 to 2018 from the National Exotic Forest Description (NEFD) (Ministry for Primary Industries, 2018b)
- deforestation mapping for 2008 to 2016 (Indufor Asia Pacific, 2013, 2016, 2018)
- estimates for 2017 and 2018 deforestation based on the Deforestation Intentions Survey 2017 (Manley, 2018) and the Deforestation Intentions Survey 2018 (Manley, 2019).

Due to the land use category definitions used by New Zealand, which split forests established before 1990 from those established after 1989, the land transition matrix is 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 2018 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 aerial photography. For deforestation occurring between 2008 and 2016, 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 Methods 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 Subantarctic 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.

11.3 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 stored 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 2018, it is estimated that 729,769 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 2018 was 698,497 hectares. Emissions from this land in 2018 were –17,593.2 kt CO_2-e, compared with –17,790.2 kt CO_2-e in 2017. Of the total area afforested or reforested between 1990 and 2018, an estimated 31,272 hectares were deforested between 1990 and 2018 (table 11.3.1). The emissions for this area are reported under *Deforestation*.

The afforestation rate between 1990 and 2018 was, on average, 25,064 hectares per year. New planting rates were high from 1992 to 1998, averaging 62,152 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 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 until 2008. Between 2008 and 2012, planting rates began to increase again, 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. Both of these schemes, the Afforestation Grant Scheme and the Permanent Forest Sink Initiative, have subsequently been replaced by the One Billion Trees Fund in 2018 (Te Uru Rākau, 2018). The afforestation rate reduced after 2012. This is likely due in part to a significant drop in the price of carbon in the NZ ETS. Between 2013 and 2018, the average afforestation rate was 4,792 hectares. A total of 7,145 hectares were subject to *Afforestation and reforestation* activities in 2018.

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 recent 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 2013 and 2018 are obtained from a national survey of forest owners (Ministry for Primary Industries, 2018b) 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 2018

	Annual area of Afforestation and reforestation (ha)			
Year	Afforestation/reforestation+	Harvesting	Deforestation	Net cumulative area
1990	14,807	0	0	14,807
1991	14,454	0	0	29,260
1992	45,364	0	0	74,624
1993	55,418	0	0	130,042
1994	87,704	0	0	217,746
1995	66,432	0	0	284,178
1996	75,118	0	0	359,296
1997	57,737	0	0	417,033
1998	47,295	0	0	464,327
1999	37,377	0	0	501,705
2000	32,368	0	0	534,073

Year	Annual area of Afforestation and reforestation (ha) Afforestation/reforestation+	Harvesting	Deforestation	Net cumulative area
2001	29,313	0	0	563,387
2002	22,247	0	702	584,932
2003	20,963	0	2,213	603,682
2004	13,198	0	2,033	614,846
2005	9,388	200	2,313	621,921
2006	6,414	600	1,982	626,352
2007	6,435	600	4,759	628,029
2008	4,418	872	1,076	631,371
2009	7,561	988	2,023	636,909
2010	9,884	1,481	1,744	645,048
2011	17,799	1,656	2,270	660,577
2012	16,411	1,844	1,353	675,635
2013	4,530	3,577	2,936	677,229
2014	3,447	4,132	1,549	679,128
2015	3,502	4,855	1,667	680,963
2016	4,281	7,565	1,322	683,921
2017 P	6,461	8,210	635	689,747
2018P	9,443	9,477	692	698,497
Total	**729,769**	**46,057**	**31,272**	**698,497**

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.

Post-1989 forests include a relatively small component of natural forest. Table 11.3.2 provides synthesised information on the correspondence between forest land categories (i.e., the area of planted forest versus natural forest as presented in common reporting format (CRF) table 4.A) and the area of *Afforestation and reforestation* reported in CRF table 4(KP-1)A.1. Furthermore, table 11.3.3 details why the area reported under *Forest management* does not reconcile with the area reported for *Forest land remaining forest land* under the convention, due to forests reported under land in transition and carbon equivalent forests (CEFs). These tables have been added to address expert review team recommendation KL.5 (FCCC/ARR/2017/NZL).

Table 11.3.2 New Zealand's estimated annual area under Afforestation and reforestation from 2013 to 2018

Year	Cumulative area of Afforestation and reforestation of different forest types (hectares) Planted forest	Natural forest	Net cumulative area
2013	632,488	44,741	677,229
2014	634,266	44,862	679,128
2015	635,937	45,026	680,963
2016	637,799	46,122	683,921
2017	641,972	47,775	689,747
2018	649,430	49,067	698,497

Table 11.3.3 New Zealand's Afforestation and reforestation reconciliation between Kyoto Protocol and Intergovernmental Panel on Climate Change Convention reporting from 2008 to 2018

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Forest remaining forest (kha)	8,812.6	8,861.0	8,916.4	8,977.6	9,038.8	9,090.1	9,131.5	9,160.2	9,179.7	9,204.8	9,216.1
Forest management (kha)	9,267.7	9,259.6	9,250.7	9,244.1	9,235.4	9,224.1	9,217.1	9,212.8	9,211.4	9,210.2	9,208.9
Difference (kha)	**–455.1**	**–398.7**	**–334.3**	**–266.5**	**–196.6**	**–133.9**	**–85.6**	**–52.7**	**–31.7**	**–5.4**	**–7.2**
Land in transition (under a 28 year transition period)											
New forest planted before 1990 – included in FM (kha)	455.1	398.7	334.3	266.5	196.6	133.9	85.6	52.1	29.0	–	–
New forest planted after 1990 – included in A&R (kha)	–	–	–	–	–	–	–	–	–	–	14.7
Carbon equivalent forests											
CEF – Newly established	–	–	–	–	–	–	–	–	0.6	2.3	4.1
CEF – Harvested and converted	–	–	–	–	–	–	0.1	0.6	2.1	3.1	3.4
Total in Forest management but not Forest remaining forest	**455.1**	**398.7**	**334.3**	**266.5**	**196.6**	**133.9**	**85.6**	**52.7**	**31.7**	**5.4**	**7.2**

Note: A&R = Afforestation and reforestation; CEF = carbon equivalent forest; FM = Forest management; kha = kilohectare. Columns may not total due to rounding.

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)
- One Billion Trees Fund (Te Uru Rākau, 2018).

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. It aims 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, 38,643 hectares of forest have been established under the scheme.

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). In total, 21,022 hectares were registered under this scheme. The scheme was discontinued in 2018 and will be replaced by a permanent post-1989 forest category in the NZ ETS.

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). To date, 25,834 hectares of forest have been established under this scheme.

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. A second afforestation grant scheme was established in 2015, and 6,146 hectares of new forest were established under this scheme. The scheme was replaced by the One Billion Trees Fund in 2018.

The One Billion Trees Fund was established in 2018 to support individuals and groups across New Zealand to plant trees and manage land sustainably. Te Uru Rākau works in partnership with landowners and organisations to achieve the goal of planting 1 billion trees by 2028 (Te Uru Rākau, 2018).

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 2018, *Deforestation* emissions were 2,146.2 kt CO_2-e, compared with 1,977.1 kt CO_2-e in 2017. 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 2018 was 3,740 hectares. This is 7.1 per cent higher than the 2017 recalculated value, resulting in higher emissions reported under *Deforestation* in 2018.

Table 11.3.4 shows the areas of *Forest land* subject to *Deforestation* activities since 2008 by forest category.

Table 11.3.4 Area of New Zealand subject to deforestation

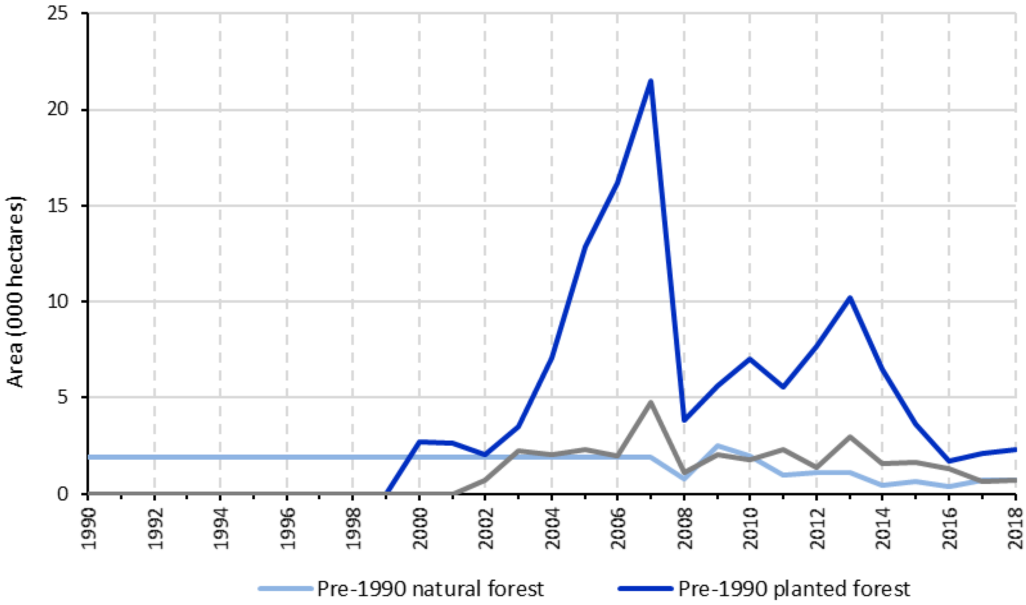
	Annual area of deforestation (ha)			
Year	**Pre-1990 natural forest**	**Pre-1990 planted forest**	**Post-1989 forest**	**Total**
2008	773	3,830	1,076	5,679
2009	2,480	5,612	2,023	10,115
2010	1,963	6,984	1,744	10,691
2011	1,004	5,546	2,270	8,821
2012	1,124	7,650	1,353	10,127
2013	1,120	10,175	2,936	14,232
2014	471	6,516	1,549	8,536
2015	612	3,644	1,667	5,923
2016	375	1,717	1,322	3,414
2017 P	740	2,117	635	3,493
2018P	740	2,308	692	3,740

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 the anticipated introduction of the NZ ETS.

Figure 11.3.1 New Zealand's annual areas of deforestation from 1990 to 2018



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. Carbon prices have since increased following 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. 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, because this is reported under Article 3.3 – *Deforestation*, and includes areas to which the carbon equivalent forest provision is applied.

In 2018, emissions on this land were –13,898.9 kt CO_2-e. This included emissions of –12,006.8 kt CO_2-e from harvested wood products originating from *Forest management*.

The total area remaining in *Forest management* at the end of 2018 was 9,208,933 hectares; this is a decrease of 165,841 hectares (or 1.8 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. This is because New Zealand applies the same methods to estimating emissions from *Forest management* activities as those applied to the equivalent land use categories of the inventory.

Where the land reported under *Forest management* has remained in the same land use sub-division for more than 20 years, mineral soil carbon stocks are assumed to have reached steady state. New Zealand models the effects of land use on mineral soil carbon based on empirical measurements collected from each land-use sub-division in steady state, specifically to model land-use change and management effects. The pre-1990 forests are subdivided into natural and planted forest types, which allows the different management methods to be taken into account. Where the land reported under *Forest management* is no longer in its native land use, irrespective of how long it has been in the land use, where organic soil is present, the soil organic carbon pool is an ongoing source of emissions, and these are reported. More detail is provided in chapter 6, section 6.3. This information has been added to address expert review team recommendation KL.4 (FCCC/ARR/2017/NZL).

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, per year). New Zealand's original FMRL was 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 and 2019 submissions. Details of these corrections are provided in annex 5.1. New Zealand undertook an additional technical correction for the 2019 submission, as discussed below and in annex 5.

The emissions for *Forest management* from 2013–18 were lower than the $FMRL_{corr}$ (technically corrected FMRL) of –9.42 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), was 11.150 Mt CO_2-e per year. For the 2016 submission, New Zealand submitted a technical correction of –17.25 Mt CO_2-e, correcting the FMRL to –6.10 Mt CO_2-e per year, to achieve consistency with the methods used for reporting of *Forest management*, including incorporating changes to *Harvested wood products*. In the 2019 submission, New Zealand submitted another technical correction, of –3.33 Mt CO_2-e, which when added to the 2016 technical correction now equals –20.57 Mt CO_2-e (rounded to two decimal places). New Zealand's technically corrected FMRL is now –9.42 Mt CO_2-e per year.

Carbon equivalent forests

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. New Zealand's carbon equivalent forests, between the 2013 and 2018 period, are summarised in table 11.3.5.

Table 11.3.5 Carbon equivalent forests (2013–18)

	2013	2014	2015	2016	2017	2018
CEF_{NE} area (ha)	NIL	–	–	612.34	1,685.68	1,795.02
Net emissions (t CO_2)	NA	–	–	–5.77	9.60	–9.85
CEF_{HC} area (ha)	NIL	52.02	543.40	1,463.21	1,041.72	321.45
Net emissions (t CO_2)	NA	44.76	469.00	1,260.66	888.10	268.14
Total (kt CO_2)	**NA**	**44.76**	**469.00**	**1,254.89**	**897.70**	**258.30**

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. NA = not available. 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 Decision 2/CMP.7 and 2013 supplementary Kyoto Protocol guidelines and the reporting under the 2006 IPCC Guidelines. 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 2018 *Afforestation and reforestation* were –2,804.5 kt CO_2-e; and for *Forest management* they were –12,006.8 kt CO_2-e.

New Zealand has a large planted forest estate that provides most of the wood products consumed domestically. The remainder of domestic production is 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 2018 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 *Wood-based 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 2018, a large proportion (approximately 60 per cent) of New Zealand's harvest was exported as raw materials in the form of logs or wood chips (Ministry for Primary Industries, 2018a). 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, 2016). 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 are 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 currently 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*).

Harvesting is the primary driver of emissions from *Forest management* land, specifically pre-1990 planted forest, for which emissions from harvested wood products are accounted for from 2013 onwards. Emissions from *Forest management* land comprised 83 per cent of the emissions from all planted forests in 2018. 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 products that 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 N_2O emissions from managed soils* (CRF 3.D). The notation key IE (included elsewhere) is reported in the 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 N_2O 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 tables 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 in a future 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 2018.

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 ±15.2 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 ±2.3 per cent (table 11.4.2).

The combined uncertainty in *Forest management* is ±53.9 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 2018

	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	±12.2	±6.5	±11.4	±12.2	±6.5	±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	**±15.2**	**±0.2**	**±1.3**	**±0.2**	**±7.1**	**±53.4**

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 ±56.0 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 2018

Variable	Uncertainty (%) at a 95% confidence interval
Afforestation and reforestation uncertainty introduced into emissions for Kyoto Protocol	±15.2
Deforestation uncertainty introduced into emissions for Kyoto Protocol	±2.3
Forest management uncertainty introduced into emissions for Kyoto Protocol	±53.9
Total uncertainty for Kyoto Protocol	**±56.0**

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 there has been an increase in the estimated total area of new planting for 2017, since the last submission. This is due to updated new planting data being provided by the NEFD survey (Ministry for Primary Industries, 2018b).

The total area of deforestation for 2017 has increased, compared with the estimate made for the 2019 submission. This is due to corrections made to the area of CEF_{HC} land deducted from the estimated area of deforestation occurring in 2017. In the last submission, an incorrect figure for 2017 CEF-hc was used leading to an underestimate of the area of 2017 deforestation area. This has been corrected in this submission.

Table 11.4.3 Recalculations of New Zealand's 2017 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 2017 (ha) 2019 submission	Area as at 2017 (ha) 2020 submission	Change from 2019 submission (%)
Afforestation and reforestation	680,086	689,747	1.4
Deforestation	200,161	197,466	–1.3
Forest management	9,245,248	9,210,186	–0.4
Activities occurring in 2017	**Area change in 2017 (ha)**		**Change from 2019 submission (%)**
New planting	4,979	6,461	29.8
Deforestation			
Pre-1990 natural forest	772	740	–4.1
Pre-1990 planted forest	1,713	2,117	23.6
Post-1989 forest	462	635	37.6

Emission factors

The post-1989 planted forest yield table has been revised for the 2020 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, 2017 and 2018. 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 chapter 6, section 6.4.2.

A revised analysis of the pre-1990 natural forest plot data was undertaken for the 2020 submission (Paul et al., unpublished). The revised analysis included a range of improvements that are outlined in chapter 6, section 6.4.2. The analysis of the data collected has provided a plot-based estimate of carbon stock and stock change within this forest type, and is further described in section 6.4.2.

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 2013–17 (Gg CO_2-e) 2019 submission	2020 submission	Change from 2019 submission (%)
Afforestation and reforestation	–88,184.1	–89,014.1	–0.9
Deforestation	22,846.9	22,631.8	0.9
Forest management	–91,428.1	–77,138.8	15.6
Total	**–156,765.3**	**–143,521.1**	**8.4**

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 in a future 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 (on a five-year cycle). These data are being incorporated into the inventory annually, as they become available.

The pre-1990 natural forest ground plot inventory is currently being re-measured on a continuous basis (on a 10-year cycle). Work is also under way to improve the classification of pre-1990 natural forest into its tall and regenerating components. These data will be incorporated into the National Inventory Report as they become available.

The re-measurement of the post-1989 natural forest ground plot inventory has recently been completed. These data are currently being analysed, and new emissions factors for this forest type will be available for inclusion in the 2021 submission.

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, 2012 and 2016 land use maps.

Other mapping improvements planned for the coming year include the development of a methodology to determine the age cohorts for forest planted after 1990.

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* occurring in each year is estimated from the NEFD survey, which includes information from the Afforestation Grant Scheme and the East Coast Forestry Project (Ministry for Primary Industries, 2018b). This information ensures that the activity is attributed to the correct year of onset. Note that the Afforestation Grant Scheme has now been replaced by the One Billion Trees Programme. However, the data for this new scheme will still be captured by the NEFD survey.

The annual area of *Deforestation* reported from 2008 to 2016 is based on wall-to-wall detection and mapping of deforestation activity supported by data from the NZ ETS. Deforestation is first detected using annual satellite imagery and confirmed using oblique and vertical aerial photography. The year of onset (destocking year) is therefore determined from the first year of detection of forest loss in the annual satellite imagery time series. Because deforestation mapping has not yet been carried out for 2017 or 2018 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 11.5.4. 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

Paragraph 5 of the annex to Decision 16/CMP.1 (UNFCCC, 2006) requires 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).

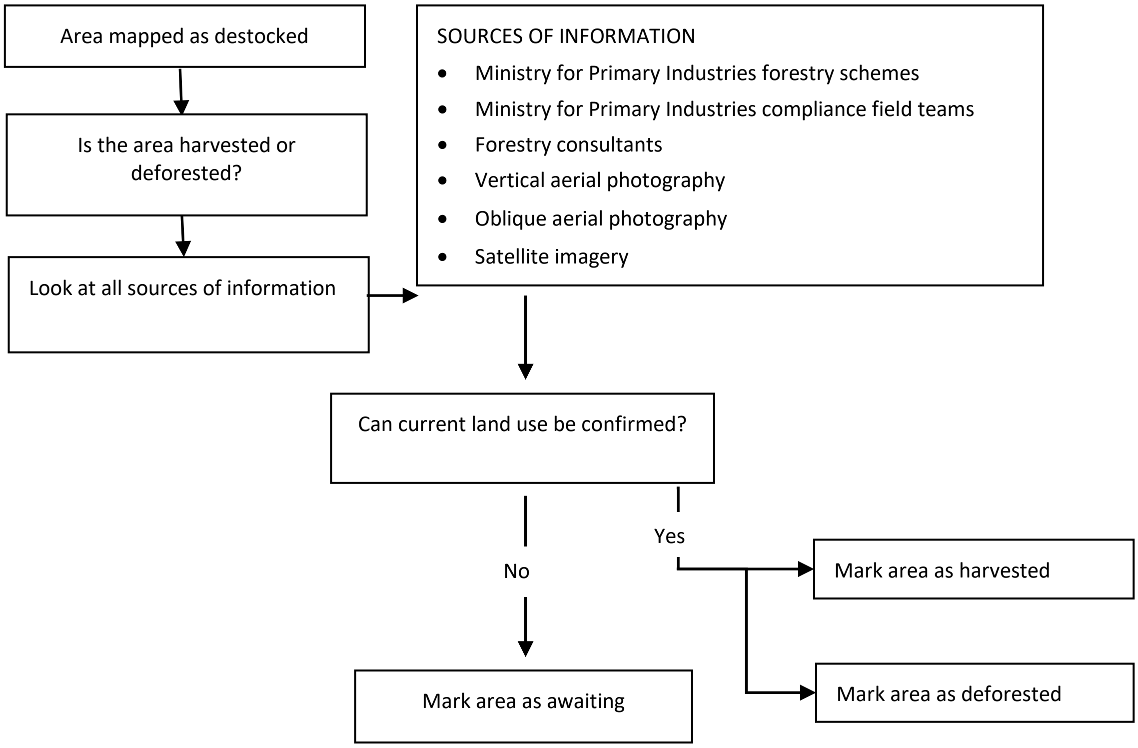
In New Zealand, temporarily unstocked or cleared areas of forest (e.g., harvested areas and areas subject to disturbances) remain designated as *Forest land* unless there is a confirmed change in land use or if, after four years, no reforestation (replanting or regeneration) has occurred. This follows the process for determining whether land is subject to direct human-induced deforestation as 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 aerial photography. The use of 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 (if they 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 Distinction between afforestation and grassland with woody biomass

For a shrubland area to be classed as post-1989 forest (and hence *Afforestation*), as opposed to grassland with woody biomass, it must meet a range of criteria including the forest definition criteria of having at least 30 per cent cover and being at least 1 hectare in size and 30 metres in width. It must also have the potential to reach 5 metres in height within a 30- to 40-year timeframe under current land management, and there must be evidence of intention for it do so.

This potential to reach 5 metres, and evidence of intention, is determined using a range of ancillary data including:

- NZ ETS forest mapping – if an area has been accepted into the NZ ETS this is considered to be strong evidence of afforestation. The area will have been checked to verify establishment date and the potential of the area to grow to 5 metres in height. The fact that the land owner has entered the area in the NZ ETS is strong evidence of intention to afforest
- location with respect to the treeline – shrub species located below but within 225 vertical metres of the treeline are not considered to have the potential to reach 5 metres in height within the required timeframe (Newsome et al., 2011)
- environmental conditions – there are a range of environmental conditions that limit growth of shrub species in New Zealand. These include, soil type, climatic conditions, geothermal activity and salt spray (Newsome et al., 2011). When a shrubland area falls within one of these zones of limitation, it is classed as grassland with woody biomass
- geographical context – shrubland areas in a grazing context are unlikely to grow to 5 metres in height unless there is evidence of stock exclusion, such as a fence line or a change to steep terrain (gully or hill), which provides a natural barrier to stock.

The decision tree relating this classification of shrubland areas is described in the grassland with woody biomass section of the Satellite Imagery Interpretation Guide for Land-Use Classes (Ministry for the Environment, 2012).

11.5.4 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 2016. 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 2014 to 2016 are shown in table 11.5.1.

Table 11.5.1 Estimate of land destocked in New Zealand between 2014 and 2016 awaiting a land use determination

Year of destocking	Pre-1990 natural forest (ha)	Pre-1990 planted forest (ha)	Post-1989 forest (ha)	Total (ha)
2014	258	3,008	1,691	4,957
2015	611	3,129	1,229	4,969
2016	790	6,052	2,974	9,816

Note: Rows may not total due to rounding. Deforestation mapping will take place over the summer of 2020. Land from 2014 and 2015 awaiting determination will be classified in the next inventory submission.

No estimates of awaiting land for 2017 and 2018 have been made because land use mapping has not been undertaken for these years. The *Deforestation* areas reported for 2017 and 2018 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 (see chapter 5).

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.

New Zealand applies a net–net approach thereby removing the need to factor out the above-mentioned processes. Net change in greenhouse gas emissions and removals are accounted by comparing greenhouse gas emissions and removals during the commitment period with a bench-mark business as usual scenario, 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

12.1.1 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.

12.1.2 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/climate-change/state-of-our-atmosphere-and-climate/new-zealands-greenhouse-gas-inventory).

General note

Abbreviations used in this chapter include:

AAUs	Assigned amount units
CDM	Clean Development Mechanism
CERs	Certified emission reduction units
ERUs	Emission reduction units
lCERs	Long-term certified emission reduction units
RMUs	Removal units
tCERS	Temporary certified emission reduction units

12.2 Summary of the standard electronic format tables for reporting Kyoto Protocol units

At the beginning of the calendar year 2019, 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 2019.

At the end of 2019, 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 2019.

The transactions made to New Zealand's national registry during 2019 are summarised below.

- No external transfers of Kyoto units occurred. A total of 89,912 AAUs and 3,154,698 ERUs were subtracted internally through voluntary cancellation. There were no conversions to ERUs. No CP2 Kyoto units were held by New Zealand during the 2019 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 2019 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 2019.
15/CMP.1 annex I.E, paragraph 13 & 14: List of CDM notifications	No CDM notifications occurred in 2019.
15/CMP.1 annex I.E, paragraph 1 15: List of non-replacements	No non-replacements occurred in 2019.
15/CMP.1 annex I.E, paragraph 1 15: List of invalid units	No invalid units exist as at 31 December 2019.
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:			

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
(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
(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 list 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.	No – the report provides a link to the project documentation on the UNFCCC site (https://ji.unfccc.int/JI_Parties/DB/E48QQ342M7VSOFWEI6MTBKVVF9NFAM/viewDFP) and is not replicated on the New Zealand's national registry website. The following information for each JI project is published: • 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. (Refer Public information and reports: Kyoto unit holdings by account. Use Search Criteria to find information about 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, lCERs, 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
(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 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

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
(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 2019 is:

Commitment period reserve (CPR) limit:	278,608,260
Units held:	512,290,486
CPR level:	512,290,486
CPR level = (% of assigned amount):	183.87%

CPR level comprises the following units:	
AAUs	308,131,270
ERUs (converted from AAUs)	107,296,223
CERs	16,262,930
RMUs	80,600,063
Total units	512,290,486

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 to the legal or institutional arrangements in the National Inventory system since the last Inventory submission (2019).

Changes in New Zealand's inventory system in the 2019 submission were associated with including greenhouse gas emissions from Tokelau in New Zealand's greenhouse gas inventory, following the extension of New Zealand's ratification of the United Nations Framework Convention on Climate Change and Paris Agreement to include Tokelau.

Chapter 1, section 1.2.2, outlines information on the responsibilities of both New Zealand's central inventory agency (Ministry for the Environment) and the Tokelau Department for Climate Change, as a result of these changes.

Details on how Tokelau's data and information are incorporated in the National Inventory Report, the Common Reporting Format, and quality assurance and quality procedures are outlined in chapter 8 and annex 6.

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 2019 submission are included in table 14.1.

Recommendations were made in the review of New Zealand's 2019 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 discrepancy 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 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
NA	There were no recommendations to be addressed	NA

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, ETS Operations 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 actions to minimise adverse social, environmental and economic impacts on non-Annex I Parties of the implementation of climate change policies and measures, 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. These include:

- 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 and production
- 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).

Further information on actions and policies is included in *New Zealand's Fourth Biennial Report*, published in December 2019 (Ministry for the Environment, 2019).

In the development of major policy initiatives related to these mitigation measures, an analysis of impacts of the proposed policy is completed. As appropriate, the benefits and risks of proposed options, including those with possible international implications, are considered.

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 on non-Annex I Parties.

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. A similar approach is taken with New Zealand's Pacific regional and multi-country climate change activities. Discussions with partners and experts in the region were central to developing the current strategy for those regional activities.

Practice standards for activities funded by the Ministry of Foreign Affairs and Trade under the New Zealand Aid Programme include assessments and responses to environmental and climate-related impacts and risks (along with gender and human rights as the other significant cross-cutting issues).

In September 2015, the international community adopted the Sustainable Development Goals, 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 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.

As a critical element of long-term sustainable development efforts, Small Island Developing States continue to increase their uptake of renewable energy. The New Zealand Aid Programme supports a major push to increase this uptake in the Pacific and reduce the region's reliance on imported diesel. Further afield, the New Zealand Aid Programme supports several programmes to increase access to affordable, reliable and clean energy in Africa, the Caribbean and South East Asia.

The Sustainable Development Goals also include Goal 13, which calls for strengthened resilience and adaptive capacity, integration of climate change measures into national policies, strategies and planning, and mobilising finance from all sources to address the needs of developing countries. The New Zealand Aid Programme supports climate change adaptation, disaster risk reduction and humanitarian response to natural disasters.

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 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.

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.

New Zealand is a founding member of the Friends of Fossil Fuel Subsidy Reform. This is an informal group of non-Group of Twenty (G20) countries that aims to build international political consensus on the importance of fossil fuel subsidy reform, including as a major contribution to climate change mitigation. The group's support for reform is based on the essential notion that it is incoherent to continue to subsidise 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 with the Friends group to encourage and support the G20 and Asia-Pacific Economic Cooperation (APEC) economies to meet their commitments to reform inefficient fossil fuel subsidies through the peer review process. In 2018, New Zealand participated in the peer review panels for Italy and Indonesia.

In December 2017, New Zealand delivered a Ministerial Statement to the World Trade Organisation (WTO), encouraging Members to address the global harm being caused by inefficient fossil fuel subsidies. Endorsed by 11 other WTO Members, the statement confirms the environmental, development and trade benefits of fossil fuel subsidy reform, and includes a political commitment to look at avenues to bring the issue into the WTO. New Zealand will also lead a renewed Ministerial Statement at the next WTO Ministerial Conference in June 2020.

In addition to previous events, New Zealand hosted a side event on fossil fuel subsidy reform at the United Nations High-Level Political Forum in July 2018. This event focused on improving energy access and responding to the Sustainable Development Goals through the phase out of fossil fuel subsidies.

At the twenty-fourth session of the Conference of the Parties (COP24) of the United Nations Framework Convention on Climate Change in December 2018, New Zealand helped launch a 'Friends Network' to broaden understanding of the need for reform and practical ways to achieve it. The Network held a series of five virtual interactive roundtables, which took place in 2019 with the participation of representatives from around 20 countries from around the world.

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, less than 10 per cent of the region's gross domestic product is expended on imported fossil fuel, and less than 70 per cent of electricity generation depends on the combustion of diesel, although actual figures vary widely between countries.

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 the Pacific, 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 all eight countries of interest, as well as in Niue, Tokelau and the North Pacific states of Nauru, Palau, Republic of Marshall Islands and the Federated States of Micronesia.

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 and uses its strong credentials in the IRENA Assemblies to support Pacific and Small Island Developing States issues. 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. Since 2016, New Zealand has provided technical support to the Government of Indonesia to identify suitable areas for geothermal development, improve clarity and communication of the regulatory framework, and increase certainty around geothermal resource size and classification. New Zealand is also providing scholarships in geothermal project management, a programme of training, coordinated technical assistance and capacity building to strengthen Indonesia's local skill base and ability to sustainably operate, manage and maintain geothermal 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.

Chapter 15: Reference

Ministry for the Environment. 2019. New Zealand’s Fourth Biennial Report under the United Nations Framework Convention on Climate Change. Wellington: Ministry for the Environment.