1990–2021

Te Rārangi Haurehu Kati Mahana a Aotearoa

New Zealand's Greenhouse Gas Inventory

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

Volume 1, chapters 1–15

Ministry for the Environment
Manatū Mō Te Taiao

Te Kāwanatanga o Aotearoa
New Zealand Government

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Abbreviations

AAP	average animal population
AAU	assigned amount unit
AD	activity data
AGB	above-ground biomass
AIC	Akaike information criterion
ANZSIC	Australian and New Zealand Standard Industrial Classification
APC	Agricultural Production Census
APEC	Asia-Pacific Economic Cooperation
APS	Agricultural Production Survey
ARR	assessment review report
BGB	below-ground biomass
BOD	biochemical oxygen demand
BRANZ	Building Research Association of New Zealand
C	carbon
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)
CER	certified emission reduction unit
CF_4	perfluoromethane
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
CSC	carbon stock change
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DCD	dicyandiamide
DDOC	decomposable degradable organic carbon
DEF	diesel exhaust fluid
DMD	dry-matter digestibility
DMI	dry-matter intake
DOC	degradable organic carbon
DOCf	fraction of degradable organic carbon
DPFI	Delivery of Petroleum Fuels by Industry survey
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
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
FFSR	Fossil Fuel Subsidy Reform
$FMRL_{corr}$	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
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
HFO	hydrofluoroolefin
IAE	International Energy Agency
IDC	International Development Cooperation
IE	included elsewhere
IEF	implied emission factor
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Processes and Product Use
IRENA	International Renewable Energy Agency
kg	kilogram(s)
kha	kilohectare(s)
kJ	kilojoule(s)
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 and 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 conversion 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 of Climate, Oceans and Resilience (Tokelau)

MJ	megajoule(s)
MOS	Monthly Oil Supply survey
MPI	Ministry for Primary Industries
MSW	municipal waste disposal
Mt	megatonne(s) or million tonne(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
NO_x	nitrogen oxides (other than nitrous oxide)
NSO	National Statistics Office (Tokelau)
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)
PRIF	Pacific Regional Infrastructure Facility
PSP	permanent sample plot
PV	photovoltaics
QA	quality assurance
QC	quality control
RGG	Reporting Governance Group
RMU	removal unit
SDGs	Sustainable Development Goals

SEF	standard electronic format
SF_6	sulphur hexafluoride
SIDS	Small Island Developing States
SO_2	sulphur dioxide
SOC	soil organic carbon
Soil CMS	Soil Carbon Monitoring System
SWDS	solid waste disposable sites
t	tonne(s)
t C	tonne(s) carbon
TACCC	transparency, accuracy, completeness, consistency and comparability
tCER	temporary certified emission reduction unit
TJ	terajoule(s)
TOW	total organic product in wastewater
UEF	unique emission factor
UNFCCC	United Nations Framework Convention on Climate Change
WTO	World Trade Organization

Executive summary

The 2023 inventory submission contains national greenhouse gas emission estimates for the period 1990 to 2021.

Key points

In 2021

- New Zealand's gross greenhouse gas emissions were 76,825 kilotonnes carbon dioxide equivalent (kt CO_2-e), comprising 45 per cent carbon dioxide, 43 per cent methane, 10 per cent nitrous oxide and 2 per cent fluorinated gases.
- The Agriculture sector, at 49 per cent, and Energy sector, at 41 per cent, were the two largest contributors to gross emissions.
- The Land Use, Land-Use Change and Forestry (LULUCF) sector offset 27 per cent of New Zealand's gross emissions.
- New Zealand's net emissions were 55,746 kt CO_2-e.

Since 1990

- New Zealand's gross and net emissions peaked in 2006.
- New Zealand's gross emissions increased by 19 per cent (12,105 kt CO_2-e). The five emissions sources that contributed the most to this increase were:
  - enteric fermentation from an increase in the dairy cattle population (methane)
  - fuel use in road transport due to traffic growth (carbon dioxide)
  - increased fertiliser use on agricultural soils (nitrous oxide)
  - fuel use in manufacturing industries and construction due to economic growth (carbon dioxide)
  - industrial and household refrigeration and air-conditioning systems from increased use of hydrofluorocarbon refrigerants that replaced ozone depleting substances.
- Emissions from the Waste sector decreased by 18 per cent (730 kt CO_2-e) due to ongoing improvements in the management of solid waste disposal at municipal landfills.
- New Zealand's net emissions increased by 25 per cent (11,198 kt CO_2-e) due to the underlying increase in gross emissions.

Between 2020 and 2021

- Gross emissions decreased by 0.7 per cent, which was largely because of a decrease in emissions from the Agriculture sector (by 1.5 per cent or 574 kt CO_2-e). The decrease in Agriculture sector emissions was driven mainly by:
  - lower dairy cattle emissions (237 kt CO_2-e) due to a decrease in the dairy cattle population
  - lower synthetic nitrogen fertiliser emissions (178 kt CO_2-e) due to a decrease in fertiliser use
  - lower sheep emissions (161 kt CO_2-e) due to a decrease in the sheep population.
- Emissions from the Energy, Industrial Processes and Product Use, and Waste sectors changed by small annual variations of 0.3 per cent (93 kt CO_2-e), 0.6 per cent (27 kt CO_2-e) and –1.6 per cent (–52 kt CO_2-e), respectively.
- Net emissions increased by 3 per cent (1,658 kt CO_2-e), due to the overall decrease in net removals of 9 per cent (2,164 kt CO_2-e) from the LULUCF sector. This was driven by an increase in harvesting of post-1989 planted forests as harvest rates returned to business as usual in 2021. In 2020, harvest rates reduced slightly due to COVID-19 restrictions.

Methodological changes

- Improvements were introduced to the inventory this year that required emissions estimates to be recalculated across the time series back to 1990. The improvements that had the largest impacts on inventory estimates were:
  - the inclusion of non-pasture feed activities in the Agriculture Inventory Model (AIM) for dairy cattle, sheep and beef operations
  - improved estimates of within-year dairy cattle population change
  - improved modelling methods for estimating planted forest harvest and deforestation area.

ES.1 Background

New Zealand's Greenhouse Gas Inventory (the inventory) is the official annual estimate of all anthropogenic (human-induced) emissions and removals of greenhouse gases (GHGs) in New Zealand.

The inventory provides the official basis for measuring New Zealand's progress under the United Nations Framework Convention on Climate Change (the Convention) and for tracking its emissions reduction targets.

New Zealand ratified the Convention on 16 September 1993 and the Paris Agreement on 4 October 2016. This commits New Zealand to submitting an inventory under the Convention by 15 April of each year.

On 13 November 2017, New Zealand's ratification of the Convention and the Paris Agreement was extended to include Tokelau. Therefore, starting from the 2019 submission, GHG emissions and removals estimates from Tokelau have been included in New Zealand's inventory.

The inventory adheres to the reporting requirements as agreed under the Convention by including a comprehensive and detailed set of methodologies for estimating national sources and sinks of anthropogenic GHGs, and a common and consistent format that enables Parties to the Convention to compare the relative contribution of different emissions sources and GHGs to climate change.

The inventory submission is comprised of a national inventory report and a set of common reporting format (CRF) tables. The national inventory report is a narrative that presents key findings, major emissions trends and methodologies for estimating emissions and removals. It also includes sections on the inventory uncertainties, recalculations and improvements. The CRF contains inventory data that cover all emissions and removals in New Zealand. In addition, data on emission units and emission reduction units in the national registry, and any unit 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). These are the most important GHGs directly emitted by humans. Indirect GHGs are also included in this report; however, only emissions and removals of the direct GHGs are included in estimates of total national emissions under the Convention.

New Zealand's GHGs are reported under five sectors: Energy; Industrial Processes and Product Use (IPPU); Agriculture; Land Use, Land-Use Change and Forestry (LULUCF); and Waste. Tokelau's emissions are also reported separately by sector as 'Other'.

ES.2 National trends

Gross emissions

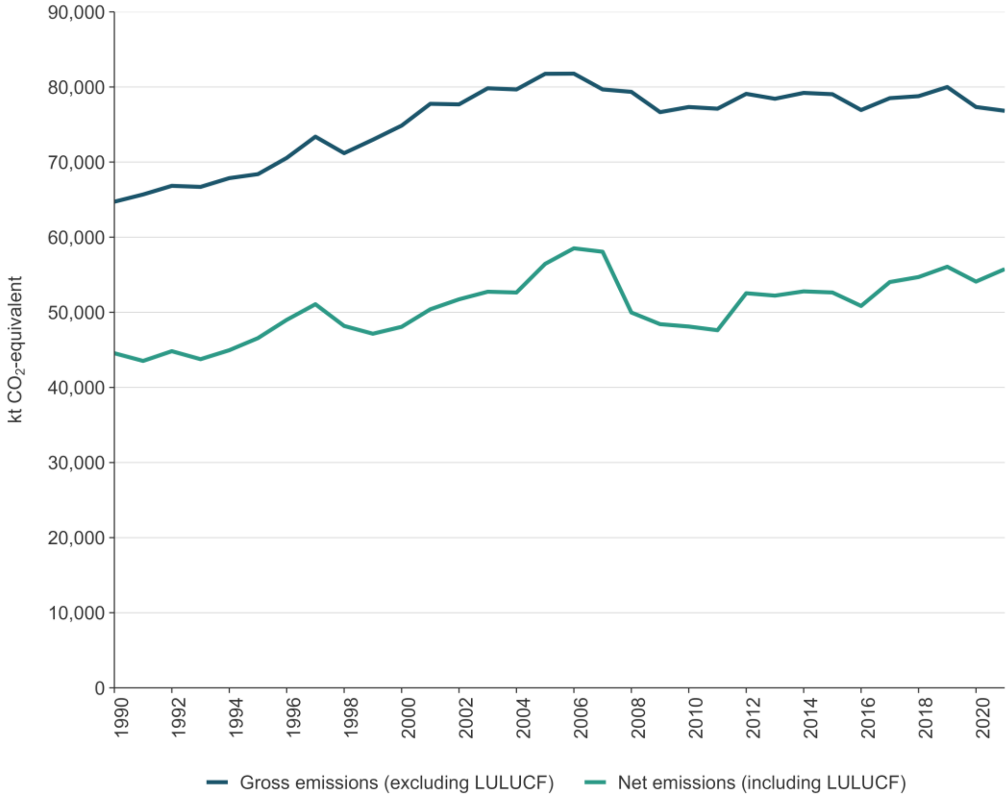
Gross emissions include those from the Energy, IPPU, Agriculture and Waste sectors, and Tokelau, but do not include emissions and removals from the LULUCF sector (UNFCCC, 2013).

1990–2021

In 1990, New Zealand's gross GHG emissions were 64,720.1 kilotonnes carbon dioxide equivalent (kt CO_2-e). Between 1990 and 2021, GHG emissions increased by 18.7 per cent (12,104.5 kt CO_2-e) to 76,824.6 kt CO_2-e in 2021 (see figure ES 2.1; and chapter 2, figure 2.1.1). From 1990 to 2021, the average annual growth in gross emissions was 0.6 per cent.

The emissions categories that contributed the most to this increase in gross emissions were: *Enteric fermentation*[1] from *Dairy cattle*, *Road transportation*, *Agricultural soils*, *Manufacturing industries and construction* (particularly from the *Chemicals* category) and *Product uses as substitutes for ODS*.[2]

Figure ES 2.1 New Zealand's gross and net emissions (under the Convention) from 1990 to 2021



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

2 'ODS' stands for ozone depleting substances.

2020–2021

Between 2020 and 2021, New Zealand's gross emissions decreased by 0.7 per cent (506.1 kt CO_2-e). The main cause was a decrease in emissions from the Agriculture sector of 1.5 per cent (574.1 kt CO_2-e) due to a decrease in fertiliser use and reduced populations of dairy cattle and sheep. The largest contributors to the overall decrease in emissions were from:

- *Agricultural soils* (N_2O)
- *Manufacturing industries and construction* (CO_2)
- *Public electricity and heat production* (CO_2).

The reductions in the *Manufacturing industries and construction* category were largely driven by a decrease in emissions from the *Chemicals* category of 17.6 per cent (272.5 kt CO_2-e) from 2020 levels. This drop was mostly due to the closure of Methanex's Waitara Valley methanol production plant.

The reductions in *Public electricity and heat production* were due to the increased share of electricity generated from renewable energy sources over this period, which displaced gas and coal-fired electricity generation.

Emissions from the Energy and IPPU sectors increased by 0.3 and 0.6 per cent respectively, while emissions from the Waste sector and Tokelau decreased by 1.6 and 9.5 per cent respectively.

New Zealand's COVID-19 response and protection framework[3] remained in place for the 2021 year. The pandemic continued to impact emissions in 2021, although to a lesser extent than in 2020. On 17 August 2021, all of New Zealand moved to the highest level of restriction.[4] The northern regions, including Auckland, remained under tighter restrictions on activities and movements for the rest of the year. While some parts of the economy rebounded, others continued to be impacted by New Zealand's COVID-19 response measures and the associated disruptions to global supply chains continued.

Net emissions – reporting under the Convention

Net emissions include gross emissions as defined above (i.e., from the Energy, IPPU, Agriculture and Waste sectors, including Tokelau) and net emissions from the LULUCF sector, as reported under the Convention.

In 1990, New Zealand's net emissions were 44,548.8 kt CO_2-e. Between 1990 and 2021, net GHG emissions increased by 25.1 per cent (11,197.6 kt CO_2-e) to 55,746.4 kt CO_2-e (see figure ES 2.1; and chapter 2, figure 2.1.1).

The four categories that contributed the most to the increase in net emissions between 1990 and 2021 were: *Land converted to forest land*, *Enteric fermentation from dairy cattle*, *Road transportation* and *Agricultural soils*.

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3 New Zealand Government. *About our COVID-19 response*. Retrieved from https://covid19.govt.nz/about-our-covid-19-response/ (22 March 2023).

4 New Zealand Government. *History of the COVID-19 alert system*. Retrieved from https://covid19.govt.nz/about-our-covid-19-response/history-of-the-covid-19-alert-system/ (22 March 2023).

Net emissions – reporting under the Kyoto Protocol

Reporting for the second commitment period (CP2) of the Kyoto Protocol (2013 to 2020) was covered in the previous (2022) inventory submission. While no further commitments have been taken under the Kyoto Protocol, it remains in force and therefore reporting requirements remain in place. In 2021, net removals were –26,854.5 kt CO_2-e from land subject to afforestation, reforestation, deforestation and forest management activities (see section ES.5 and chapter 11 for further detail).

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. No NF_3 data are included in this report because NF_3 emissions do not occur in New Zealand.

Table ES 3.1 provides a summary of emissions for each gas in 1990 and 2021 and the changes since 1990. This is also illustrated in figure ES 3.1.

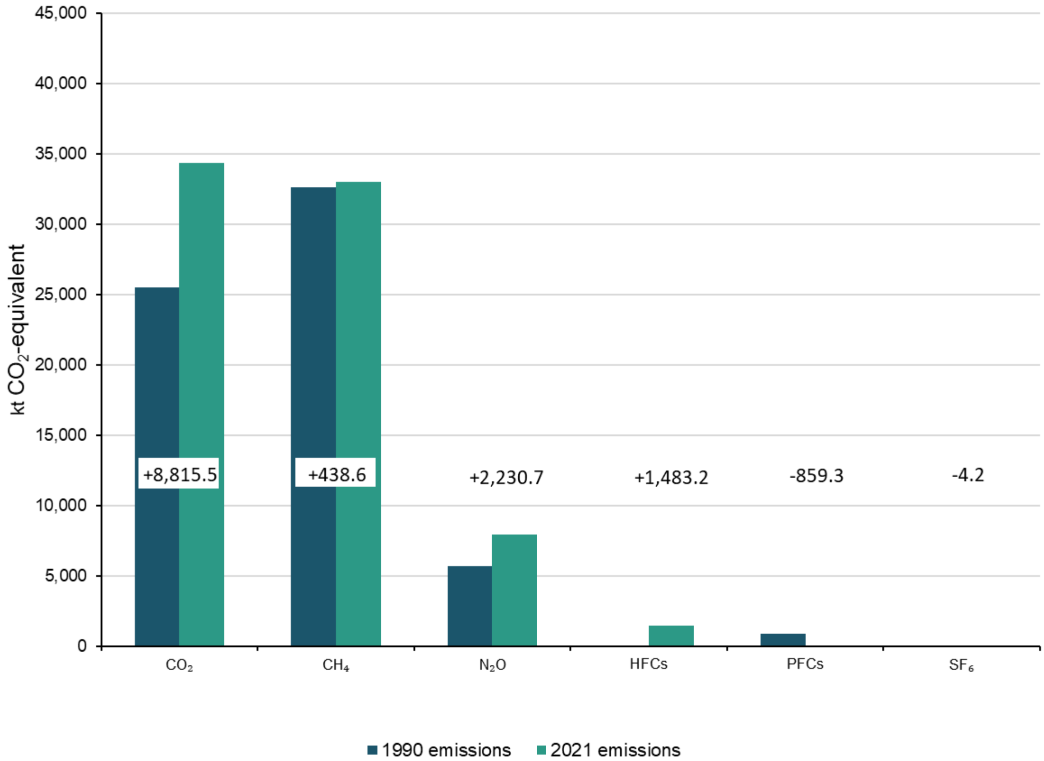
Table ES 3.1 New Zealand's gross emissions by gas in 1990 and 2021

Direct greenhouse gas emissions	1990	2021	Change from 1990 (kt CO_2-e)	Change from 1990 (%)
CO_2	25,502.5	34,318.0	8,815.5	34.6
CH_4	32,580.7	33,019.3	438.6	1.3
N_2O	5,706.9	7,937.6	2,230.7	39.1
HFCs	Not occurring	1,483.2	1,483.2	NA
PFCs	909.9	50.7	–859.3	–94.4
SF_6	20.0	15.7	–4.2	–21.2
Gross, all gases	**64,720.1**	**76,824.6**	**12,104.5**	**18.7**

Note: Gross emissions exclude net removal/s from the LULUCF sector. The percentage 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 3.1 presents for each gas the absolute change in gross emissions (LULUCF is excluded from the estimate of gross emissions), and the change between 1990 and 2021 estimates in kt CO_2-e.

Figure ES 3.1 New Zealand's gross emissions by gas in 1990 and 2021



In 1990, CH_4 made up the largest proportion of gross emissions, whereas in 2021, CO_2 contributed the largest proportion of gross emissions (see figure ES 3.1). While emissions of CH_4 have also increased over this time, the proportion of CH_4 relative to other gases in the inventory has decreased over the time series. Carbon dioxide emissions have increased by a greater amount over the period.

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 89.0 per cent of gross CO_2 emissions across the entire time series).

In 2021, removals from the LULUCF sector were –21,078.2 kt CO_2-e. This offset 27.4 per cent of New Zealand's gross emissions.

Between 1990 and 2021, the amount of CO_2-e removed from the atmosphere by the LULUCF sector increased by 4.5 per cent (906.9 kt CO_2-e) from the 1990 level of 20,171.2 kt CO_2-e. This is largely due to an increase in the production of harvested wood products, which have compensated for the emissions from the increase in forest harvesting.

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 2021 as well as the change between these years.

Table ES 3.2 New Zealand's indirect greenhouse gas emissions (excluding LULUCF) in 1990 and 2021

Indirect greenhouse gas emissions	1990	2021	Change from 1990 (kt CO_2-equivalent)	Change from 1990 (%)
CO	604.2	670.3	66.1	10.9
NMVOCs	143.7	178.8	35.1	24.4
NO_X	102.0	164.1	62.1	60.9
SO_2	58.6	72.1	13.5	23.1

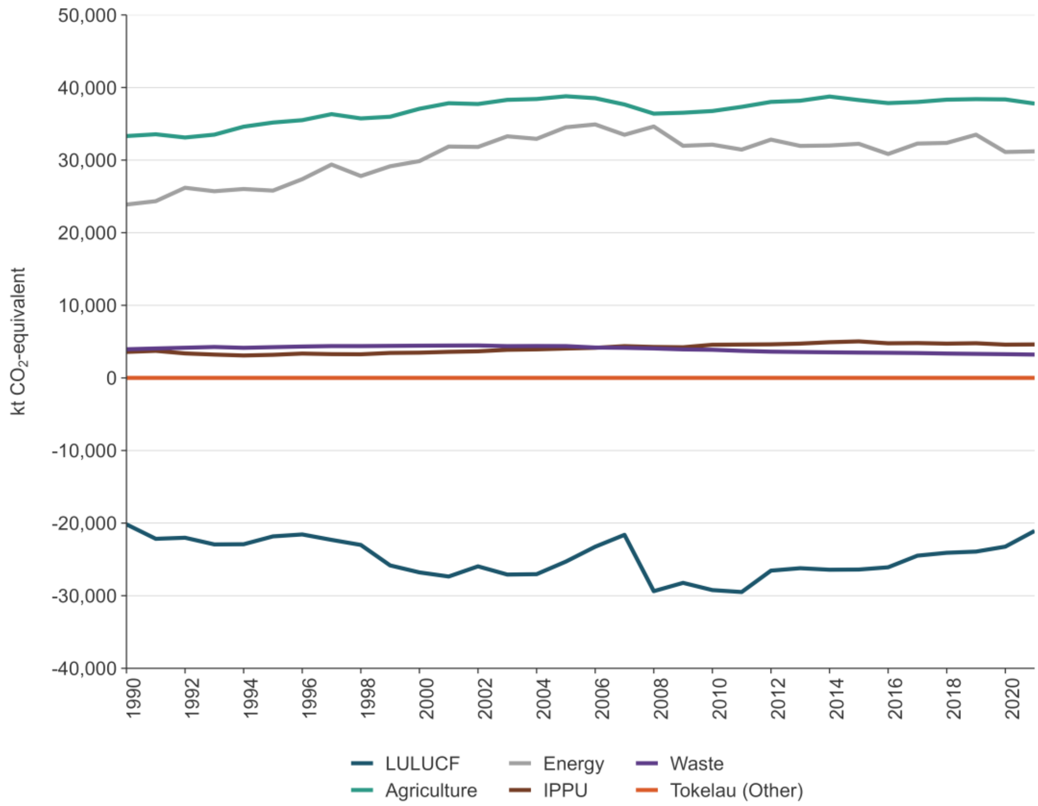
Note: Columns may not total due to rounding. Percentages presented are calculated from unrounded values.

ES.4 Sector trends

Figure ES 4.1 and figure 2.2.3 (chapter 2) show the contribution to net emissions that each inventory sector made. The Agriculture and Energy sectors dominated New Zealand's gross emissions. Together, these sectors produced almost 90 per cent of New Zealand's annual gross GHG emissions from 1990 to 2021. The IPPU and Waste sectors produced relatively small amounts of GHGs, contributing between 4 per cent and 6 per cent of the annual gross emissions for the entire time series.

Conversely, the LULUCF sector was a net sink of GHG emissions between 1990 and 2021.

Figure ES 4.1 Trends in New Zealand's greenhouse gas emissions by sector from 1990 to 2021



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

Table ES 4.1 and figure ES 4.2 summarise emissions by sector in 1990 and 2021 as well as the change between those years. A more detailed description of the emissions trends for each sector is presented in chapter 2.

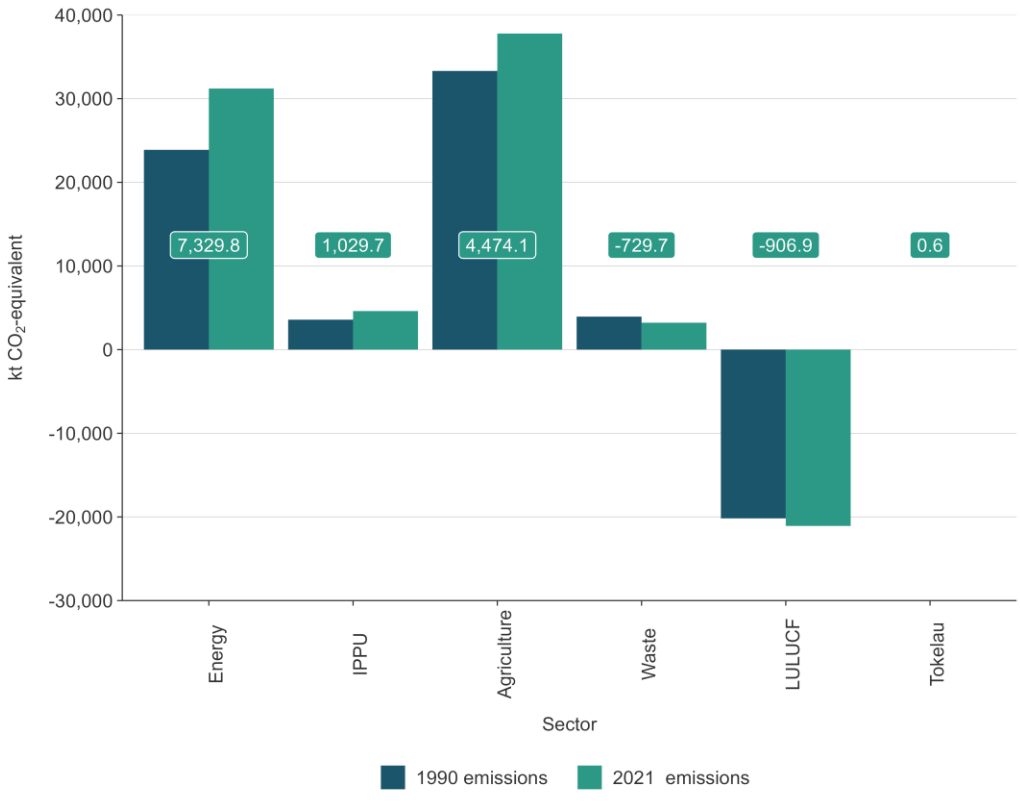
Table ES 4.1 New Zealand's emissions by sector in 1990 and 2021

Sector	1990	2021	Change from 1990 (kt CO_2-equivalent)	Change from 1990 (%)
Energy	23,880.3	31,210.1	7,329.8	30.7
IPPU	3,579.9	4,609.6	1,029.7	28.8
Agriculture	33,312.0	37,786.1	4,474.1	13.4
Waste	3,944.6	3,214.9	–729.7	–18.5
Tokelau	3.2	3.8	0.6	19.4
Gross	**64,720.1**	**76,824.6**	**12,104.5**	**18.7**
LULUCF	–20,171.2	–21,078.2	–906.9	–4.5
Net	**44,548.8**	**55,746.4**	**11,197.6**	**25.1**

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 4.2 presents the emissions estimates for each sector for 1990 and 2021, and the change between 1990 and 2021 estimates in kt CO_2-e.

Figure ES 4.2 Change in New Zealand's emissions by sector, comparing 1990 and 2021



Note: The Tokelau sector is not visible, due to its small total emissions value.

Energy (chapter 3)

2021

In 2021, emissions from the Energy sector contributed 40.6 per cent or 31,210.1 kt CO_2-e of New Zealand's gross GHG emissions (see chapter 2, figure 2.2.1).

The largest sources of emissions in the Energy sector were the *Road transportation* category, contributing 40.5 per cent (12,654.9 kt CO_2-e), and the *Manufacturing industries and construction* category, contributing 20.2 per cent (6,302.0 kt CO_2-e).

1990–2021

In 2021, emissions from the Energy sector were 31,210.1 kt CO_2-e, an increase of 30.7 per cent (7,329.8 kt CO_2-e) from the 1990 level of 23,880.3 kt CO_2-e. This growth in emissions is primarily from increases in:

- *Road transportation* (85.3 per cent; 5,825.8 kt CO_2-e)
- *Food processing, beverages and tobacco* (67.4 per cent; 1,127.5 kt CO_2-e)
- *Public electricity and heat production* (26.5 per cent; 926.5 kt CO_2-e).

In 2021, emissions from *Manufacture of solid fuels and other energy industries,* a historically significant contributor to New Zealand's emissions, were lower than the 1990 level by 85.3 per cent (1,463.9 kt CO_2-e). This decrease is primarily due to the cessation of synthetic gasoline production in 1997.

Figure 2.2.7 (chapter 2) shows the Energy sector emissions time series from 1990 to 2021. Emissions increased from 1990 to around 2005, before decreasing slightly and then remaining steady until the present day.

2020–2021

Between 2020 and 2021, emissions from the Energy sector increased by 0.3 per cent (93.2 kt CO_2-e). This is primarily due to the 5.0 per cent (606.2 kt CO_2-e) increase in emissions from category 1.A.3.b *Road transportation*, followed by a 42.7 per cent (118.1 kt CO_2-e) increase from category 1.A.2.f *Non-metallic minerals*. The increase was partially offset by category 1.A.2.c *Chemicals*, which decreased by 17.6 per cent (272.5 kt CO_2-e). A 4.4 per cent (200.9 kt CO_2-e) decrease also occurred in emissions from category 1.A.1.a *Public electricity and heat production*.

The 2020 calendar year saw disruptions to economic activity in New Zealand, with the effects of the COVID-19 pandemic being felt by the Energy sector throughout the year. The sector saw a rebound during 2021, but consumption remained below pre-2020 levels. All of New Zealand moved to Alert Level 4[5] on 17 August 2021. The northern regions of New Zealand, including Auckland, remained under tighter restrictions on activities and movements for the rest of 2021.

Restrictions on activities and movements as part of the response to the COVID-19 pandemic also affected the commercial and industrial sectors. Industries that were deemed non-essential faced restrictions on their operations, and continued disruptions to global supply chains affected business activity in New Zealand. The combination of COVID-19-related restrictions and global supply chain disruptions contributed significantly to decreases in business activity for basic metals and the mining sectors in particular.

IPPU (chapter 4)

2021

In 2021, emissions in the IPPU sector contributed 6.0 per cent (4,609.6 kt CO_2-e) of New Zealand's gross GHG emissions.

5 New Zealand Government. *History of the COVID-19 alert system*. Retrieved from https://covid19.govt.nz/about-our-covid-19-response/history-of-the-covid-19-alert-system/ (22 March 2023).

The largest category was the *Metal industry*, 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 contributed significant CO_2 emissions. Most of the non-CO_2 emissions came from the *Product uses as substitutes for ODS* category.

The IPPU sector also produced smaller amounts of CH_4 from methanol production and N_2O used for medical applications in the *Other product manufacture and use* category.

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*.

1990–2021

Emissions from the IPPU sector in 2021 were 4,609.6 kt CO_2-e, 28.8 per cent (1,029.7 kt CO_2-e) 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 ODS in refrigeration and air conditioning, and the increased use of household and commercial air conditioning.

Carbon dioxide emissions also increased due to the growing production of metals, lime and cement, but these increases were at a slower rate. In 2020 and 2021, the increase was offset by reduced emissions due to COVID-19 restrictions and the progressive shutdown of the Marsden Point oil refinery. 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.

2020–2021

Between 2020 and 2021, emissions from the IPPU sector increased by 0.6 per cent (26.7 kt CO_2-e).

This change was the result of a return to normal rates of production and emissions from the *Metal industry* and other categories, following plant shutdowns related to COVID-19 restrictions in 2020. New Zealand had a national lockdown in force from 26 March to 27 May 2020. Emissions from the Marsden Point oil refinery, however, remained at lower levels as the company prepared to shut the plant down in March 2022.

Agriculture (chapter 5)

2021

In 2021, emissions from the Agriculture sector totalled 37,786.1 kt CO_2-e, representing 49.2 per cent of New Zealand's gross emissions in 2021.

Enteric fermentation was the main source of Agriculture emissions, contributing 73.7 per cent (27,859.0 kt CO_2-e) of the sector's total. *Agricultural soils* contributed 19.4 per cent (7,315.2 kt CO_2-e), followed by *Manure management* at 4.4 per cent (1,680.5 kt CO_2-e) of the sector's total emissions. *Urea application* and *Liming* contributed 1.5 per cent (553.2 kt CO_2-e) and 0.9 per cent (355.6 kt CO_2-e) respectively. *Field burning of agricultural residues* contributed the remaining 0.1 per cent (22.6 kt CO_2-e).

Methane emissions from *Enteric fermentation* contributed 36.3 per cent (27,859.0 kt CO_2-e) of New Zealand's gross emissions, and N_2O emissions from the *Agricultural soils* category contributed 9.5 per cent (7,315.2 kt CO_2-e).

1990–2021

In 2021, New Zealand's Agriculture sector emissions were 37,786.1 kt CO_2-e, 13.4 per cent (4,474.1 kt CO_2-e) above the 1990 level of 33,312.0 kt CO_2-e.

The greatest contributions to the increase since 1990 were a 40.2 per cent (2,098.3 kt CO_2-e) increase in N_2O emissions from *Agricultural soils,* and a 117.7 per cent (849.9 kt CO_2-e) increase in CH_4 emissions from *Manure management*.

The increase in N_2O emissions from *Agricultural soils* was primarily a result of increased application of synthetic nitrogen fertiliser by around 644 per cent since 1990. This is partly due to an increase in dairy farming, as well as a general increase in fertiliser use on farms.

The increase in emissions from *Enteric fermentation* was driven by an increase in dairy cattle numbers, which was partially offset by a decrease in beef cattle and sheep numbers. Stock numbers have also reduced as a result of several voluntary initiatives driven by agricultural sector groups, which have focused on improving livestock genetics and championing the uptake of more sustainable farming practices. Alongside this, changes in New Zealand's regulatory environment, including improvements to freshwater quality and the New Zealand Emissions Trading Scheme (NZ ETS), are also likely to have led to reductions in stock numbers. The increasing carbon price in the NZ ETS has affected land-use change, with rising afforestation rates impacting stock numbers.

2020–2021

Between 2020 and 2021, total agricultural emissions decreased by 1.5 per cent (574.1 kt CO_2-e) largely due to a decrease in emissions from dairy cattle, sheep and synthetic nitrogen fertiliser. Specifically:

- dairy cattle emissions decreased by 1.3 per cent (236.9 kt CO_2-e), due to a decrease in the dairy cattle population
- synthetic nitrogen fertiliser emissions decreased by 9.5 per cent (177.9 kt CO_2-e), due to a decrease in fertiliser use
- sheep emissions decreased by 1.8 per cent (160.6 kt CO_2-e), due to a further decrease in the sheep population.

Emissions from other activities had minor increases and were not enough to offset the overall decrease in agricultural emissions. Some of these increases include:

- beef cattle emissions, which increased by 0.7 per cent (48.9 kt CO_2-e), due to a slight increase in the beef cattle population
- urea emissions, which increased by 2.1 per cent (11.2 kt CO_2-e), due to a small increase in the use of urea.

LULUCF (chapter 6)

The following information on LULUCF summarises reporting under the Convention. The Kyoto Protocol remains in force and reporting requirements remain in place. New Zealand, therefore, continues its reporting on LULUCF activities under the Kyoto Protocol in section ES.5 as well as in: chapter 2, section 2.3; and chapter 11.

2021

In 2021, net emissions from the LULUCF sector were –21,078.2 kt CO_2-e, or 27.4 per cent of New Zealand's gross GHG emissions. This comprises net removals of –21,358.2 kt of CO_2, and emissions of 32.6 kt CO_2-e of CH_4 and 247.4 kt CO_2-e of N_2O.

The category contributing the most to both removals and emissions is *Forest land remaining forest land*. This is because of large removals from the growth of all forests on *Forest land remaining forest land* and large emissions from the sustainable harvest of New Zealand's plantation forests.

1990–2021

Net emissions from the LULUCF sector were –21,078.2 kt CO_2-e in 2021, a 4.5 per cent (906.9 kt CO_2-e) decrease from the 1990 level of –20,171.2 kt CO_2-e. This is largely due to removals from forest growth and an increase in the production of harvested wood products, which have compensated for some of the emissions from the increase in forest harvesting.

Emissions in the LULUCF sector are primarily driven 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 the increase in the size of the harvested wood products pool. Nitrous oxide is emitted from soils as a by-product of nitrification and denitrification, and through the burning of organic matter. Other gases released during biomass burning include CH_4, CO, other oxides of nitrogen (NO_x) and NMVOCs.

The fluctuations in net emissions from the LULUCF sector (see chapter 2, figure 2.2.10) are primarily influenced by afforestation, harvesting and deforestation rates. Harvesting rates are driven by several factors, particularly forest age and log prices.

Net emissions in the LULUCF sector have been generally increasing over the past decade. Current harvest rates are near historic high levels due to the significant land-use changes to forest land that occurred from the 1980s to the early 1990s. The production forests that were established during this period have progressively been reaching maturity, and that will continue into the 2020s. As the high harvesting rates continue, the average age of the planted forest estate as a whole is reduced each year, as harvested forests are replanted. Young stands have low growth rates compared with older stands. Harvest and replanting cycles of New Zealand's planted forests will continue to affect the trajectory of New Zealand's net emissions in the future due to their uneven age-class profile.

Deforestation rates are driven by the relative profitability of forestry compared with alternative land uses. The increase in net emissions between 2004 and 2007 was mainly due to the increase in planted forest deforestation that occurred in the lead-up to 2008, and the introduction of the NZ ETS.[6]

From 2019 onwards, rates of afforestation have significantly increased. This is likely due to policy initiatives incentivising afforestation as well as higher carbon prices in the NZ ETS.

6 The NZ ETS included the Forestry sector from 1 January 2008.

2020–2021

Net emissions from the LULUCF sector increased between 2020 and 2021 by 9.3 per cent (2,163.9 kt CO_2-e).

The largest change occurred in the *Forest land* category, with an increase in emissions of 4,882.0 kt CO_2-e. The main reason for this change was an increase in harvest emissions between these years. In 2021, harvesting activities rebounded following the 2020 drop due to the COVID-19 restrictions. This impact was exacerbated by the ongoing high rate of harvesting occurring in New Zealand's production forests. As a result, the planted forest estate is composed of a higher proportion of young forest stands, which grow more slowly and sequester less carbon than older stands. The *Harvested wood products* category had the second-largest change, with a decrease in emissions of 1,824.3 kt CO_2-e, which was also driven by the harvest rate.

Waste (chapter 7)

2021

In 2021, emissions from the Waste sector contributed 4.2 per cent (3,214.9 kt CO_2-e) of New Zealand's gross GHG emissions. The largest source category is *Solid waste disposal*, as shown in chapter 7, table 7.1.1.

1990–2021

Emissions from the Waste sector decreased by 18.5 per cent (729.7 kt CO_2-e), from 3,944.6 kt CO_2-e in 1990 to 3,214.9 kt CO_2-e in 2021.

Annual emissions increased between 1990 and 2002, peaking at 4,470.0 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 in emissions is primarily the result of increased CH_4 recovery, driven by the National Environmental Standards for Air Quality introduced in 2004 and also by the NZ ETS since 2013. The trends are shown in: chapter 2, figure 2.2.11; and chapter 7, figures 7.1.2 and 7.1.3.

2020–2021

Between 2020 and 2021, emissions from the Waste sector decreased by 1.6 per cent (51.6 kt CO_2-e). This decrease is largely the result of decreases in CH_4 emissions in the *Managed waste disposal sites* category, which are mainly due to increasing landfill gas capture and changes in the composition of waste, with a reduction in the proportion of garden, food and paper waste disposed to those sites.

Other (Tokelau – chapter 8)

2021

In 2021, emissions from the Tokelau sector contributed 0.005 per cent (3.78 kt CO_2-e) of New Zealand's gross GHG emissions.

The largest source category is *Domestic navigation*, which contributed 69.0 per cent (1.38 kt CO_2-e) of all energy emissions and 36.6 per cent of gross emissions from Tokelau.

Carbon dioxide dominated emissions from Tokelau, contributing 53.6 per cent (2.03 kt CO_2-e) of its total emissions in 2021. At 1.99 kt CO_2-e, the Energy sector contributed 98.1 per cent of total CO_2 emissions, mostly from *Domestic navigation,* with the remaining 1.9 per cent (0.04 kt CO_2-e) coming from *Open burning of waste* in the Waste sector.

Methane emissions contributed 39.1 per cent (1.48 kt CO_2-e) to the total emissions from Tokelau. The Agriculture sector in Tokelau contributed 55.8 per cent of CH_4 emissions (0.82 kt CO_2-e), which mostly came from *Manure management*. A significant portion of CH_4 emissions, 43.8 per cent (0.65 kt CO_2-e), came from the Waste sector, largely from *Solid waste disposal*. The Energy sector contributed the remaining 0.4 per cent of CH_4 emissions (0.01 kt CO_2-e), which mostly came from *Domestic navigation*.

Nitrous oxide emissions contributed 1.2 per cent (0.05 kt CO_2-e) to the total emissions from Tokelau. The *Medical applications* category in the IPPU sector contributed the largest amount of N_2O, 47.9 per cent (0.02 kt CO_2-e) of the total N_2O. The Energy sector contributed a further 27.3 per cent (0.01 kt CO_2-e), which was largely from *Domestic navigation*. The Waste sector contributed the remaining 24.7 per cent of N_2O (0.01 kt CO_2-e) from *Open burning*.

Emissions of fluorinated gases from Tokelau consisted of HFC emissions only, contributing 6.2 per cent (0.23 kt CO_2-e) to the total emissions from Tokelau. These emissions largely resulted from the use of air conditioning. Emissions of PFCs, nitrogen trifluoride and sulphur hexafluoride are not occurring in Tokelau.

1990–2021

In 1990, total emissions from Tokelau were 3.17 kt CO_2-e. Between 1990 and 2021, the total emissions increased by 19.4 per cent (0.61 kt CO_2-e) to 3.78 kt CO_2-e (chapter 8, table 8.1.1). From 1990 to 2021, the average annual increase in gross emissions was 0.75 per cent.

The emissions categories that contributed the most to this change were *Domestic navigation* and *Electricity generation*.

The changes in *Domestic navigation* were a result of Tokelau gaining ownership and use of the ferry *Mataliki* in 2016, cargo vessel *Kalopaga* in 2018 and *Fetu o te Moana* in 2019, which led to an increasing number of sea voyages between the atolls and so increased transport emissions. Emissions from Tokelau's IPPU sector have also increased mainly due to the introduction of air conditioning after 2006. Further changes in Tokelau's Energy sector emissions are, first, a significant rise (by nearly 400 per cent) and then a major drop (by 82.5 per cent) in the consumption of imported petroleum products used for electricity production in Tokelau. Emissions from Tokelau's Agriculture sector decreased slightly as a result of a reduced swine population.

2020–2021

Total Tokelau emissions in 2021 were 9.5 per cent (0.40 kt CO_2-e) lower than emissions in 2020. The lower emissions were largely the result of decreases in CO_2 emissions in the *Domestic navigation* category.

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

Reporting for CP2 of the Kyoto Protocol (2013 to 2020) was covered in the previous inventory submission. No further commitments have been taken under the Kyoto Protocol. New Zealand has taken its next emissions reduction target under the Paris Agreement, reporting for which begins in 2024. The 1997 Kyoto Protocol, however, technically remains in force and its reporting requirements still apply. New Zealand, therefore, continues to provide supplementary information required under the Kyoto Protocol in this submission.

New Zealand reports on activities under Articles 3.3 and 3.4 of the Kyoto Protocol for the year 2021 (table ES.5.1). The Ministry for the Environment monitors trends in land use by tracking forest land use and periodically producing 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 provisional estimate[7] of *Afforestation and reforestation* for 2021 is 54,268 hectares. In 2021, net removals were 11,488.3 kt CO_2-e.

Deforestation

The provisional estimated area subject to *Deforestation* in 2021 was 2,493 hectares. In 2021, net emissions from *Deforestation* were 1,391.0 kt CO_2-e.

Forest management

The total area reported under *Forest management* at the end of 2021 was 9,195,721 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 2021 were 16,757.3 kt CO_2-e, including net removals of 7,823.3 kt CO_2-e from the *Harvested wood products* category.

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

Activity	2021[P]
Afforestation and reforestation	
Net cumulative area since 1990 (ha)	824,073
Area in calendar year (ha)	54,268
Net emissions in calendar year (kt CO_2-e)	–11,488.3
Deforestation	
Net cumulative area since 1990 (ha)	224,591
Area in calendar year (ha)	2,493
Net emissions in calendar year (kt CO_2-e)	1,391.0

7 The estimate for 2020 was based on the Afforestation and Deforestation Intentions Survey 2020 (Manley, 2021) as mapped data are not available. The methods used to estimate *Afforestation and reforestation* activities are described further in annex 3, section A3.2.2.

Activity	2021[P]
Forest management	
Area included (ha)	9,195,721
Net emissions in calendar year (kt CO_2-e)	–16,757.3
Total area included (ha)	**10,360,974**
Net emissions in calendar year (kt CO_2-e)	**–26,854.5**

Note: Where net emissions result in removals, they are expressed as a negative value as per section 2.2.3 of the Intergovernmental Panel on Climate Change Guidelines (IPCC, 2006). Columns may not total due to rounding. P = figures for 2021 are provisional. *Afforestation and deforestation* activity differs from that in chapter 6 because carbon equivalent forests are reported separately.

ES.6 Improvements introduced

The inventory follows a process of continuous improvement consistent with the Intergovernmental Panel on Climate Change (IPCC) principles. The IPCC 2006 Guidelines (IPCC, 2006) provide guidance on building and maintaining inventories that are consistent, comparable, complete, accurate and transparent in a manner that improves inventory quality over time. 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 submission.

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

Energy (chapter 3)

An improvement to the estimation of fugitive emissions from natural gas distribution networks has been introduced for the 2023 submission. Other improvements in accuracy have resulted from the standard revision of activity data. Energy activity data for the years 1990 to 2020 have been updated according to the latest energy statistics published by the Ministry of Business, Innovation and Employment (MBIE, 2021).

Projects to implement further improvements for the reference approach and sectoral approach are ongoing. Improvements have been made to the data management system for tracking and calculating emissions within the Energy sector. A further project to streamline and simplify the GHG reporting data system was completed in 2021. This project identified a number of minor inconsistencies, which were then addressed. Several upstream data systems, including the energy balance tables, have also been improved. Furthermore, work is progressing well on the construction of a new, comprehensive system for the data management of fuel properties. It is expected to be commissioned before the next submission. All source-specific planned improvements are discussed in their corresponding sections in chapter 3.

Changes to activity data in the Energy sector have resulted in a 0.01 per cent (2.4 kt CO_2-e) increase in estimated energy emissions in 1990 and a 1.1 per cent (344.5 kt CO_2-e) decrease in estimated energy emissions in 2020.

IPPU (chapter 4)

For the 2023 submission, amounts of refrigerant added to equipment in the *Refrigeration and air conditioning* category were re-estimated to better account for changes in stocks held by importers and users. Chapter 4, section 4.1.7 contains more details about improvements and recalculations for the IPPU sector.

Improvements and recalculations made in the IPPU sector have resulted in no change for 1990 and a 0.8 per cent (35.5 kt CO_2-e) decrease in emissions estimates for 2020.

Agriculture (chapter 5)

New Zealand has made the following improvements and corrections to the Agriculture sector.

- $Frac_{LEACH}$ values for grazing system and synthetic nitrogen have been updated for the entire time series (from 1990 to 2021). For details on this improvement, see: chapter 5, section 5.5.5; chapter 10, section 10.1.3; and annex 3.
- An improved dairy cattle population model has been implemented for the entire time series (1990 to 2021). For details on this improvement, see: chapter 5, section 5.1.4; chapter 10, section 10.1.3; and annex 3.
- Feed quality values have been updated for *Dairy cattle*, *Non-dairy* (beef) *cattle* and *Sheep* to reflect pasture and non-pasture feed use for the entire time series (1990 to 2021). For details on this improvement, see: chapter 5, section 5.1.3; chapter 10, section 10.1.3; and annex 3.
- Minor errors in the deer calculations have been corrected for the entire time series (1990 to 2021) and some activity data have been revised.

Improvements and recalculations made to the Agriculture sector in the 2023 submission have resulted in a 1.4 per cent (480.8 kt CO_2-e) decrease in estimated agricultural emissions in 1990 and a 2.7 per cent (1,065.4 kt CO_2-e) decrease in estimated agricultural emissions in 2020.

LULUCF (chapter 6)

The main differences between the 2023 submission and estimates of New Zealand's LULUCF net removals reported in the 2022 submission are as follows.

- Improvements to the method used to estimate deforestation for unmapped years have led to an increase in the estimated deforestation area for 2020. The overall net impact of this change to the LULUCF sector was an increase of 209 kt CO_2-e in 2020. This improvement was also largely responsible for the 41.2 per cent increase in emissions reported in the *Grassland* category for 2020 (given most deforested land is converted to grassland) (see chapter 6, section 6.3.5).
- A change was made in the estimated pre-1990 planted forest harvest area in 1988 to 1989. This drove an increase in the estimated deadwood decay in 1990, which increased the 1990 emissions estimate for the *Forest land* category (see chapter 6, section 6.3.6).
- This submission used country-specific above- and below-ground biomass carbon stocks for vegetated wetlands (Easdale et al., unpublished). Above-ground biomass carbon stocks were estimated as 20.22 tonnes of carbon per hectare (tC ha^{-1}) (11.07–29.38, at the 95 per cent confidence interval) and below-ground estimated as 7.40 tonnes C ha^{-1} (1.85–12.9, nominal error range). Previous submissions used a value of 0 for the carbon stock and carbon stock change of vegetated wetlands, which meant any emissions and removals for land transitioning in to and out of this class were not estimated

(see chapter 6, section 6.6.5). The overall net impact of this change to the LULUCF sector was a decrease of 16 kt CO_2-e in 2020 and a decrease of 39 kt CO_2-e in 1990.

Chapter 6, section 6.1.4 contains more details about improvements and recalculations for the LULUCF sector.

Improvements made to the LULUCF sector resulted in a 5.0 per cent (1,058.0 kt CO_2-e) decrease in net LULUCF removal estimates in 1990, and a 0.3 per cent (71.2 kt CO_2-e) decrease in net LULUCF removal estimates in 2020.

Waste (chapter 7)

Improvements and recalculations made to estimates in the Waste sector resulted in a 0.04 per cent (1.5 kt CO_2-e) increase in emissions in 1990 and a 0.1 per cent (2.4 kt CO_2-e) decrease in emissions in 2020.

Minor changes have been made that affect emissions as follows.

- Activity data for *Managed waste disposal sites* were revised for 2018, 2019 and 2020 to remove small amounts of cover material that should not be included in the waste tonnage.
- The Coulson Road landfill within the *Managed waste disposal sites* category stopped accepting waste in 2019. Therefore, the landfill gas capture rate was revised for the period of gas capture operation, beginning in 2018, from 68 per cent to 52 per cent (which is the value for closed sites). Furthermore, the Victoria Flats landfill had a gas capture system installed during 2021 and the estimate for 2021 reflects this.
- Activity data for *Composting* were revised upward to account for the effects of policy actions beginning in 2020.
- Activity data for *Industrial wastewater* were revised for the paper and paperboard and wood pulp industries due to revised statistics.

Further details can be found under methodological issues for each source category and also in chapter 10.

Other (Tokelau – chapter 8)

Recalculations made to emissions estimates in Tokelau resulted in no change for 1990 and a 0.004 per cent (0.0002 kt CO_2-e) increase in emissions in 2020.

Improvements to national inventory system

No changes were made in the legal or institutional arrangements in the national inventory system since the 2022 submission.

ES.7 National registry (chapters 12 and 14)

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 Environmental Protection Authority is designated as the agency responsible for implementing and operating 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 the first commitment period (CP1, covering the five-year period 2008 to 2012).

At the beginning of the 2022 calendar year, New Zealand's national registry held 308,343,858 CP1 assigned amount units (AAUs), 110,744,560 CP1 emission reduction units (ERUs), 21,685,909 CP1 certified emission reduction units (CERs) and 100,845,399 CP1 removal units (RMUs). The number and mix of units held at the end of 2022 were the same as at the beginning of 2022, 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 2022.

At the end of 2022, 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 temporary CERs or long-term CERs during 2022.

For further information, refer to chapters 12 and 14.

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Chapter 1: Introduction

1.1 Background

Greenhouse gases (GHGs) 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) Sixth Assessment Report (IPCC, 2021) confirms that the evidence showing humans have an influence on the climate system is unequivocal. Human-induced climate change is evident in extreme weather events all around the world. Events such as heatwaves, severe rainfall and droughts have become more frequent and extreme as a result of climate change and will continue to intensify.

Some of the changes to the climate system, including sea-level rise and loss of glaciers, are irreversible over centuries to millennia. The rate and magnitude of these committed changes, however, still depend on future greenhouse gas emissions. While the IPCC (2021) revised its estimate upwards of how much warming has occurred already, scenarios show that we can still limit warming to 1.5°C. To do that, the world must achieve net zero carbon dioxide (CO_2) emissions by around 2050 along with deep reductions in other greenhouse gases (IPCC, 2022).

1.1.1 United Nations Framework Convention on Climate Change

The IPCC assesses the science of climate change. In 1990, it 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 (UNFCCC or 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 take action to address climate change, including by monitoring trends in anthropogenic GHG emissions. Producing the annual inventory of GHG emissions and removals fulfils this obligation. Parties are also obliged to protect and enhance carbon sinks and reservoirs, for example, forests, and implement measures that assist in national and/or regional climate change adaptation and mitigation. In addition, Parties listed in Annex II[8] to the Convention

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

commit to providing technology transfer, capacity building and financial assistance to non-Annex I[9] Parties (developing country Parties).

Annex I Parties also agreed to 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 GHGs 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. New Zealand ratified the Paris Agreement on 4 October 2016. One result of the extension (as of 13 November 2017) of New Zealand's ratification of the Convention and the Paris Agreement to include Tokelau is that New Zealand's national inventory now includes GHG emissions and removals estimates from Tokelau. Since the 2019 submission, the inventory has included gross emissions from Tokelau.

1.1.2 Kyoto Protocol

The Kyoto Protocol operationalised the Convention by committing industrialised countries and countries with economies in transition to limit and reduce greenhouse gases emissions in accordance with agreed individual targets. The Convention itself only asks those countries to adopt policies and measures on mitigation and to report periodically.

The Kyoto Protocol expanded on 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 just applied to developed countries, or 'Annex I Parties' to the Convention.

The Kyoto Protocol placed a greater responsibility on Annex I Parties under the principle of "common but differentiated responsibility and respective capabilities". This recognised that these Parties are largely responsible for the current high levels of greenhouse gas emissions in the atmosphere.

New Zealand continues to be a Party to the Kyoto Protocol. While there are no current commitments in place, our reporting obligations under the Kyoto Protocol remain.

New Zealand has, therefore, completed supplementary activity-based reporting for Land Use, Land-Use Change and Forestry (LULUCF) as required under the Kyoto Protocol for the categories *Afforestation and reforestation* and *Deforestation*, and for *Forest management* for the 2021 reporting year. The definitions of afforestation, reforestation, deforestation and forest management activities are consistent with Decision 16/CMP.1 (UNFCCC, 2005a).

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

The information reported in this submission that relates to the Kyoto Protocol is provided to meet reporting obligations only.

As the accounting rules New Zealand applied under the Kyoto Protocol (for the period 2013 to 2020) differ from those that will be applied under the Paris Agreement, the numbers provided in this inventory cannot be used to track progress towards New Zealand's first Nationally Determined Contribution (NDC). New Zealand's approach to LULUCF accounting under the Paris Agreement is outlined in its first NDC[10] and will be fully described in its first communication under the Paris Agreement.

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 2006 IPCC Guidelines (IPCC, 2006) and in 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 for inventory reporting under the Convention are FCCC/CP/2013/10/Add.3 (UNFCCC, 2013a). In accordance with UNFCCC (2013a), New Zealand follows the 2006 IPCC Guidelines (IPCC, 2006) in preparing the inventory and applies the 100-year global warming potential values from the IPCC Fourth Assessment Report (IPCC, 2007).

A complete inventory submission contains two main components: the national inventory report (NIR) and the common reporting format (CRF) tables. Reporting for the second commitment period (CP2) of the Kyoto Protocol (2013 to 2020) was covered in the previous inventory submission. The standard electronic format (SEF) tables submitted with the previous inventory show holdings and transactions of units transferred and acquired under the Kyoto Protocol.

Inventories are subject to a technical review process administered by the UNFCCC secretariat. The results of these reviews are available on the Convention website (www.unfccc.int).

The inventory reports on emissions and removals of the gases carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3).[11] The indirect GHGs,[12] carbon monoxide (CO), sulphur dioxide (SO_2), oxides of nitrogen (NO_X) and non-methane volatile organic compounds (NMVOCs), are also included. Only emissions and removals of the direct GHGs (CO_2, CH_4, N_2O, SF_6, PFCs, HFCs and NF_3) are reported in total gross and net emissions under the Convention. The gases are reported under five sectors and gross emissions include those from Energy, Industrial Processes and Product Use (IPPU), Agriculture and Waste, but do not include emissions and removals from the LULUCF sector (UNFCCC, 2013a).

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10 The first communication is the submission of the first biennial transparency report (BTR1) and national inventory report, as required under the Paris Agreement, by 31 December 2024 at the latest.

11 Because NF_3 emissions do not occur in New Zealand, they are not included in this report.

12 Indirect GHGs 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 (e.g., where carbon monoxide is converted to carbon dioxide) or when chemical reactions in the atmosphere involving these gases change the concentrations of direct greenhouse gases.

Since the 2019 submission, GHG emissions from Tokelau, New Zealand's overseas dependent territory,[13] have been included in the inventory.

1.1.4 Supplementary information required

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

The supplementary information covers:

- information on emissions and removals for each activity under Article 3.3, and forest management 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 enacted the Climate Change Response Act 2002 (the Act).[14] This enabled New Zealand to meet its international obligations under the Convention and Kyoto Protocol. The Act has subsequently been amended to enable New Zealand to meet its obligations under the Paris Agreement. A Prime Ministerial directive for the administration of the 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 New Zealand's inventory agency are to:
    a) estimate annually New Zealand's human-induced emissions by sources and removals by sinks of greenhouse gases
    b) prepare all of 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

13 The United Nations Charter (United Nations, 1945) defines a non-self-governing territory 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 New Zealand's declaration of its intention to transmit information on the Tokelau Islands under Article 73e of the United Nations Charter.

14 The Climate Change Response Act has been amended several times since 2002. The Climate Change Response (Emissions Trading Reform) Amendment Act 2020, among other things, added reporting under the Paris Agreement to the functions of the inventory agency.

ii. report of information by New Zealand under Article 13 of the Paris Agreement[15]

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

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

a) identify source categories

b) 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)

c) estimate the emissions and removals by sinks for each source category

d) undertake assessments on uncertainties

e) undertake procedures to verify the data

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

Compliance provisions in section 36 of the Act authorise inspectors to collect information needed to estimate emissions or removals of GHGs.

1.2.2 Inventory planning, preparation and management

New Zealand has a national system in place for inventorying anthropogenic emissions by sources and removals by sinks of all GHGs not controlled by the Montreal Protocol. 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 system are documented in section 1.2.4 and chapter 13.

New Zealand maintains a set of guidelines that document the tasks required to officially submit the national inventory. These guidelines cover multiple aspects of the production of the inventory: inventory management, inventory planning and preparation, quality assurance and quality control (QA/QC) processes, communication and error management. The guidelines are a living document that is updated as required.

Inventory management

New Zealand applies a hybrid (centralised/distributed) approach to the production of the inventory. MfE, as New Zealand's inventory agency, manages and coordinates the inventory production, compiles and publishes the inventory, and submits it to the UNFCCC secretariat, in a centralised manner. The National Inventory Compiler is based at MfE. A number of designated government departments carry out sector-specific work, which includes obtaining and processing activity data, estimating emissions, preparing sectoral CRF or SEF tables and writing sectoral inventory chapters. Arrangements with these government departments have evolved and continue to do so, as resources and capacity allow, in response to growing understanding of the reporting requirements and when those requirements change.

[15] Inserted, on 23 June 2020, by section 56(1) of the Climate Change Response (Emissions Trading Reform) Amendment Act 2020 (2020 No 22).

Inventory governance within each sector, as well as sector-level quality control, is managed by the department responsible for the sector. 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 the manager of the inventory compilation team (within MfE). 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), as well as observers (Ministry of Foreign Affairs and Trade (MFAT), Government of Tokelau and Stats NZ). The main roles and expectations of the RGG include:

- guiding, conferring and approving (on the basis of advice from technical experts) major inventory recalculations and improvements; GHG emissions projections and their assumptions; analytical systems and tools for climate change reporting; planning and priorities; key messages; and 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 and technical specialists involved in this work
- sharing information, providing feedback and resolving any differences among agencies that impact on the delivery of the inventory work programme
- monitoring and reporting to a 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.

In addition to its overall inventory coordination role, MfE compiles estimates for:

- emissions for the IPPU sector (non-CO_2 gases through industry surveys and CO_2 data provided by MBIE and the EPA)
- emissions for the Waste sector
- emissions and removals for the LULUCF sector.

MfE conducts field measurement programmes and undertakes land use mapping from satellite imagery to estimate the emissions and removals from the LULUCF sector. This is supplemented with data from forestry grant schemes, harvested wood products production and non-CO_2 emissions that are collected through surveys of the sector.

MfE coordinates the preparation of Tokelau's inventory data and information with the Tokelau Ministry of Climate, Oceans and Resilience (MiCORE).

MBIE estimates all emissions from the Energy sector and CO_2 emissions from the IPPU sector, based in part on New Zealand Emissions Trading Scheme (NZ ETS) returns.

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 Stats NZ and key sector organisations.

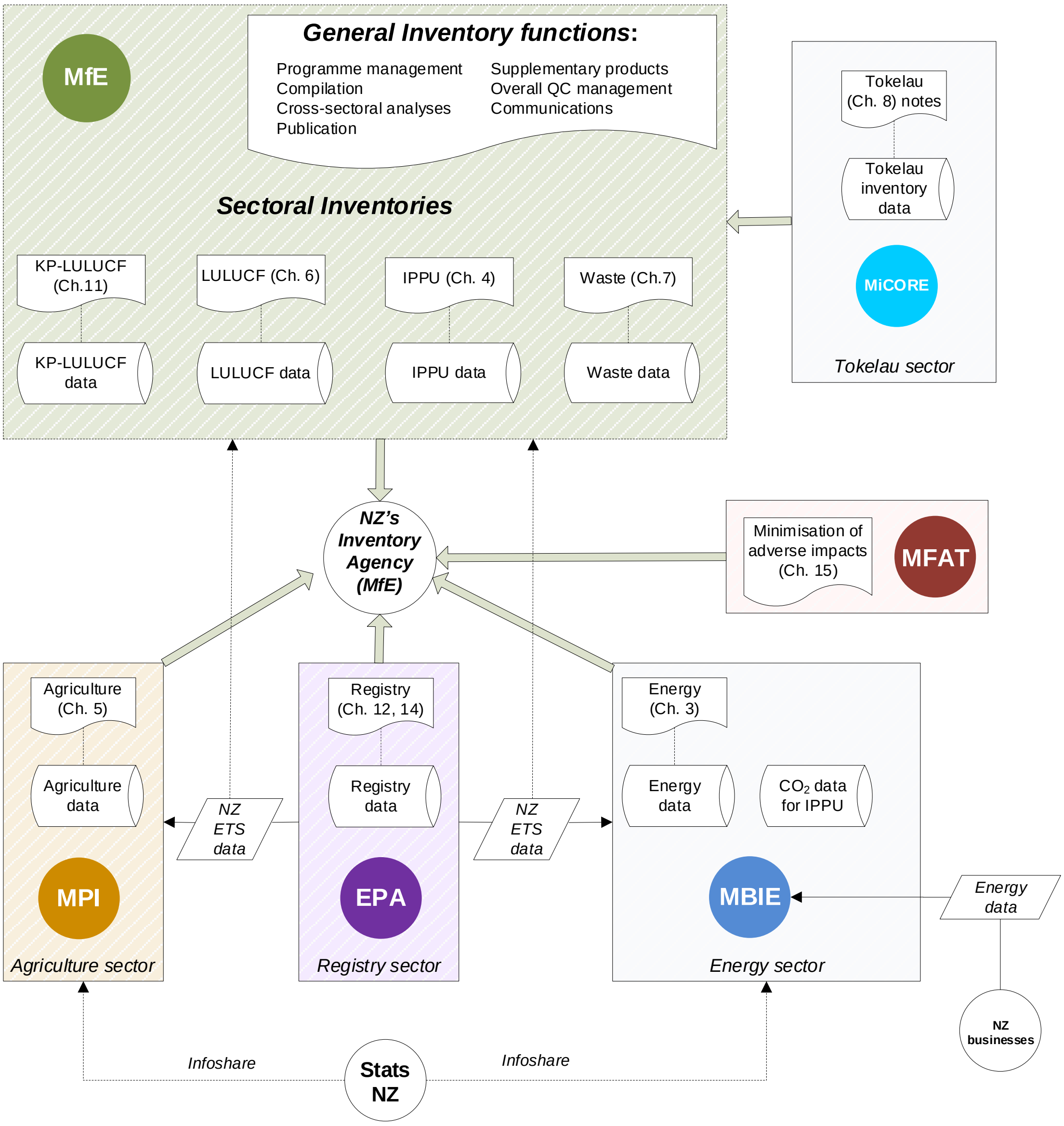
MFAT provides information on the minimisation of adverse impacts under Article 13.4 of the Kyoto Protocol, as reported in chapter 15.

MiCORE and the Tokelau National Statistics Office coordinate efforts in activity data collection and data processing to estimate 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 implementing and operating New Zealand's national registry, the New Zealand Emissions Trading Register (the Register). The Register is electronic and accessible via the internet (www.emissionsregister.govt.nz). Information on the annual holdings and transactions of transferred and acquired Kyoto Protocol units is provided in chapters 12 and 14.

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 submission.

Figure 1.2.1 New Zealand's inventory system at a glance: how different agencies are involved

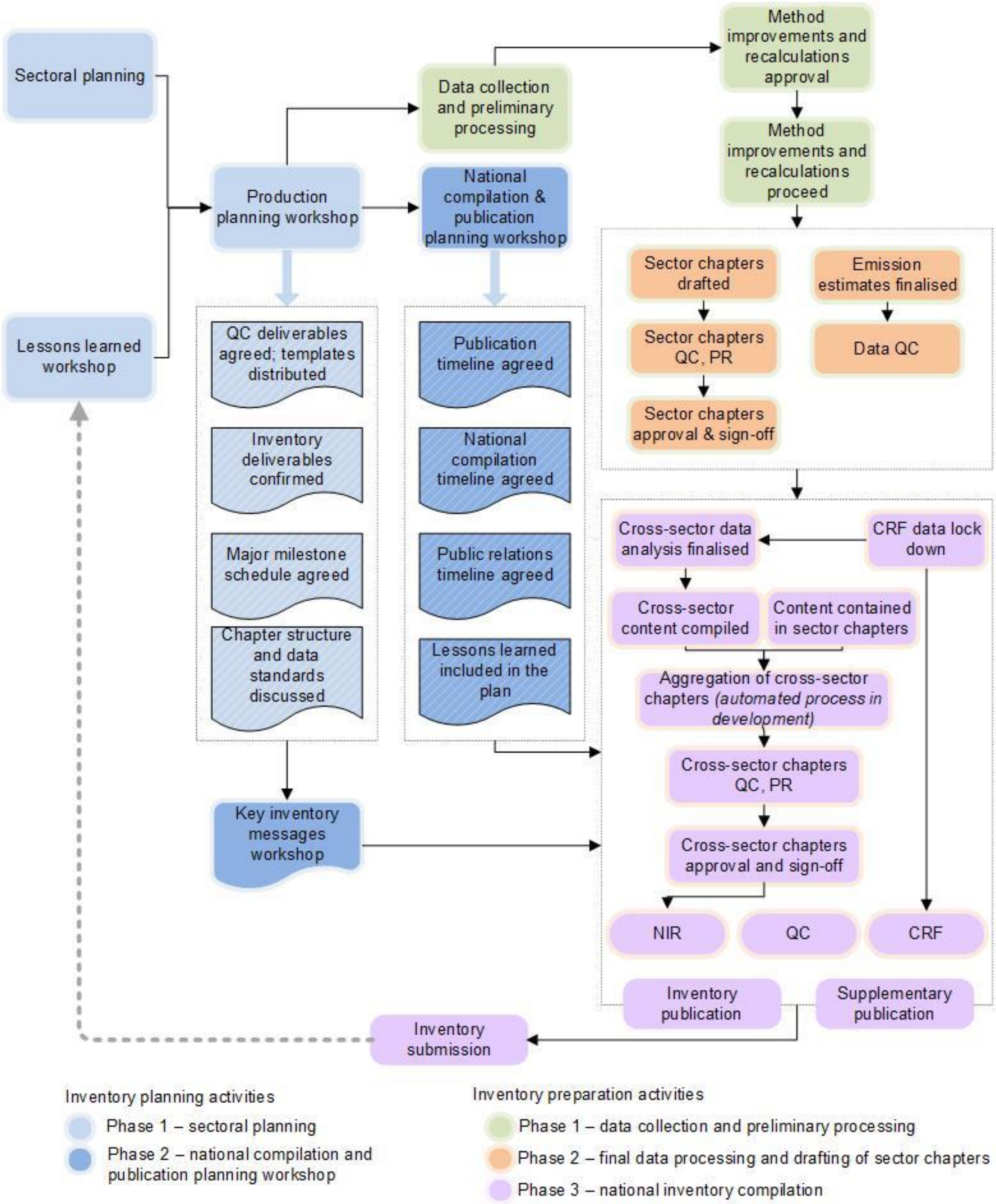


Note: EPA = Environmental Protection Authority; NZ ETS = New Zealand Emissions Trading Scheme; IPPU = Industrial Processes and Product Use; KP-LULUCF = Land Use, Land-Use Change and Forestry activities under the Kyoto Protocol; LULUCF = Land Use, Land-Use Change and Forestry; MBIE = Ministry of Business, Innovation and Employment; MFAT = Ministry of Foreign Affairs and Trade; MfE = Ministry for the Environment; MiCORE = Ministry of Climate, Oceans and Resilience (Tokelau); MPI = Ministry for Primary Industries; QC = quality control; registry = New Zealand Emissions Trading Register.

Inventory planning and preparation

Figure 1.2.2 summarises the inventory planning and preparation process.

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, 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 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 analysing 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, is comprised of two workshops. The first workshop, scheduled towards the end of each calendar year, is dedicated to cross-sectoral compilation and publication planning. Participants include MfE's publication and public liaison teams as well as the inventory production team. Timelines discussed and agreed cover:

- national compilation
- publication
- public relations.

Lessons learned are also considered in developing the plan.

The second workshop in the second phase of the inventory planning is 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 among the sector leads, National Inventory Compiler and primary peer reviewers. The key messages are used for both the NIR and the inventory summary on MfE's website, which presents a brief description of the inventory findings.

The inventory planning process for Tokelau is governed by a Memorandum of Understanding between New Zealand and Tokelau. For further information, see 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 to 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 to January) includes final data processing and drafting of sector chapters. During this phase, emissions estimates are finalised, final data quality control and verification are performed, data are loaded into the CRF Reporter and sector chapters are updated, reviewed and approved.

The final phase of the inventory preparation (February to April) includes cross-sector analyses, national inventory compilation and publication, and the production of supplementary material for New Zealand's Minister of Climate Change and the general public. Since 2020, the inventory compilation team has been developing and implementing new automated processes for the compilation of some of its cross-sector chapters.

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

During the inventory planning and preparation cycles, the National Inventory Compiler, technical lead and inventory project manager have regular meetings with sector leads and experts to ensure that all issues are addressed and the production proceeds 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. The National Inventory Compiler, technical lead 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[16] and quality control[17] are integral parts of preparing New Zealand's inventory. MfE's QA/QC plan, following reporting guidelines under the Convention (UNFCCC, 2006, 2013a), formalises the documentation and archiving of the QA/QC procedures. This plan has been updated over time as the QC tools have been developed and, where possible, automated. Details of the QA/QC activities performed during the compilation of the 2023 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 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 have been introduced 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.

[16] Quality assurance (QA) is a planned system of review procedures conducted by personnel not directly involved in the inventory compilation and development process.

[17] Quality control (QC) is a system of routine technical activities to assess and maintain the quality of the inventory as it is being compiled. It is performed by personnel compiling the inventory.

Completion of the IPCC 2006 Tier 1 QC check sheets for each sector is the responsibility of the sector leads (see table 1.2.1 for a list of the responsible agencies). The Tier 1 checks are in line with the 2006 IPCC Guidelines (IPCC, 2006). Wherever possible, manual checking is replaced by, or supplemented with, automated checks.

The sectoral contributions to the inventory – that is, sector chapters and data preparation – and Tier 1 QC checks are signed off by the responsible agency before final approval of the inventory by the national inventory agency (MfE) and submission to the UNFCCC secretariat.

MfE uses 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 are checked for anomalies, errors and omissions.

After the CRF data is compiled in each inventory sector, MfE personnel review the CRF data for each sector and category for data integrity and time-series consistency before sector finalisation. The purpose of this review is to ensure that the CRF Reporter does not contain blank entries in the reported categories, and that 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 are provided to the sector leads so they could make any corrections and include the relevant references and explanations, if required, in order to finalise the CRF data for each inventory sector.

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

Table 1.2.1 Agency responsible for each sector

Responsibility	Responsible New Zealand agency
Energy sector	Ministry of Business, Innovation and Employment
IPPU sector	Ministry for the Environment
LULUCF sector and KP-LULUCF	Ministry for the Environment
Waste sector	Ministry for the Environment
Tokelau	Ministry for the Environment, Tokelau Government
Agriculture sector	Ministry for Primary Industries
Registry	Environmental Protection Authority
Minimisation of adverse impacts	Ministry of Foreign Affairs and Trade
National inventory agency	Ministry for the Environment

The Energy and Agriculture activity data provided by Stats NZ are official national statistics (Tier 1). As such, they are subject to their own rigorous QA/QC procedures.

Human population and animal production statistics provided by Stats NZ are also used for estimating emissions from the Waste sector.

Tokelau's activity data undergo QC processes at the Tokelau National Statistics Office. Tokelau's inventory estimates in the CRF undergo QA/QC processes that are similar to those of other inventory sectors.

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 Convention as an important element of QA. The main aspects of QA 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 lead discussed sectoral issues with the Danish inventory team during bilateral meetings in 2017 dedicated to different aspects of the Energy sectoral inventory. Specific issues were: data sources, data collection and verification processes; using 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. In 2019, an external consultant was contracted to review and develop a QA plan for the Energy sector. Most recommendations from that review have already been implemented, and work continues on addressing the remaining issues.

The Agriculture sector completed a major QA review of its calculation models with an external party in 2013. Since then, other QA activities for Agriculture have included a bilateral review with Australia in 2014, and an external review of equations used to determine metabolisable energy requirements in 2016. For more information, see chapter 5, section 5.1.6.

Prioritisation of improvements

Priorities for the development of the inventory are guided by:

- the results of key category analyses (level and trend)
- the degree of improvement to be achieved for existing emissions 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 in 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 reduce uncertainty, then the change is likely to be accepted. Sectors are encouraged to develop annual inventory improvement and QA and QC plans to reflect current and future development of the inventory.

Acceptance of improvements and recalculations

All proposed 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 2006 IPCC Guidelines (IPCC, 2006) for the preparation and continuous improvement of national greenhouse gas inventories.

Given the significance of the Agriculture sector to New Zealand’s emissions, the Government established the Agriculture Inventory Advisory Panel. The Panel is an independent group of experts, who assess if proposed improvements and recalculations in the sector’s emissions are scientifically robust enough to include in the inventory. Reports and/or papers on proposed changes must be peer reviewed before they are presented to the Panel. The Panel then advises MPI of its recommendations. Refer to chapter 5, section 5.1.5 for further details.

All recalculations for and improvements to the inventory require the approval of the RGG. The recalculations need to be sufficiently explained in terms of improving one or more of the TACCC principles. If, due to the recalculations, emissions from the recalculated category are higher than 500 kilotonnes carbon dioxide equivalent (kt CO_2-e), the results of 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 chapters 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 to verify the emissions estimates for CO_2 obtained from the sectoral approach.

Treatment of confidentiality issues

When specific emissions 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 inventory is a Tier 1 statistic under New Zealand's official statistics system. The inventory compilation process adheres to the *Principles and Protocols for Producers of Tier 1 Statistics* (Stats NZ, 2007). The relevant definition of confidentiality (protocol 4) is as follows.

- Confidentiality refers to the protection of individuals' and organisations' information, and ensuring that the information is not made available or disclosed to unauthorised individuals or entities.
- The protection of respondents' information is a cornerstone of maintaining the integrity of the Official Statistics System.

Confidential data are aggregated so as to draw out the information that is important to the user, without disclosing confidential data (IPCC, 2006). 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 breach 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 keep the data confidential.

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

- Where emissions cannot 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' 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. Emissions from natural gas used as fuel in *Ammonia production* are reported in the Energy sector.

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 (2022) submission.

1.3 Inventory preparation: data collection, processing and storage

Inventory planning and preparation are described in section 1.2.2.

The National Inventory Compiler coordinates the calculation of level and trend uncertainties, along with key category assessment, and finalises the inventory. The inventory is then approved for publication by the New Zealand Secretary for the Environment 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 Convention websites.

Data archiving, security and recovery

To provide data security and file recovery for the inventory, the information and data are held in secured locations in MfE's Microsoft 365 (M365) environment. MfE's security policies and settings, including version control and retention, protect against data breach and data loss.

New Zealand's inventory archiving system reflects the distributed system as follows.

- All files for the inventory are stored in MfE's secure file management system and backed up on several different devices held in different locations. 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, 2006), 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, 2013a) and the Kyoto Protocol decisions on reporting and review (UNFCCC, 2005a–k, 2012, 2013b, 2016a, 2016b).

The guiding documents provide a number of possible methodologies for calculating emissions or removals from a given category (IPCC, 2006). 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.

This section provides a brief description of the methodology for each sector in the inventory. 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 demand based and involves processing energy data collected on a regular basis through various surveys. For verification, New Zealand also applies the IPCC reference approach to estimate CO_2 emissions from fuel combustion for the time series 1990 to 2021 (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* (MBIE, 2022). 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.

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 the *Other process uses of carbonates* category (2.A.4) to aggregate the data with other sources and preserve confidentiality. Fuel-related emissions from ammonia production are reported in the Energy sector. 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*[18] category, updated activity data have been obtained through a detailed annual survey covering the electrical, refrigeration and other industry participants (Verum Group Ltd, unpublished), 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 in 2006 by a detailed industry survey and analysis (CRL Energy Ltd, unpublished). Emissions and activity data have been extrapolated since 2006.

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

Agriculture

New Zealand has developed a largely Tier 2 (with some Tier 1 aspects and other aspects reflecting Tier 3) methodology with country-specific emission factors for a range of emissions sources. 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, 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 Stats NZ. Productivity data are available from the Livestock Improvement Corporation and industry organisations, such as Beef + Lamb New Zealand Ltd and Dairy NZ, 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. There is no known farming of fur-bearing animals in New Zealand.

For estimating emissions from the *Agricultural soils* category, New Zealand uses methodologies based on the 2006 IPCC Guidelines (IPCC, 2006), the outputs of the Tier 2 livestock population characterisation, modelling of the livestock nutrition and energy requirements, and data on the application of nitrogen fertilisers. 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 given in chapter 5 (tables 5.5.2, 5.5.3 and 5.5.4) and annex 3 (tables A3.1.5, A3.1.6 and A3.1.7). Chapter 5, table 5.5.5 contains the parameters used to estimate emissions where specific mitigation technologies are used. Activity data for the *Liming* category are obtained from Stats NZ, 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. No rice cultivation or CO_2 emissions from other carbon-containing fertilisers occur in New Zealand.

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

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 for Article 3.3 and Article 3.4 activities under the Kyoto Protocol (KP-LULUCF activities). 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 natural forest*, *Post-1989 planted 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 program for the LULUCF sector called the Land Use and Carbon Analysis System (LUCAS). The LUCAS program 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 (Paul et al., 2020, unpublished(a), unpublished(b), unpublished(c); Paul and Wakelin, 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 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 (Eunomia, unpublished) and for treatment of some types of industrial wastewater (Cardno, unpublished).

Methodological issues are discussed under each source category in chapter 7.

Other sector (Tokelau)

The Tokelau National Statistics Office collects and processes activity data from Tokelau for inventory preparation. Chapter 8, table 8.1.2 contains the key sources of the activity data from Tokelau used in Tokelau's GHG inventory.

1.5 Key categories

1.5.1 Reporting under the Convention

The 2006 IPCC Guidelines (IPCC, 2006) 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.

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, 2006). This is because some categories in the inventory apply default uncertainty values for emissions estimates, and developing country-specific uncertainty values is resource prohibitive.

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 2021, or the trend of emissions. New Zealand does not currently use qualitative assessment to identify any key categories. The key categories identified in the 2021 year are summarised in table 1.5.1.

In accordance with the 2006 IPCC Guidelines (IPCC, 2006), the key category analysis is performed once for the inventory excluding the LULUCF sector and then repeated for the inventory including 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 in the analysis that includes the LULUCF sector.

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 is 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 2021 are:

- CH_4 emissions from *Dairy cattle – Enteric fermentation* (12.7 per cent)
- CO_2 emissions from *Road transportation – Liquid fuels* (11.9 per cent)
- CO_2 emissions from *Forest land remaining forest land* (11.6 per cent)
- CO_2 emissions from *Harvested wood products* (8.2 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 2021, are:

- CO_2 emissions from *Forest land remaining forest land* (15.5 per cent as a decrease)
- CH_4 emissions from *Sheep – Enteric fermentation* (13.4 per cent as a decrease)
- CO_2 emissions from *Forest land – Land converted to forest land* (13.4 per cent as an increase)
- CO_2 emissions from *Forest land – Harvested wood products* (9.1 per cent as a decrease).

For gross emissions, table 1.5.2(b) identifies that the major contributions to the level analysis for 2021 are:

- CH_4 emissions from *Dairy cattle – Enteric fermentation* (17.4 per cent)
- CO_2 emissions from *Road transportation – Liquid fuels* (16.3 per cent)
- CH_4 emissions from *Sheep – Enteric fermentation* (10.4 per cent)
- CH_4 emissions from *Non-dairy* (beef) *cattle – Enteric fermentation* (7.7 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 2021, are:

- CH_4 emissions from *Sheep – Enteric fermentation* (21.5 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* (11.4 per cent as an increase)
- CO_2 emissions from *Energy industries – Manufacture of solid fuels* and *Other energy industries – Gaseous fuels* (4.3 per cent as a decrease).

Table 1.5.1 Summary of New Zealand's key categories for the 2021 level assessment and the trend assessment for 1990 to 2021 (including LULUCF activities)

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

Quantitative method used: IPCC Tier 1			
1.A.3.b	Transport – Road Transportation Gaseous Fuels	CO_2	T1
1.A.3.d	Domestic Navigation – Residual Fuel Oil	CO_2	L1
1.A.4.a	Other Sectors – Commercial/Institutional Liquid Fuels	CO_2	L1, T1
1.A.4.a	Other Sectors – Commercial/Institutional Gaseous Fuels	CO_2	L1, T1
1.A.4.a	Other Sectors – Commercial/Institutional Solid Fuels	CO_2	T1
1.A.4.b	Other Sectors – Residential Liquid Fuels	CO_2	L1, T1
1.A.4.b	Other Sectors – Residential Gaseous Fuels	CO_2	L1, T1
1.A.4.b	Other Sectors – Residential Solid Fuels	CO_2	T1
1.A.4.c	Other Sectors – Agriculture/Forestry/Fishing Liquid Fuels	CO_2	L1
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.c.2.iii	Flaring – Combined	CO_2	T1
1.B.2.d	Other (please specify) – Geothermal	CO_2	L1, T1
IPPU			
2.A.1	Mineral Industry – Cement Production	CO_2	L1, T1
2.B.10	Chemical Industry – Other (please specify)	CO_2	T1
2.C.1	Metal Industry – Iron and Steel Production	CO_2	L1, T1
2.C.3	Metal Industry – Aluminium Production	CO_2	L1
2.C.3	Metal Industry – Aluminium Production	PFCs	T1
2.F.1	Product Uses as Substitutes for ODS – Refrigeration and Air conditioning	HFCs	L1, T1
Agriculture			
3.A.1	Option A – Dairy Cattle	CH_4	L1, T1
3.A.1	Option A – Non-Dairy Cattle	CH_4	L1, T1
3.A.2	Other (please specify) – Sheep	CH_4	L1, T1
3.A.4	Other Livestock – Deer	CH_4	L1
3.A.4	Other Livestock – Goats	CH_4	T1
3.B.1.1	Option A – Dairy Cattle	CH_4	L1, T1
3.D.1.1	Direct N_2O Emissions From Managed Soils – Inorganic N Fertilisers	N_2O	L1, T1
3.D.1.3	Direct N_2O Emissions From Managed Soils – Urine and Dung Deposited by Grazing Animals	N_2O	L1, T1
3.D.1.4	Direct N_2O Emissions From Managed Soils – Crop Residues	N_2O	L1
3.D.1.6	Direct N_2O Emissions From Managed Soils – Cultivation of Organic Soils	N_2O	L1, T1
3.D.2.1	Indirect N_2O Emissions From Managed Soils – Atmospheric Deposition	N_2O	L1
3.D.2.2	Indirect N_2O Emissions From Managed Soils – Nitrogen Leaching and Run-off	N_2O	L1
3.G	Agriculture – Liming	CO_2	L1
3.H	Agriculture – Urea Application	CO_2	L1, T1
LULUCF			
4.A.1	Forest Land – Forest Land Remaining Forest Land	CO_2	L1, T1
4.A.2	Forest Land – Land Converted to Forest Land	CO_2	L1, T1
4.B.1	Cropland – Cropland Remaining Cropland	CO_2	L1, 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

Quantitative method used: IPCC Tier 1			
Waste			
5.A	Waste – Solid Waste Disposal	CH_4	L1, T1
5.C	Waste – Incineration and Open Burning of Waste	CO_2	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. According to the 2006 IPCC Guidelines (IPCC, 2006), L1 indicates a level assessment for a Tier 1 key category, and T1 indicates a trend assessment for a Tier 1 key category.

Table 1.5.2(a & b) 2021 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): 2021

CRF category code	IPCC category	Gas	2021 estimate (kt CO_2-e)	Level assessment (%)	Cumulative total (%)
3.A.1	Option A – Dairy Cattle	CH_4	13,382.5	12.7	12.7
1.A.3.b	Transport – Road Transportation Liquid Fuels	CO_2	12,555.0	11.9	24.7
4.A.1	Forest Land – Forest Land Remaining Forest Land	CO_2	–12,163.5	11.6	36.3
4.G	Land Use, Land-Use Change and Forestry – Harvested Wood Products	CO_2	–8,658.8	8.2	44.5
3.A.2	Other (please specify) – Sheep	CH_4	8,011.9	7.6	52.1
3.A.1	Option A – Non-Dairy Cattle	CH_4	5,944.0	5.7	57.8
4.A.2	Forest Land – Land Converted to Forest Land	CO_2	–3,831.3	3.6	61.4
3.D.1.3	Direct N_2O Emissions From Managed Soils – Urine and Dung Deposited by Grazing Animals	N_2O	3,510.0	3.3	64.8
5.A	Waste – Solid Waste Disposal	CH_4	2,578.2	2.5	67.2
1.A.1.a	Energy Industries – Public Electricity and Heat Production Solid Fuels	CO_2	2,346.4	2.2	69.5
1.A.1.a	Energy Industries – Public Electricity and Heat Production Gaseous Fuels	CO_2	2,035.5	1.9	71.4
2.C.1	Metal Industry – Iron and Steel Production	CO_2	1,718.1	1.6	73.0
4.C.2	Grassland – Land Converted to Grassland	CO_2	1,485.2	1.4	74.4
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Solid Fuels	CO_2	1,446.5	1.4	75.8
2.F.1	Product Uses as Substitutes for ODS – Refrigeration and Air conditioning	HFCs	1,401.8	1.3	77.2
3.D.1.1	Direct N_2O Emissions From Managed Soils – Inorganic N Fertilisers	N_2O	1,398.9	1.3	78.5
3.B.1.1	Option A – Dairy Cattle	CH_4	1,341.1	1.3	79.8
1.A.4.b	Other Sectors – Residential Liquid Fuels	CO_2	1,332.4	1.3	81.0
1.A.2.c	Manufacturing Industries and Construction – Chemicals Gaseous Fuels	CO_2	1,267.1	1.2	82.2
1.A.4.c	Other Sectors – Agriculture/Forestry/Fishing Liquid Fuels	CO_2	1,262.5	1.2	83.4
4.C.1	Grassland – Grassland Remaining Grassland	CO_2	1,222.9	1.2	84.6
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Gaseous Fuels	CO_2	1,053.3	1.0	85.6
3.D.2.1	Indirect N_2O Emissions From Managed Soils – Atmospheric Deposition	N_2O	854.7	0.8	86.4
1.A.3.a	Domestic Aviation – Jet Kerosene	CO_2	797.2	0.8	87.2
1.A.4.a	Other Sectors – Commercial/Institutional Liquid Fuels	CO_2	726.4	0.7	87.9

CRF category code	IPCC category	Gas	2021 estimate (kt CO_2-e)	Level assessment (%)	Cumulative total (%)
3.D.1.6	Direct N_2O Emissions From Managed Soils – Cultivation of Organic Soils	N_2O	667.4	0.6	88.5
1.A.1.b	Energy Industries – Petroleum Refining Liquid Fuels	CO_2	617.3	0.6	89.1
3.D.2.2	Indirect N_2O Emissions From Managed Soils – Nitrogen Leaching and Run-off	N_2O	554.5	0.5	89.6
3.H	Agriculture – Urea Application	CO_2	553.2	0.5	90.1
2.C.3	Metal Industry – Aluminium Production	CO_2	541.8	0.5	90.7
1.A.2.g.v	Other (please specify) – Construction	CO_2	522.6	0.5	91.2
3.A.4	Other Livestock – Deer	CH_4	468.3	0.4	91.6
1.B.2.d	Other (please specify) – Geothermal	CO_2	431.6	0.4	92.0
1.A.4.a	Other Sectors – Commercial/Institutional Gaseous Fuels	CO_2	412.5	0.4	92.4
1.A.4.b	Other Sectors – Residential Gaseous Fuels	CO_2	385.5	0.4	92.8
2.A.1	Mineral Industry – Cement Production	CO_2	369.6	0.4	93.1
1.A.2.g.iii	Other (please specify) – Mining (excluding fuels) and Quarrying Liquid Fuels	CO_2	367.6	0.3	93.5
3.G	Agriculture – Liming	CO_2	355.6	0.3	93.8
4.B.1	Cropland – Cropland Remaining Cropland	CO_2	320.7	0.3	94.1
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Liquid Fuels	CO_2	287.1	0.3	94.4
5.D	Waste – Wastewater Treatment and Discharge	CH_4	256.9	0.2	94.6
3.D.1.4	Direct N_2O Emissions From Managed Soils – Crop Residues	N_2O	255.7	0.2	94.9
1.A.1.c	Energy Industries – Manufacture of Solid Fuels and Other Energy Industries Gaseous Fuels	CO_2	240.4	0.2	95.1

(b) IPCC Tier 1 category level assessment – excluding LULUCF (gross emissions): 2021

CRF category code	IPCC category	Gas	2021 estimate (kt CO_2-e)	Level assessment (%)	Cumulative total (%)
3.A.1	Option A – Dairy Cattle	CH_4	13,382.5	17.4	17.4
1.A.3.b	Transport – Road Transportation Liquid Fuels	CO_2	12,555.0	16.3	33.8
3.A.2	Other (please specify) – Sheep	CH_4	8,011.9	10.4	44.2
3.A.1	Option A – Non-Dairy Cattle	CH_4	5,944.0	7.7	51.9
3.D.1.3	Direct N_2O Emissions From Managed Soils – Urine and Dung Deposited by Grazing Animals	N_2O	3,510.0	4.6	56.5
5.A	Waste – Solid Waste Disposal	CH_4	2,578.2	3.4	59.9
1.A.1.a	Energy Industries – Public Electricity and Heat Production Solid Fuels	CO_2	2,346.4	3.1	62.9
1.A.1.a	Energy Industries – Public Electricity and Heat Production Gaseous Fuels	CO_2	2,035.5	2.6	65.6
2.C.1	Metal Industry – Iron and Steel Production	CO_2	1,718.1	2.2	67.8
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Solid Fuels	CO_2	1,446.5	1.9	69.7
2.F.1	Product Uses as Substitutes for ODS – Refrigeration and Air conditioning	HFCs	1,401.8	1.8	71.5
3.D.1.1	Direct N_2O Emissions From Managed Soils – Inorganic N Fertilizers	N_2O	1,398.9	1.8	73.3
3.B.1.1	Option A – Dairy Cattle	CH_4	1,341.1	1.7	75.1
1.A.4.b	Other Sectors – Residential Liquid Fuels	CO_2	1,332.4	1.7	76.8

CRF category code	IPCC category	Gas	2021 estimate (kt CO_2-e)	Level assessment (%)	Cumulative total (%)
1.A.2.c	Manufacturing Industries and Construction – Chemicals Gaseous Fuels	CO_2	1,267.1	1.6	78.5
1.A.4.c	Other Sectors – Agriculture/Forestry/Fishing Liquid Fuels	CO_2	1,262.5	1.6	80.1
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Gaseous Fuels	CO_2	1,053.3	1.4	81.5
3.D.2.1	Indirect N_2O Emissions From Managed Soils – Atmospheric Deposition	N_2O	854.7	1.1	82.6
1.A.3.a	Domestic Aviation – Jet Kerosene	CO_2	797.2	1.0	83.6
1.A.4.a	Other Sectors – Commercial/Institutional Liquid Fuels	CO_2	726.4	0.9	84.6
3.D.1.6	Direct N_2O Emissions From Managed Soils – Cultivation of Organic Soils	N_2O	667.4	0.9	85.4
1.A.1.b	Energy Industries – Petroleum Refining Liquid Fuels	CO_2	617.3	0.8	86.2
3.D.2.2	Indirect N_2O Emissions From Managed Soils – Nitrogen Leaching and Run-off	N_2O	554.5	0.7	87.0
3.H	Agriculture – Urea Application	CO_2	553.2	0.7	87.7
2.C.3	Metal Industry – Aluminium Production	CO_2	541.8	0.7	88.4
1.A.2.g.v	Other (please specify) – Construction	CO_2	522.6	0.7	89.1
3.A.4	Other Livestock – Deer	CH_4	468.3	0.6	89.7
1.B.2.d	Other (please specify) – Geothermal	CO_2	431.6	0.6	90.2
1.A.4.a	Other Sectors – Commercial/Institutional Gaseous Fuels	CO_2	412.5	0.5	90.8
1.A.4.b	Other Sectors – Residential Gaseous Fuels	CO_2	385.5	0.5	91.3
2.A.1	Mineral Industry – Cement Production	CO_2	369.6	0.5	91.8
1.A.2.g.iii	Other (please specify) – Mining (excluding fuels) and Quarrying Liquid Fuels	CO_2	367.6	0.5	92.2
3.G	Agriculture – Liming	CO_2	355.6	0.5	92.7
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Liquid Fuels	CO_2	287.1	0.4	93.1
5.D	Waste – Wastewater Treatment and Discharge	CH_4	256.9	0.3	93.4
3.D.1.4	Direct N_2O Emissions From Managed Soils – Crop Residues	N_2O	255.7	0.3	93.7
1.A.1.c	Energy Industries – Manufacture of Solid Fuels and Other Energy Industries Gaseous Fuels	CO_2	240.4	0.3	94.0
1.B.2.c.1.ii	Venting – Gas	CO_2	234.2	0.3	94.4
1.A.2.g.viii	Other (please specify) – Other (please specify) Liquid Fuels	CO_2	221.0	0.3	94.6
1.A.3.d	Domestic Navigation – Residual Fuel Oil	CO_2	201.3	0.3	94.9
1.A.2.d	Manufacturing Industries and Construction – Pulp, Paper and Print Gaseous Fuels	CO_2	194.9	0.3	95.2

Table 1.5.3(a & b) 1990–2021 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)	2021 estimate (kt CO_2-e)	Trend assessment	Absolute contribution to trend (%)	Absolute cumulative total (%)
4.A.1	Forest Land – Forest Land Remaining Forest Land	CO_2	–784.0	–12,163.5	0.131	15.5	15.5
3.A.2	Other (please specify) – Sheep	CH_4	14,407.4	8,011.9	0.114	13.4	28.9
4.A.2	Forest Land – Land Converted to Forest Land	CO_2	–18,491.9	–3,831.3	0.114	13.4	42.4
4.G	Land Use, Land-Use Change and Forestry – Harvested Wood Products	CO_2	–2,481.2	–8,658.8	0.077	9.1	51.5
3.A.1	Option A – Dairy Cattle	CH_4	6,012.9	13,382.5	0.066	7.9	59.3
1.A.3.b	Transport – Road Transportation Liquid Fuels	CO_2	6,519.0	12,555.0	0.050	5.9	65.2
1.A.1.c	Energy Industries – Manufacture of Solid Fuels and Other Energy Industries Gaseous Fuels	CO_2	1,715.3	240.4	0.022	2.6	67.8
1.A.1.a	Energy Industries – Public Electricity and Heat Production Solid Fuels	CO_2	474.8	2,346.4	0.020	2.3	70.1
1.A.1.a	Energy Industries – Public Electricity and Heat Production Gaseous Fuels	CO_2	2,999.6	2,035.5	0.020	2.3	72.4
5.A	Waste – Solid Waste Disposal	CH_4	3,318.2	2,578.2	0.018	2.1	74.6
2.F.1	Product Uses as Substitutes for ODS – Refrigeration and Air Conditioning	HFCs	0.0	1,401.8	0.016	1.9	76.4
3.A.1	Option A – Non-Dairy Cattle	CH_4	5,861.6	5,944.0	0.016	1.9	78.3
3.D.1.1	Direct N_2O Emissions From Managed Soils – Inorganic N Fertilisers	N_2O	230.3	1,398.9	0.013	1.5	79.8
2.C.3	Metal Industry – Aluminium Production	PFCs	909.9	50.7	0.012	1.5	81.2
4.C.2	Grassland – Land Converted to Grassland	CO_2	422.4	1,485.2	0.011	1.3	82.5
4.C.1	Grassland – Grassland Remaining Grassland	CO_2	219.6	1,222.9	0.011	1.3	83.8
3.B.1.1	Option A – Dairy Cattle	CH_4	413.8	1,341.1	0.009	1.1	84.9
1.A.2.g.viii	Other (please specify) – Other (please specify) Solid Fuels	CO_2	731.1	104.4	0.009	1.1	86.0
1.A.2.c	Manufacturing Industries and Construction – Chemicals Gaseous Fuels	CO_2	524.8	1,267.1	0.007	0.8	86.8
3.H	Agriculture – Urea Application	CO_2	39.2	553.2	0.006	0.7	87.5
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Gaseous Fuels	CO_2	443.4	1,053.3	0.006	0.7	88.1
1.A.4.b	Other Sectors – Residential Solid Fuels	CO_2	344.9	21.8	0.005	0.5	88.7
1.B.1.a.1	Coal Mining and Handling – Underground Mines	CH_4	289.6	0.0	0.004	0.5	89.2
1.A.1.b	Energy Industries – Petroleum Refining Liquid Fuels	CO_2	778.9	617.3	0.004	0.5	89.7
1.A.3.a	Domestic Aviation – Jet Kerosene	CO_2	892.6	797.2	0.004	0.4	90.1
1.A.4.b	Other Sectors – Residential Liquid Fuels	CO_2	814.5	1,332.4	0.004	0.4	90.5
1.B.2.b.5	Natural Gas – Distribution	CH_4	277.5	39.1	0.003	0.4	90.9

CRF category code	IPCC category	Gas	1990 estimate (kt CO_2-e)	2021 estimate (kt CO_2-e)	Trend assessment	Absolute contribution to trend (%)	Absolute cumulative total (%)
1.A.2.f	Manufacturing Industries and Construction – Non-metallic Minerals Solid Fuels	CO_2	382.9	187.7	0.003	0.4	91.3
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Solid Fuels	CO_2	938.6	1,446.5	0.003	0.4	91.7
1.A.2.g.iii	Other (please specify) – Mining (excluding fuels) and Quarrying Liquid Fuels	CO_2	94.1	367.6	0.003	0.3	92.0
1.A.2.d	Manufacturing Industries and Construction – Pulp, Paper and Print Gaseous Fuels	CO_2	347.6	194.9	0.003	0.3	92.3
3.A.4	Other Livestock – Goats	CH_4	196.6	26.1	0.002	0.3	92.6
1.A.2.g.v	Other (please specify) – Construction	CO_2	245.0	522.6	0.002	0.3	92.9
3.D.1.3	Direct N_2O Emissions From Managed Soils – Urine and Dung Deposited by Grazing Animals	N_2O	2,959.6	3,510.0	0.002	0.3	93.2
2.A.1	Mineral Industry – Cement Production	CO_2	448.7	369.6	0.002	0.3	93.4
1.A.3.b	Transport – Road Transportation Gaseous Fuels	CO_2	140.3	0.0	0.002	0.2	93.7
3.D.1.6	Direct N_2O Emissions From Managed Soils – Cultivation of Organic Soils	N_2O	658.7	667.4	0.002	0.2	93.9
1.A.2.g.viii	Other (please specify) – Other (please specify) Liquid Fuels	CO_2	52.3	221.0	0.002	0.2	94.1
1.A.4.b	Other Sectors – Residential Gaseous Fuels	CO_2	184.9	385.5	0.002	0.2	94.3
2.B.10	Chemical Industry – Other (please specify)	CO_2	152.3	43.4	0.002	0.2	94.5
1.B.2.d	Other (please specify) – Geothermal	CO_2	228.6	431.6	0.002	0.2	94.7
1.A.4.a	Other Sectors – Commercial/Institutional Solid Fuels	CO_2	142.2	44.8	0.002	0.2	94.9
4.B.1	Cropland – Cropland Remaining Cropland	CO_2	351.2	320.7	0.001	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)	2021 estimate (kt CO_2-e)	Trend assessment	Absolute contribution to trend (%)	Absolute cumulative total (%)
3.A.2	Other (please specify) – Sheep	CH_4	14,407.4	8,011.9	0.140	21.5	21.5
3.A.1	Option A – Dairy Cattle	CH_4	6,012.9	13,382.5	0.096	14.8	36.3
1.A.3.b	Transport – Road Transportation Liquid Fuels	CO_2	6,519.0	12,555.0	0.074	11.4	47.7
1.A.1.c	Energy Industries – Manufacture of Solid Fuels and Other Energy Industries Gaseous Fuels	CO_2	1,715.3	240.4	0.028	4.3	52.0
1.A.1.a	Energy Industries – Public Electricity and Heat Production Solid Fuels	CO_2	474.8	2,346.4	0.028	4.2	56.2
1.A.1.a	Energy Industries – Public Electricity and Heat Production Gaseous Fuels	CO_2	2,999.6	2,035.5	0.024	3.6	59.8
2.F.1	Product Uses as Substitutes for ODS – Refrigeration and Air Conditioning	HFCs	0.0	1,401.8	0.022	3.3	63.1

CRF category code	IPCC category	Gas	1990 estimate (kt CO_2-e)	2021 estimate (kt CO_2-e)	Trend assessment	Absolute contribution to trend (%)	Absolute cumulative total (%)
5.A	Waste – Solid Waste Disposal	CH_4	3,318.2	2,578.2	0.021	3.2	66.4
3.D.1.1	Direct N_2O Emissions From Managed Soils – Inorganic N Fertilisers	N_2O	230.3	1,398.9	0.017	2.7	69.0
2.C.3	Metal Industry – Aluminium Production	PFCs	909.9	50.7	0.016	2.4	71.5
3.A.1	Option A – Non-Dairy Cattle	CH_4	5,861.6	5,944.0	0.016	2.4	73.9
3.B.1.1	Option A – Dairy Cattle	CH_4	413.8	1,341.1	0.013	2.0	75.9
1.A.2.g.viii	Other (please specify) – Other (please specify) Solid Fuels	CO_2	731.1	104.4	0.012	1.8	77.7
1.A.2.c	Manufacturing Industries and Construction – Chemicals Gaseous Fuels	CO_2	524.8	1,267.1	0.010	1.5	79.2
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Gaseous Fuels	CO_2	443.4	1,053.3	0.008	1.2	80.5
3.H	Agriculture – Urea Application	CO_2	39.2	553.2	0.008	1.2	81.7
1.A.4.b	Other Sectors – Residential Solid Fuels	CO_2	344.9	21.8	0.006	0.9	82.6
1.A.4.b	Other Sectors – Residential Liquid Fuels	CO_2	814.5	1,332.4	0.006	0.9	83.5
1.B.1.a.1	Coal Mining and Handling – Underground Mines	CH_4	289.6	0.0	0.005	0.8	84.3
1.A.2.e	Manufacturing Industries and Construction – Food Processing, Beverages and Tobacco Solid Fuels	CO_2	938.6	1,446.5	0.005	0.8	85.1
1.A.1.b	Energy Industries – Petroleum Refining Liquid Fuels	CO_2	778.9	617.3	0.005	0.7	85.8
1.B.2.b.5	Natural Gas – Distribution	CH_4	277.5	39.1	0.004	0.7	86.5
1.A.2.f	Manufacturing Industries and Construction – Non-metallic Minerals Solid Fuels	CO_2	382.9	187.7	0.004	0.6	87.1
1.A.3.a	Domestic Aviation – Jet Kerosene	CO_2	892.6	797.2	0.004	0.6	87.7
1.A.2.g.iii	Other (please specify) – Mining (excluding fuels) and Quarrying Liquid Fuels	CO_2	94.1	367.6	0.004	0.6	88.3
1.A.2.g.v	Other (please specify) – Construction	CO_2	245.0	522.6	0.004	0.5	88.9
1.A.2.d	Manufacturing Industries and Construction – Pulp, Paper and Print Gaseous Fuels	CO_2	347.6	194.9	0.003	0.5	89.4
3.A.4	Other Livestock – Goats	CH_4	196.6	26.1	0.003	0.5	89.9
2.C.1	Metal Industry – Iron and Steel Production	CO_2	1,306.7	1,718.1	0.003	0.4	90.3
1.A.3.b	Transport – Road Transportation Gaseous Fuels	CO_2	140.3	0.0	0.003	0.4	90.7
1.A.4.b	Other Sectors – Residential Gaseous Fuels	CO_2	184.9	385.5	0.003	0.4	91.1
2.A.1	Mineral Industry – Cement Production	CO_2	448.7	369.6	0.003	0.4	91.5
1.B.2.d	Other (please specify) – Geothermal	CO_2	228.6	431.6	0.002	0.4	91.8
1.A.2.g.viii	Other (please specify) – Other (please specify) Liquid Fuels	CO_2	52.3	221.0	0.002	0.4	92.2

CRF category code	IPCC category	Gas	1990 estimate (kt CO_2-e)	2021 estimate (kt CO_2-e)	Trend assessment	Absolute contribution to trend (%)	Absolute cumulative total (%)
2.B.10	Chemical Industry – Other (please specify)	CO_2	152.3	43.4	0.002	0.3	92.5
1.A.4.a	Other Sectors – Commercial/ Institutional Gaseous Fuels	CO_2	235.2	412.5	0.002	0.3	92.8
1.A.4.a	Other Sectors – Commercial/ Institutional Liquid Fuels	CO_2	500.7	726.4	0.002	0.3	93.2
1.A.4.a	Other Sectors – Commercial/ Institutional Solid Fuels	CO_2	142.2	44.8	0.002	0.3	93.5
3.D.1.6	Direct N_2O Emissions From Managed Soils – Cultivation of Organic Soils	N_2O	658.7	667.4	0.002	0.3	93.7
1.A.1.b	Energy Industries – Petroleum Refining Gaseous Fuels	CO_2	0.0	111.7	0.002	0.3	94.0
1.A.2.d	Manufacturing Industries and Construction – Pulp, Paper and Print Solid Fuels	CO_2	109.5	24.8	0.002	0.2	94.2
1.B.2.c.1.ii	Venting – Gas	CO_2	109.3	234.2	0.002	0.2	94.5
1.B.2.c.2.iii	Flaring – Combined	CO_2	114.1	34.3	0.002	0.2	94.7
5.C	Waste – Incineration and Open Burning of Waste	CO_2	158.9	90.6	0.002	0.2	95.0
1.A.4.c	Other Sectors – Agriculture/ Forestry/Fishing Solid Fuels	CO_2	35.1	139.3	0.002	0.2	95.2

Note: Removals from the LULUCF sector are shown as negatives in this table. In line with the methodology for key category analysis, 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 2021, *Afforestation and reforestation*, *Deforestation* and *Forest management* were all identified as key categories in both the level and trend assessments.

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, 2006). Inventories prepared in accordance with the 2006 IPCC Guidelines (IPCC, 2006) will typically contain a wide range of emissions 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, 2006).

New Zealand includes an uncertainty analysis of the aggregated figures, as required by the inventory reporting guidelines (UNFCCC, 2013a), applying approach 1 from the 2006 IPCC Guidelines (IPCC, 2006).

Uncertainties in the categories are combined to provide uncertainty estimates for all emissions for the latest reporting year and the base year, and the uncertainty in the trend over time. Annex 2 sets out uncertainties for net emissions, where removals under LULUCF categories are included (table A2.1.1), and gross emissions excluding LULUCF (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, 2006). 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 to various extents by the sector compiling agencies as far as the second-level category for each of CO_2, CH_4, N_2O and SF_6 separately and for HFCs and PFCs as groups. These data at the aggregated category level 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 (IPCC, 2006, equation 3.2, page 3.28).

In the IPPU sector (for the ODS category only), most of 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, 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 2012 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 in the 2006 IPCC Guidelines (IPCC, 2006, equation 3.1 and equation 3.2, page 3.28). These uncertainties incorporate natural variability, measurement error and model prediction error. The uncertainties in the net carbon emissions for each category in the LULUCF sector are given within the relevant sections of chapter 6. Detailed analysis of LULUCF uncertainties is presented in annex 3, section A3.2.8.

Gross emissions

Uncertainty in 2021 – level assessment

The uncertainty in gross emissions (excluding emissions and removals from the LULUCF sector) in 2021 is ±8.5 per cent. This is a decrease of 0.3 per cent from that reported for 2020 in the previous submission. Emissions contributing the most to the overall uncertainty of gross emissions in 2021 were CH_4 from *Enteric fermentation* (±16.0 per cent) at 5.8 per cent, N_2O from *Agricultural soils* (±55.3 per cent) at 5.3 per cent and CH_4 from *Solid waste disposal* (±95.8 per cent) at 3.2 per cent. The uncertainty in these categories reflects the inherent variability when estimating emissions from natural systems.

Uncertainty in 1990 – level assessment

In 1990, the uncertainty in gross emissions was ±9.5 per cent. This is a decrease of 0.04 per cent from the previous submission. Emissions of CH_4 from *Enteric fermentation* contributed 6.7 per cent, CH_4 from *Solid waste disposal* contributed 4.9 per cent and N_2O from *Agricultural soils* contributed 4.5 per cent 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 2021 is ±6.1 per cent. This is a decrease of 0.3 per cent from the previous submission. This decrease is primarily due to CH_4 in *Solid waste disposal*, mainly because of an increase in activity data for an underlying category with lower uncertainty than the average for *Solid waste disposal.* As a result, the combined uncertainty *Solid waste disposal* has reduced.

Net emissions

Uncertainty in 2021 – level assessment

The uncertainty for New Zealand's inventory, including emissions and removals from the LULUCF sector, in 2021 is ±28.2 per cent. There has been a 1.3 per cent increase in uncertainty between 2020 and 2021.

This increase is primarily a result of an increase to the LULUCF *Forest land* uncertainties. Emissions contributing the most to the overall uncertainty in net emissions for 2021 were CO_2 from *Forest land* (±80.8 per cent) at 23.2 per cent, CO_2 from *Harvested wood products* (±68.2 per cent) at 10.6 per cent and CH_4 from *Enteric fermentation* (±16.0 per cent) at 8.0 per cent.

Uncertainty in 1990 – level assessment

In 1990, the uncertainty in net emissions was 37.8 per cent. There has been an increase of 5.8 per cent between 2020 and 2021.

This increase is primarily a result of an increase to the LULUCF *Forest land* uncertainties. Emissions of CO_2 from *Forest land* contributed 35.0 per cent, CH_4 from *Enteric fermentation* 9.7 per cent and CH_4 from *Solid waste disposal* 7.1 per cent 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 2021 is ±19.4 per cent. This is an increase of 5.6 per cent when compared with the uncertainty for 2020. This increase is primarily a result of an increase to the LULUCF *Forest land* uncertainties.

1.6.2 LULUCF activities under the Kyoto Protocol

The combined uncertainty for net emissions from *Afforestation and reforestation* category activities in 2021 is ±14.7 per cent. The uncertainty for net emissions from the *Deforestation* category in 2021 is ±4.0 per cent.

The uncertainty for net emissions from the *Forest management* category in 2021 is ±56.9 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. As 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 in emissions for LULUCF activities under the Kyoto Protocol of ±58.7 per cent.

Chapter 11, section 11.4.1 provides 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 2021 is complete. In accordance with the 2006 IPCC Guidelines (IPCC, 2006), New Zealand has focused its resources for inventory development in the key categories and non-key categories that are mandatory. Additional information on the use of the notation key 'NE' in the context of paragraph 37(b) of the Convention reporting guidelines is presented in annex 6, section A6.2.

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* under the Kyoto Protocol. See chapter 11, section 11.1 for more information.

1.8 National registry

The national registry (the New Zealand Emissions Trading 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 Environmental Protection Authority is designated as the agency responsible for implementing and operating 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 the first commitment period (CP1) (covering the five-year period 2008 to 2012).

At the end of CP1, 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 Convention websites) to meet CP1 Kyoto Protocol obligations. While remaining a Party to the Kyoto Protocol, New Zealand did not take a target under the Kyoto Protocol for the second commitment period (CP2). Instead, New Zealand joins countries that have made international pledges under the Convention. As such, New Zealand had 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 must be able to be reconciled via the International Transaction Log. New Zealand 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 from the Clean Development Mechanism and voluntary unit cancellation transactions to occur. Details of these transactions are included in chapter 12. Also, changes to international trading may occur when new arrangements under Article 6 of the Paris Agreement come into effect.

New Zealand replaced its registry system in August 2016. The Register was tested and reviewed by the UNFCCC secretariat before it went live.

At the beginning of the calendar year 2022, New Zealand's national registry held 308,343,858 CP1 assigned amount units (AAUs), 110,744,560 CP1 emission reduction units (ERUs), 21,685,909 CP1 certified emission reduction units (CERs) and 100,845,399 CP1 removal units (RMUs). The number and mix of units held at the end of 2022 were the same as at the beginning of 2022, 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 2022.

At the end of 2022, 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 temporary CERs or long-term CERs during 2022.

Any changes to the Register are captured in chapter 14 (table 14.3).

For further information on accounting of the Kyoto Protocol units and the national registry, refer to chapters 12 and 14.

1.9 New Zealand Emissions Trading Scheme

The NZ ETS is one of the Government's primary tools for reducing greenhouse gas emissions. This section explains 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 New Zealand Units (NZUs), which are created and distributed by the New Zealand Government. The scheme was established through an amendment to the Climate Change Response Act 2002[19] and came into effect progressively from 2008, with coverage since 2010 of all substantial emissions except agricultural CH_4 and N_2O. 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. Units are also supplied as industrial allocation to firms carrying out activities that are emissions intensive and trade exposed to address the risk of emissions leakage, and via quarterly auctions. The emissions price is 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.

[19] Climate Change Response (Emissions Trading) Amendment Act 2008.

Amendments to the Climate Change Response Act 2002[20] in 2020 made changes to the NZ ETS that have now been implemented. The most significant changes are the introduction of auctioning and caps on the supply of emission units, which took effect from 1 January 2021. The fixed price option, or price ceiling, was increased for 2020 and removed entirely for emissions occurring after 1 January 2021.

1.9.2 Verification

Participants in the NZ ETS 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 annually surrender NZUs to cover their emissions. 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 to verify activity data on municipal waste disposal. Data reported under the Waste Minimisation Act 2008 have been used as the primary data (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
Stationary energy, including 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' because of insufficient data.

[20] Climate Change Response (Emissions Trading Reform) Amendment Act 2020.

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.

New Zealand publishes the key methodological changes that are being introduced to the inventory, and their estimated impact on emissions compared with the method used previously. This information was published before the publication of this inventory to increase the transparency of inventory improvements (Ministry for the Environment, 2023).

Chapter 10 summarises all recalculations made to estimates of emissions and removals.

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

Energy

An improvement to the estimation of fugitive emissions from natural gas distribution networks has been introduced for the 2023 submission. Other improvements in accuracy have resulted from the standard revision of activity data. Energy activity data for the years 1990 to 2020 have been updated according to the latest energy statistics published by MBIE (MBIE, 2022).

Projects to implement further improvements for the reference approach and sectoral approach are ongoing. Improvements have been made to the data management system for tracking and calculating emissions within the Energy sector. A further project to streamline and simplify the greenhouse gas reporting data system was completed in 2021. This project identified a number of minor inconsistencies, which were then addressed. Several upstream data systems, including the energy balance tables, have also been improved. Furthermore, work is progressing well on the construction of a new, comprehensive system for the data management of fuel properties. It is expected to be commissioned before the next submission. All source-specific planned improvements are discussed in their corresponding sections in chapter 3.

Changes to activity data in the Energy sector have resulted in a 0.01 per cent (2.4 kt CO_2-e) increase in estimated energy emissions in 1990 and a 1.1 per cent (344.5 kt CO_2-e) decrease in estimated energy emissions in 2020.

IPPU

For the 2023 submission, amounts of refrigerant added to equipment in the *Refrigeration and air conditioning* category were re-estimated to better account for changes in stocks held by importers and users.

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

Improvements and recalculations made in the IPPU sector have resulted in no change for 1990 and a 0.8 per cent (35.5 kt CO_2-e) decrease in emissions estimates for 2020.

Agriculture

New Zealand has made the following improvements and corrections to the Agriculture sector.

- $Frac_{LEACH}$ values for grazing system and synthetic nitrogen have been updated for the entire time series (from 1990 to 2021). For details on this improvement, see: chapter 5, section 5.5.5; chapter 10, section 10.1.3; and annex 3.

- An improved dairy cattle population model has been implemented for the entire time series (1990 to 2021). For details on this improvement, see: chapter 5, section 5.1.4; chapter 10, section 10.1.3; and annex 3.
- Feed quality values for *Dairy cattle*, *Non-dairy* (beef) *cattle* and *Sheep* have been updated to reflect pasture and non-pasture feed use for the entire time series (1990 to 2021). For details on this improvement, see: chapter 5, section 5.1.3; chapter 10, section 10.1.3; and annex 3.
- Minor errors in the deer calculations have been corrected for the entire time series (1990 to 2021) and some activity data have been revised.

Improvements and recalculations made to the Agriculture sector in the 2023 submission have resulted in a 1.4 per cent (480.8 kt CO_2-e) decrease in estimated agricultural emissions in 1990 and a 2.7 per cent (1,065.4 kt CO_2-e) decrease in estimated agricultural emissions in 2020.

LULUCF

The main differences between the 2023 submission and estimates of New Zealand's LULUCF net removals reported in the 2022 submission are as follows.

- Improvements to the method used to estimate deforestation for unmapped years have led to an increase in the estimated deforestation area for 2020. The overall net impact of this change to the LULUCF sector was an increase of 209 kt CO_2-e in 2020. This improvement was also largely responsible for the 41.2 per cent increase in emissions reported in the *Grassland* category for 2020 (given most deforested land is converted to grassland) (see chapter 6, section 6.3.5).
- A change in the estimated pre-1990 planted forest harvest area in 1988 to 1989 drove an increase in the estimated deadwood decay in 1990, which increased the 1990 emissions estimate for the *Forest land* category (see chapter 6, section 6.3.6).
- This submission used country-specific above- and below-ground biomass carbon stocks for vegetated wetlands (Easdale et al., unpublished). Above-ground biomass carbon stocks were estimated as 20.22 tonnes of carbon per hectare (t C ha^{-1}) (11.07 to 29.38, 95 per cent confidence interval) and below-ground as 7.40 tonnes C ha^{-1} (1.85 to 12.9, nominal error range). Previous submissions used a value of 0 for the carbon stock and carbon stock change of vegetated wetlands, which meant any emissions and removals for land transitioning in to and out of this class were not estimated (see chapter 6, section 6.6.5). The overall net impact of this change to the LULUCF sector was a decrease of 16 kt CO_2-e in 2020 and a decrease of 39 kt CO_2-e in 1990.

Section 6.1.4 in chapter 6 contains more details about improvements and recalculations for the LULUCF sector.

Improvements made to the LULUCF sector resulted in a 5.0 per cent (1,058.0 kt CO_2-e) decrease in net LULUCF removal estimates in 1990, and a 0.3 per cent (71.2 kt CO_2-e) decrease in net LULUCF removal estimates in 2020.

Waste

Improvements and recalculations made to estimates in the Waste sector have resulted in a 0.04 per cent (1.5 kt CO_2-e) increase in emissions in 1990 and a 0.1 per cent (2.4 kt CO_2-e) decrease in emissions in 2020.

Minor changes have been made that affect emissions as follows.

- Activity data for *Managed waste disposal sites* were revised for 2018, 2019 and 2020, to remove small amounts of cover material that should not be included in the waste tonnage.
- The Coulson Road landfill within the *Managed waste disposal sites* category stopped accepting waste in 2019. Therefore, the landfill gas capture rate was revised for the duration of gas capture beginning in 2018, from 68 per cent to 52 per cent, which is the value for closed sites. Furthermore, the Victoria Flats landfill had a gas capture system installed during 2021 and the estimate for 2021 reflects this.
- Activity data for *Composting* were revised upward to account for the effects of policy actions beginning in 2020.
- Activity data for *Industrial wastewater* were revised for the paper and paperboard and wood pulp industries due to revised statistics.

Further details can be found under methodological issues for each source category and also in chapter 10.

Other sector (Tokelau)

Recalculations made to emissions estimates in Tokelau resulted in no change for 1990 and a 0.004 per cent (0.0002 kt CO_2-e) increase in emissions in 2020.

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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, and Tokelau, but do not include emissions and removals from the Land Use, Land-Use Change and Forestry (LULUCF) sector (UNFCCC, 2013).

1990–2021

In 1990, New Zealand's gross GHG emissions were 64,720.1 kilotonnes carbon dioxide equivalent (kt CO_2-e). Between 1990 and 2021, GHG emissions increased by 18.7 per cent (12,104.5 kt CO_2-e) to 76,824.6 kt CO_2-e in 2021 (see figure 2.1.1). From 1990 to 2021, the average annual growth in gross emissions was 0.6 per cent.

The emission categories that contributed the most to this increase in gross emissions were: *Enteric fermentation*[21] from *Dairy cattle*, *Road transportation*, *Agricultural soils*, *Manufacturing industries and construction* (particularly from the *Chemicals* category) and *Product uses as substitutes for ODS*.[22]

2020–2021

Between 2020 and 2021, New Zealand's gross emissions decreased by 0.7 per cent (506.1 kt CO_2-e). The main cause was a decrease in emissions from the Agriculture sector of 1.5 per cent (574.1 kt CO_2-e) due to a decrease in fertiliser use and reduced dairy cattle and sheep populations. The largest contributors to the overall decrease in emissions were from:

- *Agricultural soils* (nitrous oxide (N_2O))
- *Manufacturing industries and construction* (carbon dioxide (CO_2))
- *Public electricity and heat production* (CO_2).

The reductions in the *Manufacturing industries and construction* category were largely driven by a decrease in emissions from the *Chemicals* category of 17.6 per cent (272.5 kt CO_2-e) from 2020 levels. This drop was mostly due to the closure of Methanex's Waitara Valley methanol production plant.

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

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

The reductions in the *Public electricity and heat production* category were due to the increased share of electricity generated from renewable energy sources over this period, which displaced gas and coal-fired electricity generation.

Emissions from the Energy and IPPU sectors increased by 0.3 per cent and 0.6 per cent respectively; while emissions from the Waste sector and Tokelau decreased 1.6 per cent and 9.5 per cent respectively.

New Zealand's COVID-19 response and protection framework[23] remained in place for the 2021 year. The pandemic continued to affect emissions in 2021, although to a lesser extent than in 2020. On 17 August 2021, all of New Zealand moved to the highest level of restriction,[24] with the northern regions, including Auckland, remaining under tighter restrictions on activities and movements for the remainder of the year. While some parts of the economy rebounded, others continued to be affected by New Zealand's COVID-19 response measures, and the associated disruptions to global supply chains continued to be felt.

Net emissions

Net emissions include gross emissions as defined above (i.e., from the Energy, IPPU, Agriculture and Waste sectors, including Tokelau) and net emissions from the LULUCF sector, as reported under the United Nations Framework Convention on Climate Change (the Convention).

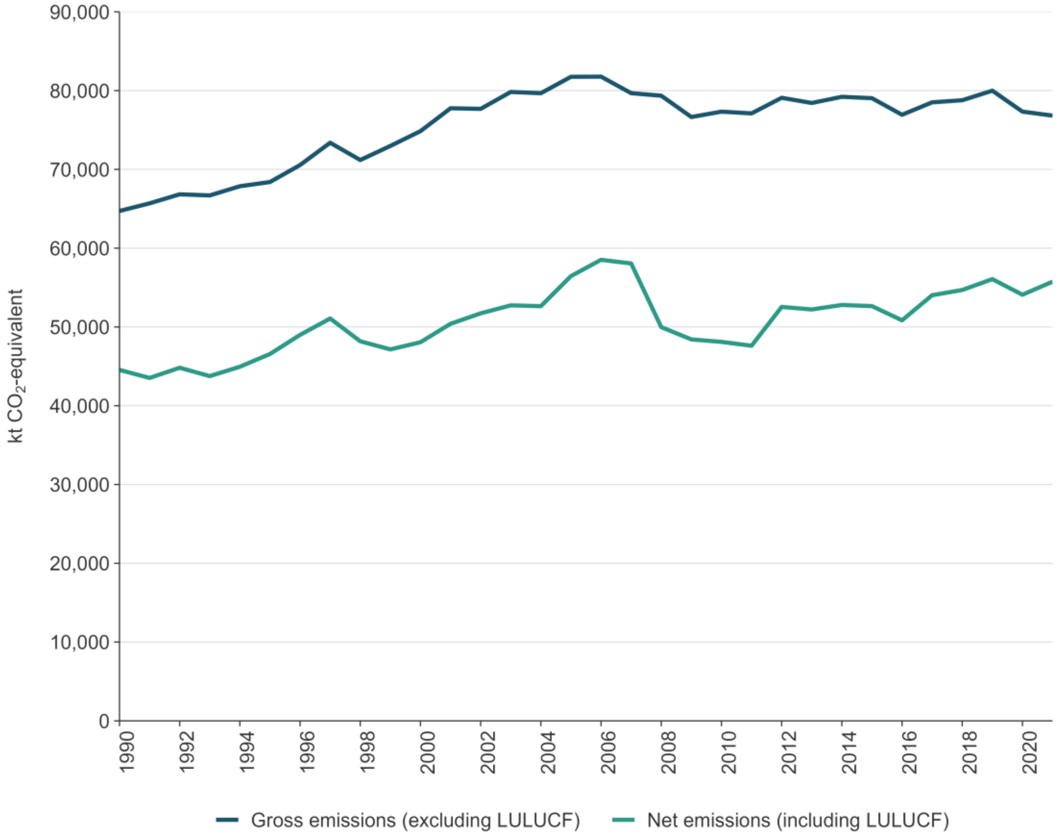
In 1990, New Zealand's net emissions were 44,548.8 kt CO_2-e. Between 1990 and 2021, net GHG emissions increased by 25.1 per cent (11,197.6 kt CO_2-e) to 55,746.4 kt CO_2-e (see figure 2.1.1).

The four categories that contributed the most to the increase in net emissions between 1990 and 2021 were: *Land converted to forest land*, *Enteric fermentation from dairy cattle*, *Road transportation* and *Agricultural soils*.

23 For more information, see https://covid19.govt.nz/about-our-covid-19-response/.

24 For more information, see https://covid19.govt.nz/about-our-covid-19-response/history-of-the-covid-19-alert-system/.

Figure 2.1.1 New Zealand's gross and net emissions (under the Convention) from 1990 to 2021



2.2 Emission trends by sector

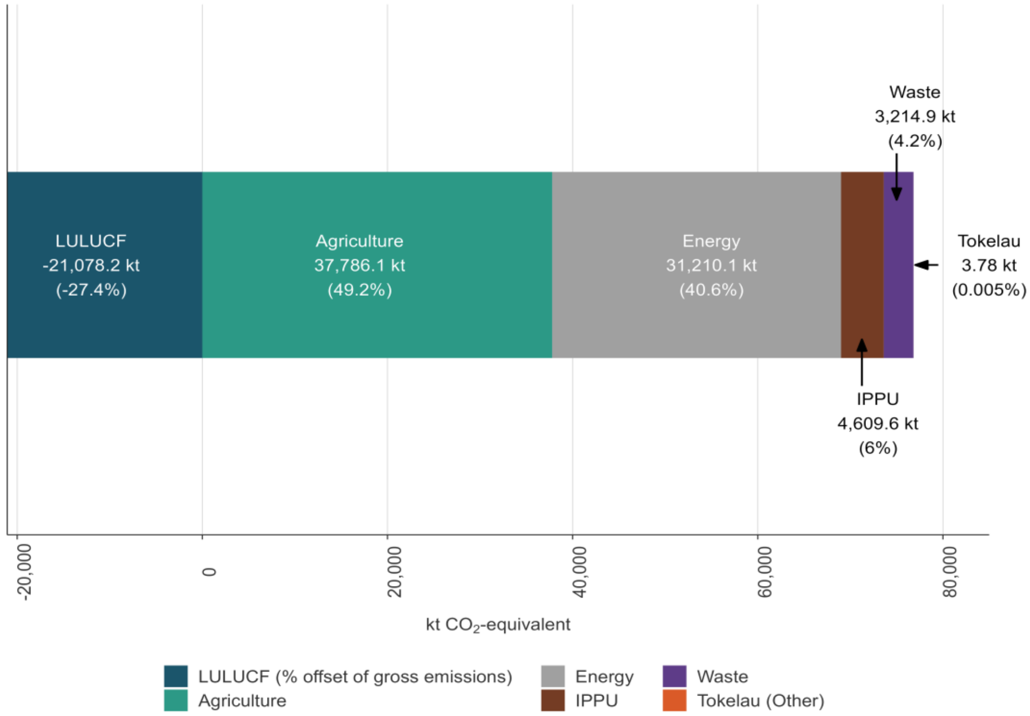
New Zealand reports emissions and removals for the Energy, IPPU, Agriculture, LULUCF and Waste sectors. Tokelau's emissions are also reported separately by sector as 'Other'.

2.2.1 New Zealand's emissions by sector and by gas in 2021

New Zealand's emissions by sector reflect the composition of the national economy. The Agriculture sector contributed 49.2 per cent of New Zealand's gross emissions in 2021. New Zealand's Energy sector contributed 40.6 per cent to the national gross emissions, while the IPPU and Waste sectors contributed 6.0 per cent and 4.2 per cent respectively (figure 2.2.1). New Zealand's '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 –21,078.2 kt CO_2-e. This offset 27.4 per cent of New Zealand's gross emissions in 2021.

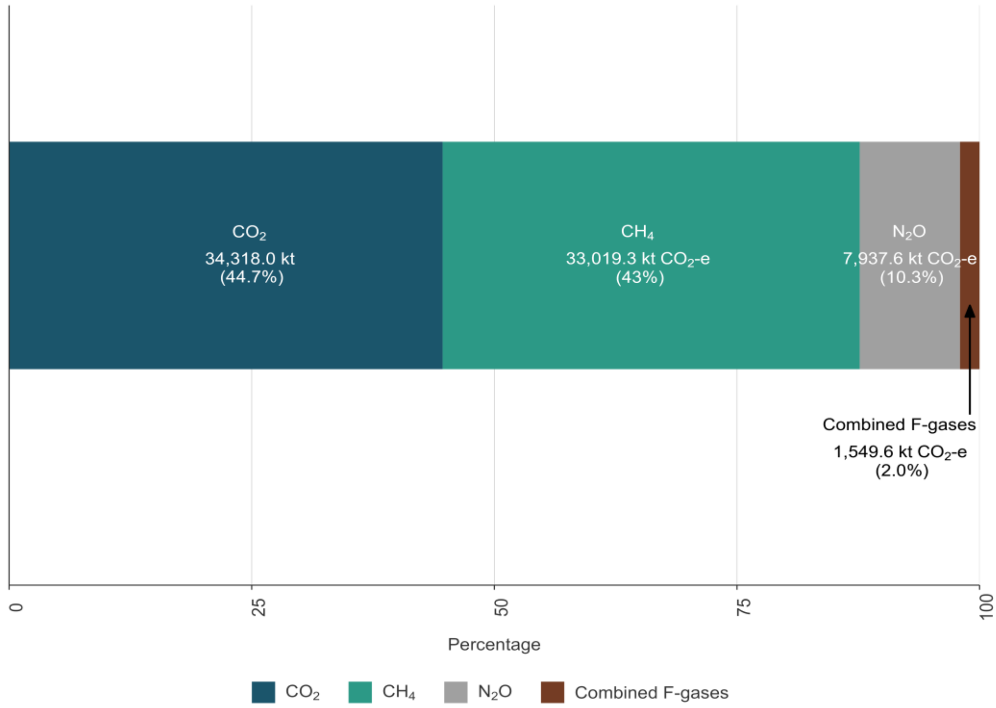
Figure 2.2.1 New Zealand's emissions by sector in 2021



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. The Tokelau sector is not visible, due to its small contribution (3.8 kt CO_2-e or 0.005 per cent of New Zealand's gross GHG emissions).

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

Figure 2.2.2 New Zealand's gross emissions by gas in 2021



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 contributes 44.7 per cent to New Zealand's gross emissions (34,318.0 kt CO_2) (figure 2.2.2). The Energy sector produces the largest amount of CO_2 at 30,423.5 kt (88.7 per cent) of New Zealand's CO_2 emissions in 2021. The categories contributing most to CO_2 emissions in the Energy sector are *Transport* (13,733.4 kt CO_2, 40.0 per cent) and *Manufacturing industries and construction* (6,205.1 kt CO_2, 18.1 per cent). In 2021, the LULUCF sector was a CO_2 sink, sequestering –21,358.2 kt CO_2 (62.2 per cent) of New Zealand's CO_2 emissions. This resulted in net CO_2 emissions of 12,959.8 kt in 2021.

The amount of methane (CH_4) emitted in New Zealand in 2021 is 43.0 per cent of gross emissions (33,019.3 kt CO_2-e). Nitrous oxide, at 10.3 per cent (7,937.6 kt CO_2-e), is the third-largest component of New Zealand's gross emissions. The Agriculture sector produces the largest amount of both CH_4 and N_2O. In 2021, the contributions of the Agriculture sector to national emissions of CH_4 and N_2O were 89.2 per cent and 93.6 per cent respectively. The major source of CH_4 in the Agriculture sector is *Enteric fermentation* (27,859.0 kt CO_2-e, 84.4 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 (7,315.2 kt CO_2-e, 92.2 per cent of New Zealand's gross N_2O emissions).

Methane is also the largest component of New Zealand's Waste sector emissions, contributing 2,955.3 kt CO_2-e, or 9.0 per cent, of gross CH_4 emissions.

Fluorinated gases (hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6))[25] collectively contribute 2.0 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 1,549.6 kt CO_2-e in 2021. No manufacture of any of the fluorinated GHGs occurs in New Zealand. Emissions of fluorinated gases are dominated by HFCs (95.7 per cent of all fluorinated gases). The PFCs and SF_6 contribute 3.3 per cent and 1.0 per cent to total emissions of fluorinated gases respectively. Almost all of New Zealand's PFC emissions (99.99 per cent) result from aluminium production.

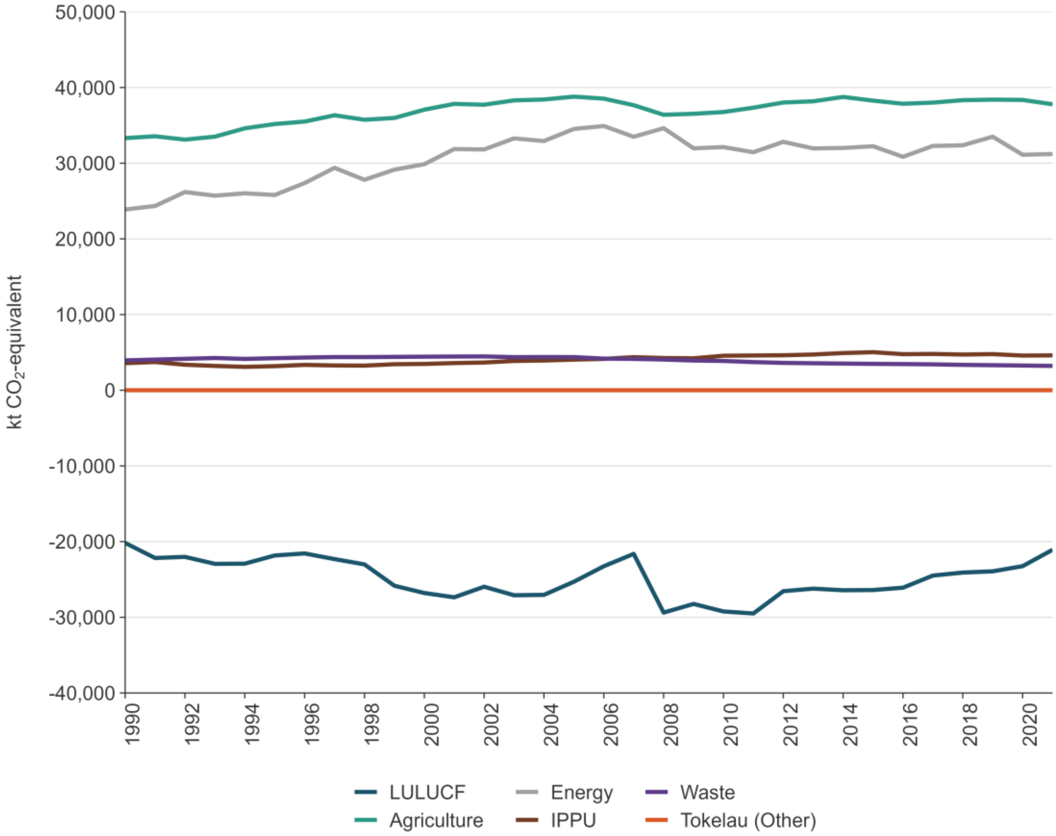
2.2.2 Emission trends by sector from 1990 to 2021

Figure 2.2.3 shows the contribution to net emissions that each inventory sector made. The Agriculture and Energy sectors dominated New Zealand's gross emissions. Together, these sectors produced almost 90 per cent of New Zealand's annual gross GHG emissions from 1990 to 2021. The IPPU and Waste sectors produced relatively small amounts of GHGs, contributing between 4 per cent and 6 per cent of the annual gross emissions for the entire time series.

Conversely, the LULUCF sector was a net sink of GHG emissions between 1990 and 2021.

25 New Zealand does not produce or consume nitrogen trifluoride (NF_3).

Figure 2.2.3 **Trends in New Zealand's greenhouse gas emissions by sector from 1990 to 2021**



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

Table 2.2.1 presents New Zealand's emissions by sector in 1990 and 2021 and the change between the years in absolute terms and by percentage. Figure 2.2.4 shows the changes in emissions by sector between 1990 and 2021.

Table 2.2.1 **New Zealand's emissions by sector between 1990 and 2021**

Sector	1990	2021	Change from 1990 (kt CO_2-equivalent)	Change from 1990 (%)
Energy	23,880.3	31,210.1	7,329.8	30.7
IPPU	3,579.9	4,609.6	1,029.7	28.8
Agriculture	33,312.0	37,786.1	4,474.1	13.4
Waste	3,944.6	3,214.9	–729.7	–18.5
Tokelau	3.2	3.8	0.6	19.4
Gross	**64,720.1**	**76,824.6**	**12,104.5**	**18.7**
LULUCF	–20,171.2	–21,078.2	–906.9	–4.5
Net	**44,548.8**	**55,746.4**	**11,197.6**	**25.1**

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 presents the emissions estimates by sector, and the change between 1990 and 2021 in kt CO_2 equivalents.

Figure 2.2.4 Change in New Zealand's emissions by sector comparing 1990 and 2021

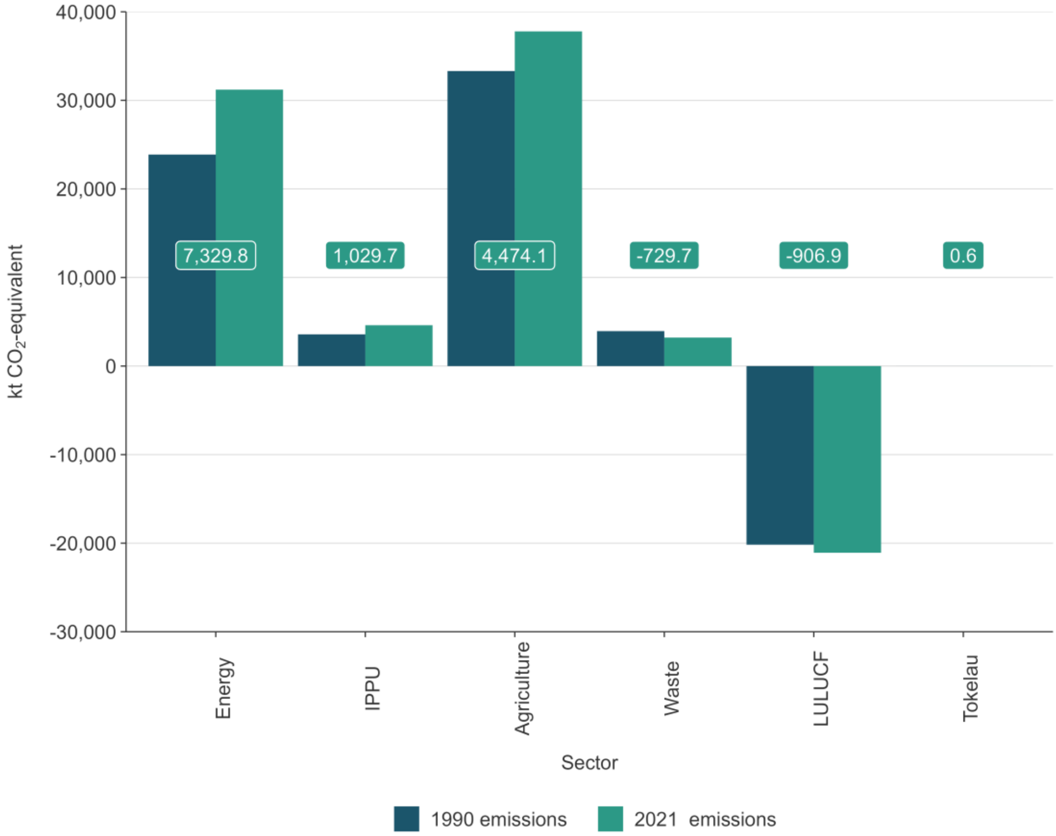


Figure 2.2.5 presents the absolute change in gross emissions for each sector (LULUCF is excluded from the estimate of gross emissions) and the change between 1990 and 2021 estimates is provided for each sector in kt CO_2 equivalents.

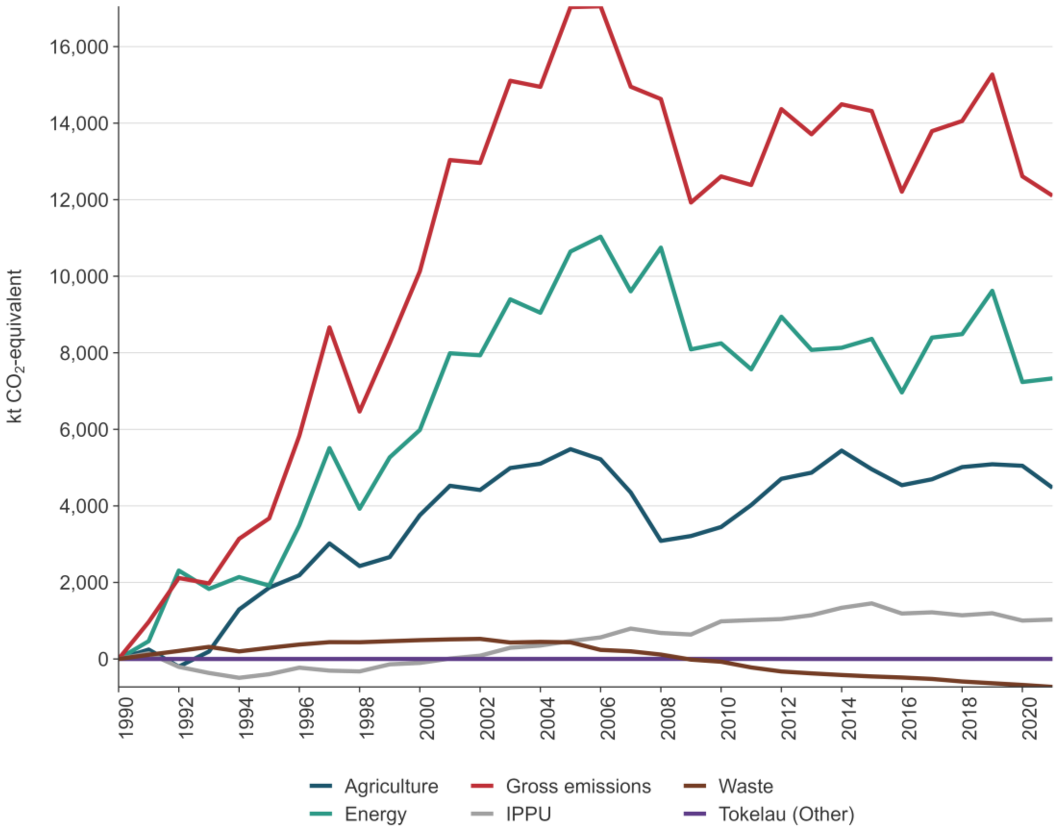
The figure shows that the absolute changes in New Zealand's gross emissions were mostly influenced by changes in the Agriculture and Energy sectors. This is to be expected because they are the largest sectors of the New Zealand economy and show higher sensitivity to both changes in global economic conditions, extreme weather conditions and natural disasters.

For example, during droughts, the level of inflow to hydro lakes is low resulting in lower levels of hydro electricity production. Consequently, electricity produced from fossil fuels makes a higher contribution to the national electricity grid resulting in increased emissions from the Energy sector.

Droughts also affect the size of the livestock population and livestock productivity, which usually results in reduced emissions from the Agriculture sector as the population and productivity declines.

Emissions from Tokelau have increased since 1990, mainly due to increases in CO_2 emissions from the *Domestic navigation* category (figure 2.2.5). Note that, because of the small size of the Tokelau sector, the change in emissions over time is unable to be seen.

Figure 2.2.5 Absolute change in New Zealand's gross emissions by sector from 1990 to 2021



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 mainly influenced by harvesting, afforestation and deforestation rates (see the LULUCF sector section below).

Figure 2.2.6 Absolute change in net emissions from the LULUCF sector from 1990 to 2021

Energy sector

Emissions from the Energy sector are dominated by CO_2 (97.5 per cent of all emissions from the sector on a CO_2-e basis) and smaller amounts of CH_4 and N_2O (1.7 per cent and 0.8 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. Electricity generated from renewable energy sources was 82 per cent in 2021.

2021

In 2021, emissions from the Energy sector contributed 40.6 per cent or 31,210.1 kt CO_2-e of New Zealand's gross GHG emissions (figure 2.2.1).

The largest sources of emissions in the Energy sector were the *Road transportation* category, contributing 40.5 per cent (12,654.9 kt CO_2-e), and the *Manufacturing industries and construction* category, contributing 20.2 per cent (6,302.0 kt CO_2-e).

1990–2021

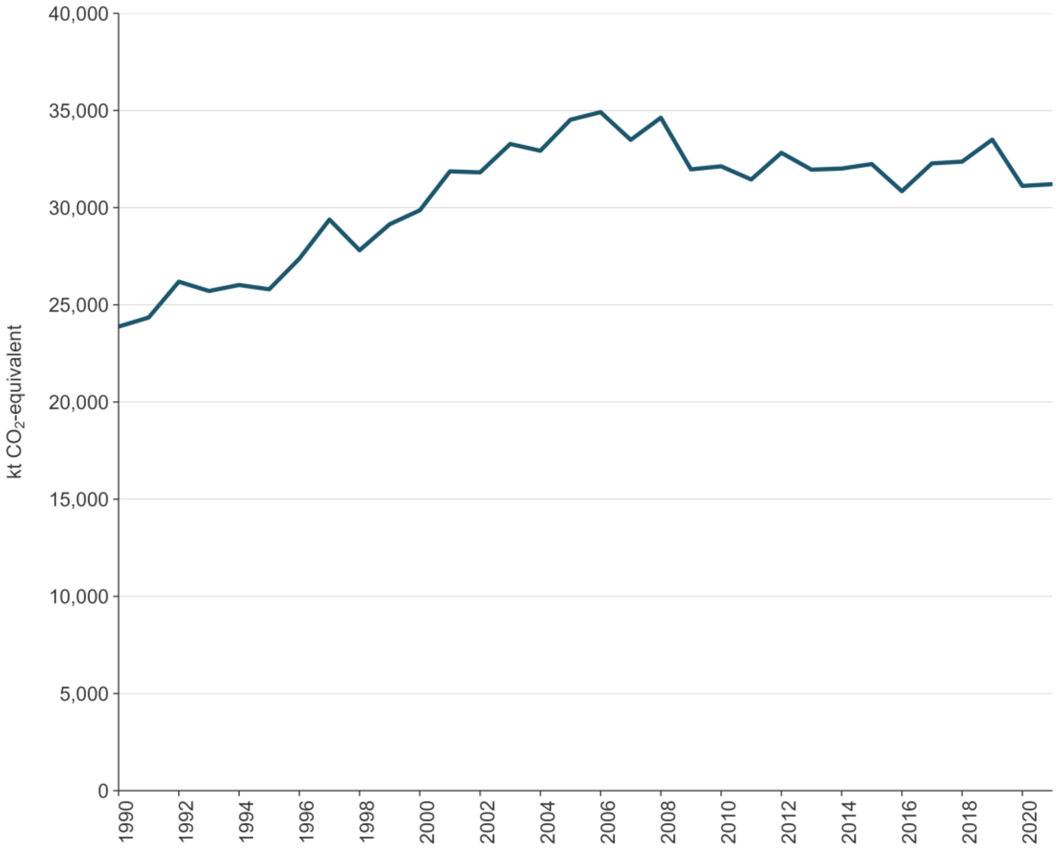
In 2021, emissions from the Energy sector were 31,210.1, an increase of 30.7 per cent (7,329.8 kt CO_2-e) from the 1990 level of 23,880.3 kt CO_2-e. This growth in emissions is primarily from increases in:

- *Road transportation*, which increased by 85.3 per cent (5,825.8 kt CO_2-e)
- *Food processing, beverages and tobacco*, which increased by 67.4 per cent (1,127.5 kt CO_2-e)
- *Public electricity and heat production*, which increased by 26.5 per cent (926.5 kt CO_2-e).

In 2021, emissions from the *Manufacture of solid fuels and other energy industries* category – a historically significant contributor to New Zealand's emissions – were lower than the 1990 level by 85.3 per cent (1,463.9 kt CO_2-e). 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 2021. Emissions increased from 1990 to around 2005, before decreasing slightly and then remaining steady until the present day.

Figure 2.2.7 New Zealand's Energy sector emissions from 1990 to 2021



2020–2021

Between 2020 and 2021, emissions from the Energy sector increased by 0.3 per cent (93.2 kt CO_2-e). This is primarily due to the 5.0 per cent (606.2 kt CO_2-e) increase in emissions from category 1.A.3.b *Road transportation*, followed by a 42.7 per cent (118.1 kt CO_2-e) increase from category 1.A.2.f *Non-metallic minerals*. The increase was partially offset by category 1.A.2.c *Chemicals*, which decreased by 17.6 per cent (272.5 kt CO_2-e). A 4.4 per cent (200.9 kt CO_2-e) decrease also occurred in emissions from category 1.A.1.a *Public electricity and heat production*.

The 2020 calendar year saw disruption to economic activity in New Zealand, with the effects of the COVID-19 pandemic being felt by the Energy sector throughout the year. The sector saw a rebound during 2021, but consumption remained below pre-2020 levels. All of New Zealand moved to Alert Level 4[26] on 17 August 2021, with the northern regions of New Zealand, including Auckland, remaining under tighter restrictions on activities and movements for the remainder of 2021.

Restrictions on activities and movement, as part of the response to the COVID-19 pandemic, also affected the commercial and industrial sectors. Industries that were deemed non-essential faced restrictions on their operations, and continued disruptions to global supply chains affected business activity in New Zealand. The combination of COVID-19-related restrictions and global supply chain disruptions contributed significantly to decreases in business activity for the basic metals and the mining sectors in particular.

IPPU sector

The IPPU sector in New Zealand produces CO_2 emissions (62.8 per cent), fluorinated gases (33.3 per cent) and smaller amounts of CH_4 and N_2O. The major categories in the IPPU sector are *Iron and steel production*, *Refrigeration and air conditioning*, *Aluminium production* and *Cement production*. Coal and natural gas are also 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.

2021

Emissions in the IPPU sector contributed 6.0 per cent (4,609.6 kt CO_2-e) of New Zealand's gross GHG emissions.

The largest category was the *Metal industry*, 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. Most of the non-CO_2 emissions came 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.

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*.

1990–2021

Emissions from the IPPU sector in 2021 were 4,609.6 kt CO_2-e, 28.8 per cent (1,029.7 kt CO_2-e) 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 ODS in refrigeration and air conditioning and the increased use of household and commercial air conditioning.

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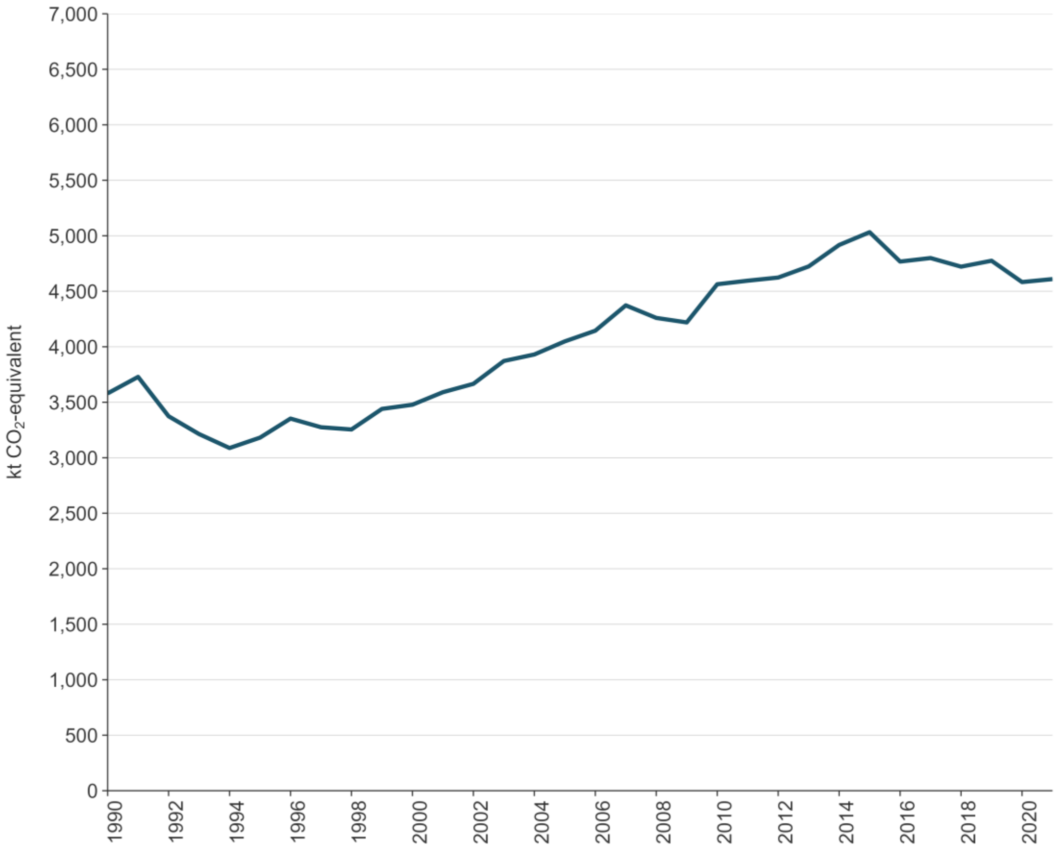
[26] For more information, see https://covid19.govt.nz/about-our-covid-19-response/history-of-the-covid-19-alert-system/.

Carbon dioxide emissions also increased due to the growing production of metals, lime and cement, but these were at a slower rate. In 2020 and 2021 the increase was offset by reduced emissions due to COVID-19 restrictions and the progressive shutdown of the Marsden Point oil refinery. 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 2021



2020–2021

Between 2020 and 2021, emissions from the IPPU sector increased by 0.6 per cent (26.7 kt CO_2-e).

This change was the result of a return to normal rates of production and emissions from the *Metal industry* and other categories, following plant shutdowns related to COVID-19 restrictions in 2020. New Zealand had a national lockdown in force from 26 March to 27 May 2020. Emissions from the Marsden Point oil refinery, however, remained at lower levels as the company prepared to shut the plant down in March 2022.

Agriculture sector

The Agriculture sector in New Zealand produces three main GHGs, CH_4, N_2O and CO_2, which comprise 77.9 per cent, 19.7 per cent and 2.4 per cent of all Agriculture sector emissions respectively. Trends in Agriculture sector emissions are largely driven by the populations of ruminant livestock (dairy cattle, non-dairy (beef) cattle, sheep and deer). The largest contributing categories in the Agriculture sector are *Enteric fermentation* and *Agricultural soils*. Emissions from the Agriculture sector reflect the total livestock population, the types of livestock and farming systems, and levels 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 non-dairy (beef) cattle populations have decreased as the profitability of dairy products has risen relative to sheep and beef products (see chapter 5, figure 5.1.3a and figure 5.1.3b)
- increases in livestock productivity (for both milk and meat yield per head of livestock), which have been achieved by New Zealand farmers since 1990. This has resulted in increased feed intake per animal to meet higher energy demands of increased production. Increased feed intake results in increased CH_4 (from increased enteric fermentation) and N_2O emissions (from increased excreta deposited on pasture) per animal
- incidence of severe droughts, which have resulted in reduced livestock productivity and livestock populations, which in turn reduced livestock-related emissions. The Ministry for Primary Industries produces quarterly reports that summarise the effects of these events at a sector level and provide short-term forecasts[27]
- commodity price fluctuations that drive farmer investment decisions in livestock numbers and species as well as production inputs. The 'Situation and Outlook for Primary Industries' reports produced by the Ministry for Primary Industries summarise these decisions at a sector level and provides short-term forecasts[28]
- shifting land use across different types of livestock farming and other agricultural enterprises, including forestry. The Agriculture sector uses around 45 per cent of New Zealand's land area, mostly for grazing of pastoral land. Between 1990 and 2021, the area used for sheep, beef and deer grazing has decreased by approximately 37 per cent (Beef + Lamb New Zealand Ltd, 2022), while the area used for dairy grazing has increased by 69.1 per cent (LIC and DairyNZ, 2021). The amount of synthetic nitrogen fertiliser applied to agricultural land has increased by 644 per cent since 1990.

2021

Emissions from the Agriculture sector totalled 37,786.1 kt CO_2-e, representing 49.2 per cent of New Zealand's gross emissions in 2021.

Enteric fermentation was the main source of Agriculture emissions, contributing 73.7 per cent (27,859.0 kt CO_2-e) of the sector's total. *Agricultural soils* contributed 19.4 per cent (7,315.2 kt CO_2-e), followed by *Manure management* at 4.4 per cent (680.5 kt CO_2-e) of the sector's total emissions. *Urea application* and *Liming* contributed 1.5 per cent (553.2 kt CO_2) and 0.9 per cent (355.6 kt CO_2) respectively. *Field burning of agricultural residues* contributed the remaining 0.1 per cent (22.6 kt CO_2).

Methane emissions from *Enteric fermentation* contributed 36.3 per cent of New Zealand's gross emissions, and N_2O emissions from the *Agricultural soils* category contributed 9.5 per cent.

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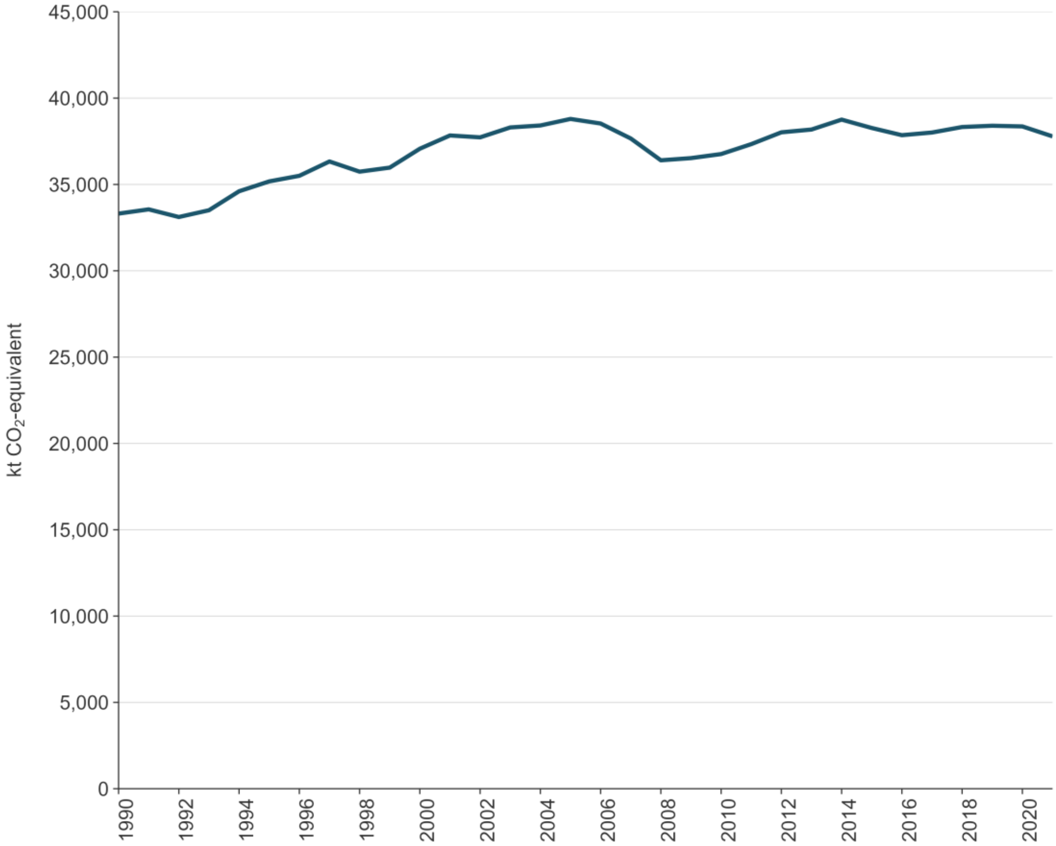
27 For more information, see www.mpi.govt.nz/news-and-resources/economic-intelligence-unit/situation-and-outlook-for-primary-industries/.

28 For more information, see www.mpi.govt.nz/news-and-resources/economic-intelligence-unit/situation-and-outlook-for-primary-industries/.

Figure 2.2.9 New Zealand's Agriculture sector emissions from 1990 to 2021



1990–2021

In 2021, New Zealand's Agriculture sector emissions were 37,786.1 kt CO_2-e, 13.4 per cent (4,474.1 kt CO_2-e) above the 1990 level of 33,312.0 kt CO_2-e.

The greatest contributions to the increase since 1990 were a 40.2 per cent (2,098.3 kt CO_2-e) increase in N_2O emissions from *Agricultural soils* and a 117.7 per cent (849.9 kt CO_2-e) increase in CH_4 emissions from *Manure management*.

The increase in N_2O emissions from *Agricultural soils* was primarily a result of increased application of synthetic nitrogen fertiliser by around 644 per cent since 1990. This is partly due to an increase in dairy farming, as well as a general increase in fertiliser use on farms.

The increase in emissions from *Enteric fermentation* was driven by an increase in dairy cattle numbers, which was partially offset by a decrease in beef cattle and sheep numbers. Stock numbers have also reduced as a result of several voluntary initiatives driven by agricultural sector groups, which have focused on improving livestock genetics and championing the uptake of more sustainable farming practices. Alongside this, changes in New Zealand's regulatory environment, including improvements to freshwater quality policies and the New Zealand Emissions Trading Scheme (NZ ETS), are also likely to have led to reductions in stock numbers. The increasing carbon price in the NZ ETS has affected land use change, with rising afforestation rates impacting stock numbers.

2020–2021

Between 2020 and 2021, total agricultural emissions decreased by 1.5 per cent (574.1 kt CO_2-e) largely due to a decrease in emissions from dairy cattle, sheep and synthetic nitrogen fertiliser. Specifically:

- dairy cattle emissions decreased by 1.3 per cent (236.9 kt CO_2-e) due to a decrease in the dairy cattle population
- synthetic nitrogen fertiliser emissions decreased by 9.5 per cent (177.9 kt CO_2-e) due to a decrease in fertiliser use
- sheep emissions decreased by 1.8 per cent (160.6 kt CO_2-e) due to a further decrease in the sheep population.

Emissions from other activities had minor increases and were not enough to offset the overall decrease in agricultural emissions. Some of these increases include:

- beef cattle emissions, which increased by 0.7 per cent (48.9 kt CO_2-e) due to a slight increase in the beef cattle population
- urea emissions, which increased by 2.1 per cent (11.2 kt CO_2-e) due to a small increase in the use of urea.

LULUCF sector

The following information on LULUCF summarises reporting under the Convention. The Kyoto Protocol remains in force and reporting requirements remain in place. New Zealand, therefore, continues its reporting on LULUCF activities under the Kyoto Protocol in section 2.3, the Executive summary, section ES.5, and chapter 11.

2021

In 2021, net emissions from the LULUCF sector were –21,078.2 kt CO_2-e, or –27.4 per cent of New Zealand's gross GHG emissions. This comprises net removals of –21,358.2 kt of CO_2, and emissions of 32.6 kt CO_2-e of CH_4 and 247.4 kt CO_2-e of N_2O. The category contributing the most to both removals and emissions is *Forest land remaining forest land*. This is because of large removals from the growth of all forests on *Forest land remaining forest land* and also large emissions from the sustainable harvest of New Zealand's plantation forests.

1990–2021

Net emissions from the LULUCF sector were –21,078.2 kt CO_2-e in 2021, a 4.5 per cent (906.9 kt CO_2-e) decrease from the 1990 level of –20,171.2 kt CO_2-e. This is largely due to removals from forest growth and an increase in the production of harvested wood products, which have compensated for some of the emissions from the increase in forest harvesting.

Emissions in the LULUCF sector are primarily driven 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 an increase in the size of the harvested wood products pool. Nitrous oxide is emitted from soils as a by-product of nitrification and denitrification, and through the burning of organic matter. Other gases released during biomass burning include CH_4, carbon monoxide, other oxides of nitrogen and non-methane volatile organic compounds.

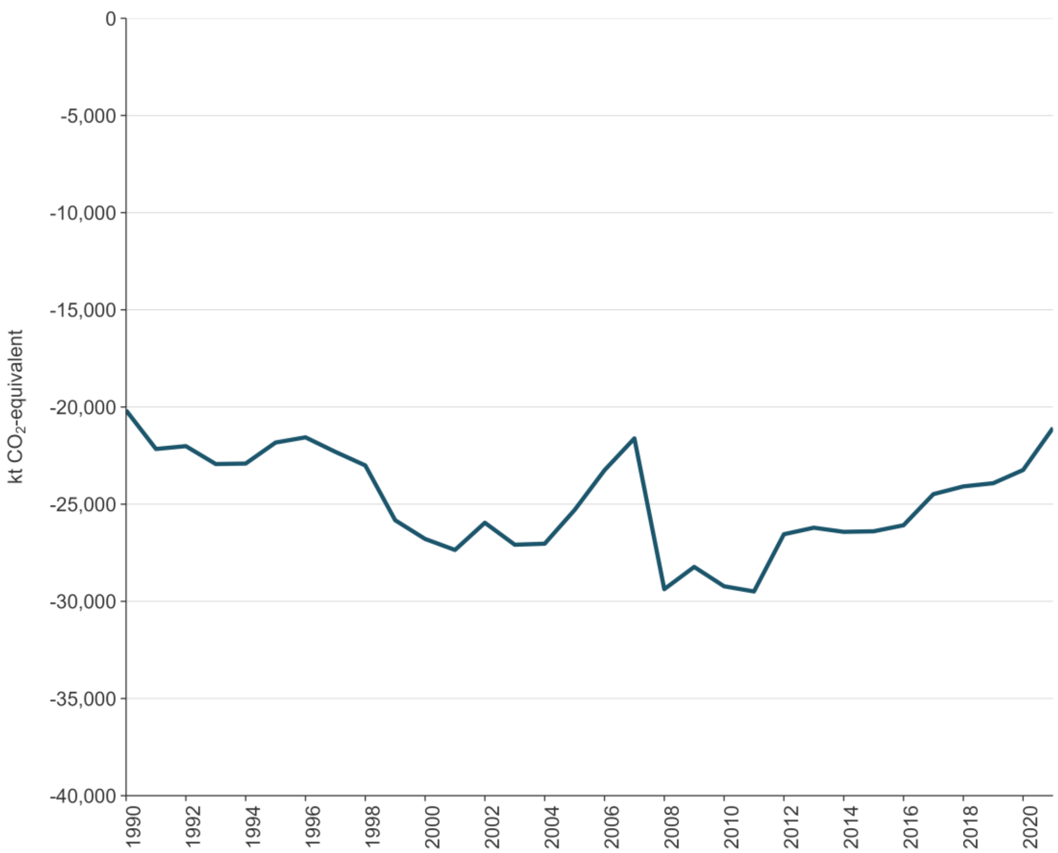
The fluctuations in net emissions from the LULUCF sector (see figure 2.2.10) are primarily influenced by afforestation, harvesting and deforestation rates. Harvesting rates are driven by several factors, particularly forest age and log prices.

Net emissions in the LULUCF sector have been generally increasing over the past decade. Current harvest rates are near historic high levels due to the significant land use changes to forest land that occurred from the 1980s and into the early 1990s. The production forests that were established during this period have progressively been reaching maturity and that will continue into the 2020s. As the high harvesting rates continue, the average age of the planted forest estate as a whole is reduced each year, as harvested forests are replanted. Young stands have low growth rates compared with older, faster growing stands. Harvest and replanting cycles of New Zealand's planted forests will continue to affect the trajectory of New Zealand's net emissions in the future due to their uneven age-class profile.

Deforestation rates are driven by the relative profitability of forestry compared with alternative land uses. The increase in net emissions between 2004 and 2007 was mainly due to the increase in planted forest deforestation that occurred in the lead up to 2008, and the introduction of the New Zealand Emissions Trading Scheme (NZ ETS).[29]

From 2019 onwards, rates of afforestation have significantly increased. This is likely due to policy initiatives incentivising afforestation as well as higher carbon prices in the NZ ETS.

Figure 2.2.10 New Zealand's LULUCF sector net emissions from 1990 to 2021



[29] The NZ ETS included the Forestry sector from 1 January 2008.

2020–2021

Net emissions from the LULUCF sector increased between 2020 and 2021 by 9.3 per cent (2,163.9 kt CO_2-e).

The largest change occurred in the *Forest land* category, with an increase in emissions of 4,882.0 kt CO_2-e. The reason for this change was largely due to an increase in harvest emissions between these years. In 2021, harvesting activities rebounded following the 2020 drop due to the COVID-19 restrictions. This impact was exacerbated by the ongoing high rate of harvesting occurring in New Zealand's production forests. As a result, the planted forest estate is composed of a higher proportion of young forest stands, which grow more slowly and sequester less carbon than faster growing older stands. The *Harvested wood products* category had the second-largest change, with a decrease in emissions of 1,824.3 kt CO_2-e, which was also driven by harvest rate.

Waste sector

The Waste sector in New Zealand produces mainly CH_4 emissions (91.9 per cent) followed by N_2O (5.3 per cent) and CO_2 emissions (2.8 per cent). The Waste sector produces 9.0 per cent of gross CH_4 emissions in New Zealand. There are also emissions of CO_2 from the disposal of solid waste, but these are of biogenic origin and are not reported.

2021

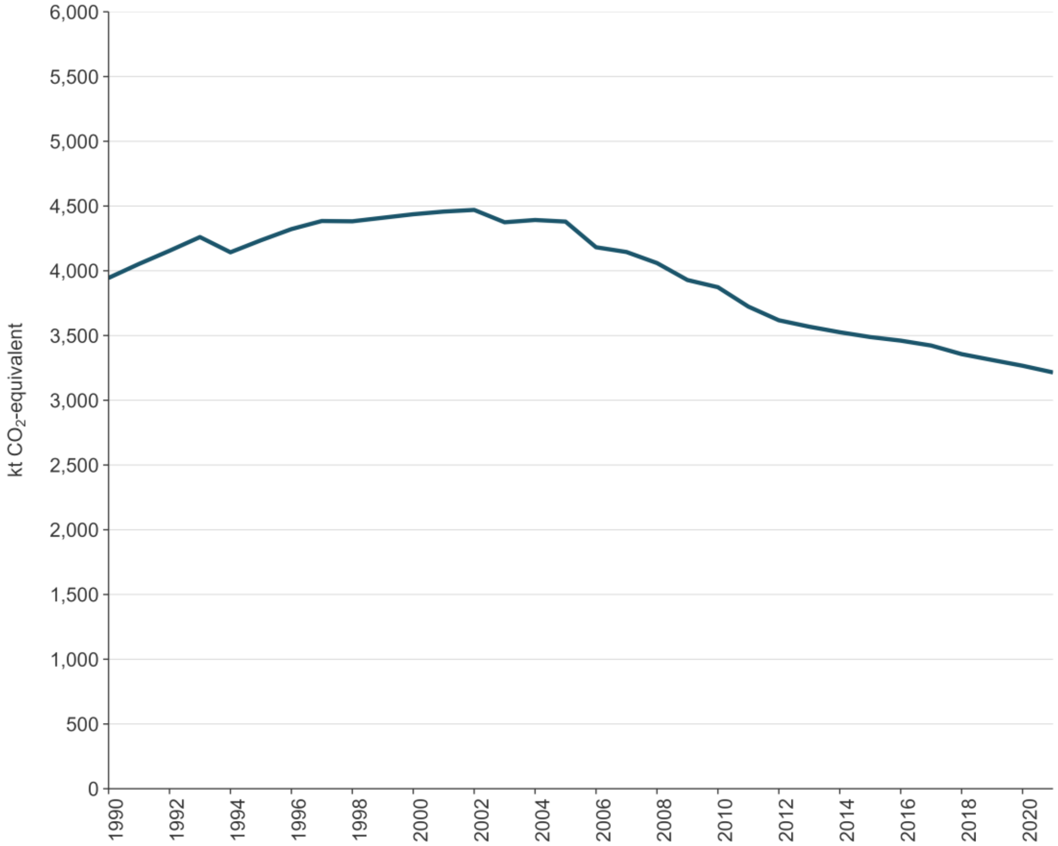
In 2021, emissions from the Waste sector contributed 4.2 per cent (3,214.9 kt CO_2-e) of New Zealand's gross GHG emissions. The largest source category is *Solid waste disposal*, as shown in chapter 7, table 7.1.1.

1990–2021

Emissions from the Waste sector decreased by 18.5 per cent (729.7 kt CO_2-e), from 3,944.6 kt CO_2-e in 1990 to 3,214.9 kt CO_2-e in 2021.

Annual emissions increased between 1990 and 2002, peaking at 4,470.0 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 in emissions is primarily the result of increased CH_4 recovery driven by the National Environmental Standards for Air Quality introduced in 2004 and also by the NZ ETS since 2013. The trends are shown in figure 2.2.11 and in chapter 7, figure 7.1.2 and figure 7.1.3.

Figure 2.2.11 **New Zealand's Waste sector emissions from 1990 to 2021**



2020–2021

Between 2020 and 2021, emissions from the Waste sector decreased by 1.6 per cent (51.6 kt CO_2-e). This decrease is largely the result of decreases in CH_4 emissions in the *Managed waste disposal sites* category mainly due to increasing landfill gas capture and changes in the composition of waste, with a reduction in the proportion of garden, food and paper waste disposed to those sites.

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 are 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 used varies greatly between Tokelau's inventory and the inventory for New Zealand's mainland territory, emissions from Tokelau are reported in the Other sector. Methodological issues for Tokelau are detailed in chapter 8, separately from the sectoral chapters that focus on methods for New Zealand's mainland territory only. Annex 7 provides common reporting format tables of the time series for emissions and activity data, and information on methods and emission factors for each sector and category contributing to the gross emissions from Tokelau.

Due to its 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. In relative terms, emissions have increased overall since 1990, due to increasing per capita consumption despite a decrease in population. Tokelau produces mainly CO_2 emissions (53.6 per cent) and CH_4 emissions (39.1 per cent) followed by HFCs (6.2 per cent) and N_2O emissions (1.2 per cent). Emissions from HFCs largely come from the use of domestic fridges and freezers.

Table 2.2.2 Emissions from Tokelau, 1990 and 2021

Sector	1990	2021	Change from 1990 (kt CO_2-equivalent)	Change from 1990 (%)	Contribution to gross for Tokelau (%)	Contribution to gross NZ (incl Tokelau) (%)
Energy for Tokelau	1.26	2.01	0.74	58.68	53.04	0.003
IPPU for Tokelau	0.05	0.26	0.21	441.92	6.75	0.000
Agriculture for Tokelau	1.15	0.82	–0.33	–28.29	21.79	0.001
Waste for Tokelau	0.71	0.70	–0.01	–1.59	18.42	0.001
Gross emissions for Tokelau	3.17	3.78	0.61	19.37	100.00	0.005

Note: The 2023 submission includes emissions from Tokelau's largest contributing sectors, which are the Energy, IPPU, Agriculture and Waste sectors. The LULUCF sector is not estimated. Because Tokelau has no planted or managed forests, the LULUCF sector is expected to be insignificant. The percentages may not add up to 100 per cent due to rounding.

2021

In 2021, emissions from the Tokelau sector contributed 0.005 per cent (3.78 kt CO_2-e) of New Zealand's gross GHG emissions.

The largest source category is *Domestic navigation*, which contributed 69.0 per cent (1.38 kt CO_2-e) of all energy emissions and 36.6 per cent of gross emissions from Tokelau.

Carbon dioxide dominated emissions from Tokelau, contributing 53.6 per cent (2.03 kt CO_2-e) of its total emissions in 2021. At 1.99 kt CO_2, the Energy sector contributed 98.1 per cent of total CO_2 emissions, mostly from *Domestic navigation*, with the remaining 1.9 per cent (0.04 kt CO_2-e) coming from *Open burning of waste* in the Waste sector.

Methane emissions contributed 39.1 per cent (1.48 kt CO_2-e) to the total emissions from Tokelau. The Agriculture sector in Tokelau contributed 55.8 per cent of CH_4 emissions (0.82 kt CO_2-e), which mostly came from *Manure management*. A significant portion of CH_4 emissions, 43.8 per cent (0.65 kt CO_2-e), came from the Waste sector, largely from *Solid waste disposal*. The Energy sector contributed the remaining 0.4 per cent of CH_4 emissions (0.01 kt CO_2-e), which mostly came from *Domestic navigation*.

Nitrous oxide emissions contributed 1.2 per cent (0.05 kt CO_2-e) to the total emissions from Tokelau. The *Medical applications* category in the IPPU sector contributed the largest amount of N_2O, 47.9 per cent (0.02 kt CO_2-e) of the total N_2O. The Energy sector contributed a further 27.3 per cent (0.01 kt CO_2-e), which was largely from *Domestic navigation*. The Waste sector contributed the remaining 24.7 per cent of N_2O (0.01 kt CO_2-e) from *Open burning*.

Emissions of fluorinated gases from Tokelau consisted of HFC emissions only, contributing 6.2 per cent (0.23 kt CO_2-e) to the total emissions from Tokelau. These emissions largely resulted from the use of *Air conditioning*. Emissions of PFCs, nitrogen trifluoride and sulphur hexafluoride are not occurring in Tokelau.

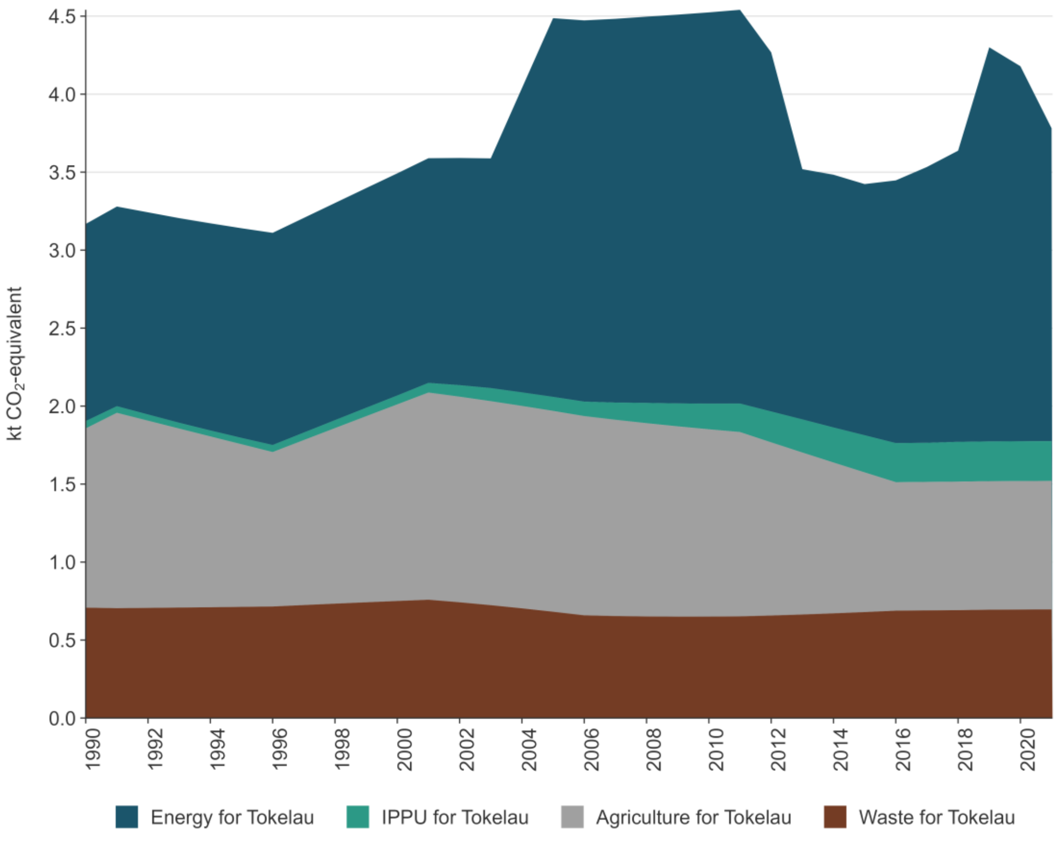
1990–2021

In 1990, total emissions from Tokelau were 3.17 kt CO_2-e. Between 1990 and 2021, the total emissions increased by 19.4 per cent (0.61 kt CO_2-e) to 3.78 kt CO_2-e (table 2.2.2; chapter 8, table 8.1.2). From 1990 to 2021, the average annual increase in gross emissions was 0.75 per cent.

The emission categories that contributed the most to this change were *Domestic navigation* and *Electricity generation*.

The changes in *Domestic navigation* were a result of Tokelau gaining ownership and use of the ferry *Mataliki* in 2016, cargo vessel *Kalopaga* in 2018, and *Fetu o te Moana* in 2019 leading to an increasing number of sea voyages between the atolls, which increased transport emissions. Emissions from Tokelau's IPPU sector have also increased mainly due to the introduction of air conditioning after 2006. Further changes in Tokelau's Energy sector emissions are a significant rise and then drop (by nearly 400 per cent and 82.5 per cent respectively) in the consumption of imported petroleum products used for electricity production in Tokelau. Emissions from Tokelau's Agriculture sector decreased slightly as a result of a reduced swine population.

Figure 2.2.12 Emissions by sector for Tokelau from 1990 to 2021



2020–2021

Total Tokelau emissions in 2021 were 9.5 per cent (0.40 kt CO_2-e) lower than emissions in 2020. The lower emissions were largely the result of decreases in CO_2 emissions in the *Domestic navigation* category.

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

Chapter 11 provides a summary of emissions and removals from the LULUCF sector based on the Kyoto Protocol reporting requirements. This summary is provided as reporting obligations under the Kyoto Protocol remain. It is for information only. Accounting rules have not been applied to these estimates and they cannot be used to track progress towards New Zealand's first Nationally Determined Contribution. New Zealand's approach to LULUCF accounting under the Paris Agreement is outlined in its first Nationally Determined Contribution and will be fully described in its first Biennial Transparency Report to be submitted under the Paris Agreement in 2024.

In 2021, net emissions from land subject to Article 3.3 and Article 3.4 activities under the Kyoto Protocol were –26,854.5 kt CO_2-e.[30] This estimate includes net removals from the growth of all forest types and their conversion into harvested wood products, as well as emissions from:

- decay of harvested wood products from *Afforestation and reforestation* and *Forest management* land
- *Deforestation* of all forest types
- conversion of land to post-1989 forest
- biomass burning
- soil disturbance associated with land use conversion.

New Zealand's estimates 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.

Afforestation and reforestation

During 2021, an estimated 54,268 hectares of new forest were established (see chapter 11, table 11.3.1). In 2021, net removals from *Afforestation and reforestation* were 11,488.3 kt CO_2-e.

Deforestation

The provisional estimated area subject to *Deforestation* in 2021 was 2,493 hectares. In 2021, net emissions from *Deforestation* were 1,391.0 kt CO_2-e.

Forest management

The total area reported under *Forest management* at the end of 2021 was 9,195,721 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 2021 were 16,757.3 kt CO_2-e, including net removals of 7,823.3 kt CO_2-e from the *Harvested wood products* category.

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30 In the 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.

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:

- 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* have 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 and a relatively old vehicle fleet (average age of light passenger fleet was around 14 years in 2021). Most freight is transported by trucks, with smaller quantities transported by rail and coastal shipping. Due to New Zealand's sparse population and rural-based economy, its domestic transport emissions per capita are high compared with many other Annex I countries.

New Zealand's electricity generation system relies heavily on renewable energy sources, but is supported by the combustion of coal, oil and gas. In 2021, fossil fuel thermal plants provided 17.8 per cent of New Zealand's total electricity supply, which is very low by international standards. New Zealand's main renewable energy source is hydroelectric power generation (meeting 55.5 per cent of total demand), which is complemented by other renewable power sources such as geothermal (18.4 per cent) and wind (6.0 per cent). While this provides a strong power generation base in years with good hydro inflows, electricity emissions remain sensitive to rainfall in the key catchment areas. New Zealand has low levels of hydro lake storage compared with other countries whose supply depends heavily on hydroelectric power.

Fugitive emissions make up a relatively minor portion of New Zealand's energy emissions profile. The main sources of fugitive emissions in New Zealand are 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. Because emissions from Tokelau are calculated using significantly different methods, integrating these with New Zealand's emissions would be prohibitively complex. For this reason, 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. All emissions reported under the Energy sector are from New Zealand only, and exclude Tokelau. Please refer to chapter 8 of the National Inventory Report for details of methods applied and the emissions for Tokelau.

2021

In 2021, emissions from the Energy sector contributed 31,210.1 kilotonnes carbon dioxide equivalent (kt CO_2-e), or 40.6 per cent, of New Zealand's gross greenhouse gas emissions (see chapter 2, figure 2.2.1).

The largest sources of emissions in the Energy sector were the *Road transportation* category, contributing 12,654.9 kt CO_2-e (40.5 per cent), and the *Manufacturing industries and construction* category, contributing 6,302.0 kt CO_2-e (20.2 per cent) to energy emissions.

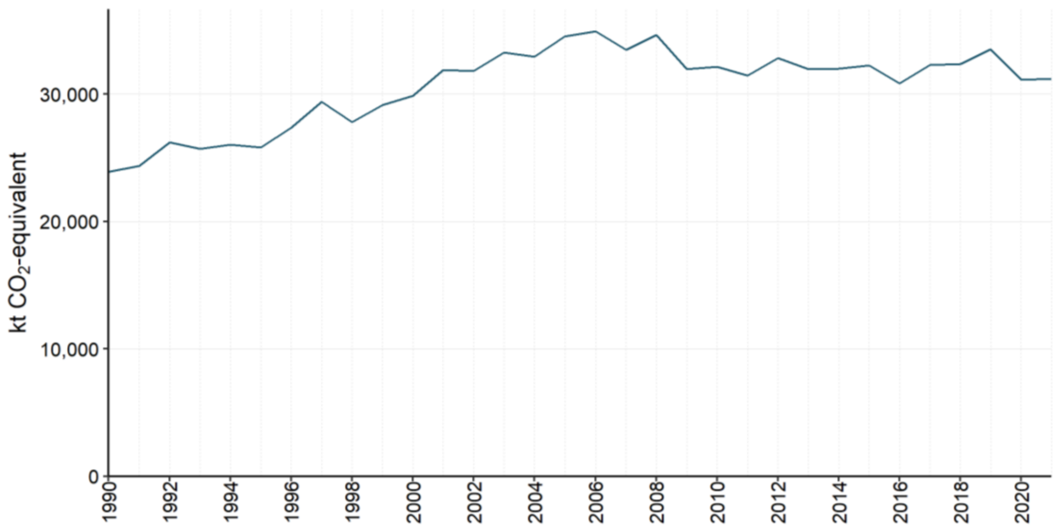
1990–2021

In 2021, emissions from the Energy sector had increased by 30.7 per cent (7,329.8 kt CO_2-e), from the 1990 level of 23,880.3 kt CO_2-e. This growth is primarily due to *Road transportation*, which increased by 5,825.8 kt CO_2-e (85.3 per cent), *Food processing, beverages and tobacco*, which increased by 1,127.5 kt CO_2-e (67.4 per cent), and *Public electricity and heat production,* which increased by 926.5 kt CO_2-e (26.5 per cent).

In 2021, emissions from *Manufacture of solid fuels and other energy industries* – a historically significant contributor to New Zealand's emissions – were lower than the 1990 level by 1,463.9 CO_2-e (85.3 per cent). This decrease is primarily due to the cessation of synthetic gasoline production in 1997.

Figure 3.1.1 shows the Energy sector emissions time series from 1990 to 2021. Emissions increased from 1990 to around 2005, before decreasing slightly and then remaining steady until the present day.

Figure 3.1.1 New Zealand's Energy sector emissions from 1990 to 2021



2020–2021

Between 2020 and 2021, emissions from the Energy sector increased by 93.2 kt CO_2-e (0.3 per cent). This is primarily due to the 606.2 kt CO_2-e (5.0 per cent) increase in emissions from category 1.A.3.b *Road transportation*, followed by a 118.1 kt CO_2-e (42.7 per cent) increase from category 1.A.2.f *Non-metallic minerals*. The increase was partially offset by category 1.A.2.c *Chemicals*, which decreased by 272.5 kt CO_2-e (17.6 per cent). A 200.9 kt CO_2-e (4.4 per cent) decrease also occurred in emissions from category 1.A.1.a *Public electricity and heat production*.

The 2020 calendar year saw disruption to economic activity in New Zealand, with the effects of the COVID-19 pandemic being felt by the Energy sector throughout the year. The sector saw a rebound during 2021, but consumption remained below pre-2020 levels. All of New Zealand moved to Alert Level 4 on 17 August 2021, with the Auckland region remaining under tighter restrictions on activities and movements for the remainder of 2021.

Restrictions on activities and movement as part of the response to the COVID-19 pandemic also affected the commercial and industrial sectors. Industries that were deemed non-essential faced restrictions on their operations, and continued disruptions to global supply chains affected business activity in New Zealand. The combination of COVID-19-related restrictions and global supply chain disruptions contributed significantly to decreases in business activity for basic metals and mining sectors in particular.

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 Solid Fuels	CO_2	L1, T1
1.A.1.a	Energy Industries – Public Electricity and Heat Production Gaseous Fuels	CO_2	L1, T1
1.A.1.b	Energy Industries – Petroleum Refining Liquid Fuels	CO_2	L1, T1
1.A.1.b	Energy Industries – Petroleum Refining Gaseous Fuels	CO_2	T1
1.A.1.c	Energy Industries – Manufacture of Solid Fuels and Other Energy Industries Gaseous Fuels	CO_2	L1, T1
1.A.2.c	Manufacturing Industries and Construction – Chemicals Gaseous Fuels	CO_2	L1, T1
1.A.2.d	Manufacturing Industries and Construction – Pulp, Paper and Print Gaseous Fuels	CO_2	L1, 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
1.A.2.f	Manufacturing Industries and Construction – Non-metallic Minerals Solid Fuels	CO_2	T1
1.A.2.g.iii	Other (please specify) – Mining (excluding fuels) and quarrying Liquid Fuels	CO_2	L1, T1
1.A.2.g.v	Other (please specify) – Construction	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 Liquid Fuels	CO_2	L1, T1
1.A.4.a	Other Sectors – Commercial/Institutional Gaseous 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 Liquid Fuels	CO_2	L1, T1
1.A.4.b	Other Sectors – Residential Gaseous Fuels	CO_2	L1, T1
1.A.4.b	Other Sectors – Residential Solid Fuels	CO_2	T1

CRF category code	IPCC categories	Gas	Criteria for identification
1.A.4.c	Other Sectors – Agriculture/Forestry/Fishing Liquid Fuels	CO_2	L1
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.c.2.iii	Flaring – Combined	CO_2	T1
1.B.2.d	Other (please specify) – Geothermal	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.

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 from 1990 to 2021 (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, 2022). 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 (2022). This data release uses information from oil company survey returns through two surveys provided to MBIE.

- The **Delivery of Petroleum Fuels by Industry** survey (DPFI) is a quarterly survey that collects data on observed demand (i.e., actual sales figures) broken down by industrial sector.
- The **Monthly Oil Supply** survey (MOS) is a monthly survey that asks companies selling fuels to provide a liquid fuels supply balance.

Some of the international bunkers data in CRF table 1.A.b are from the MOS, whereas the international bunkers data in CRF table 1.D are from the DPFI. Companies that respond to the DPFI are asked to reconcile their figures there with their figures in the MOS. Discrepancies between the surveys are usually very small, and the companies attribute these differences to the difference in approach between the two surveys (the MOS follows a top-down approach, while the DPFI follows a bottom-up approach). Furthermore, the MOS and DPFI 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.

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 total fuel supplied. 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 under the IPPU sector and (where appropriate) in CRF 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 CRF category 1.A.2.c. 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.
- 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 CRF category 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 under 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	NA
Urea	80–93[31]	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

Note: NA = not applicable.

All ammonia produced in New Zealand is processed into urea, and the split of feedstock gas and fuel gas used in producing urea 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 under urea application in the Agriculture sector.

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

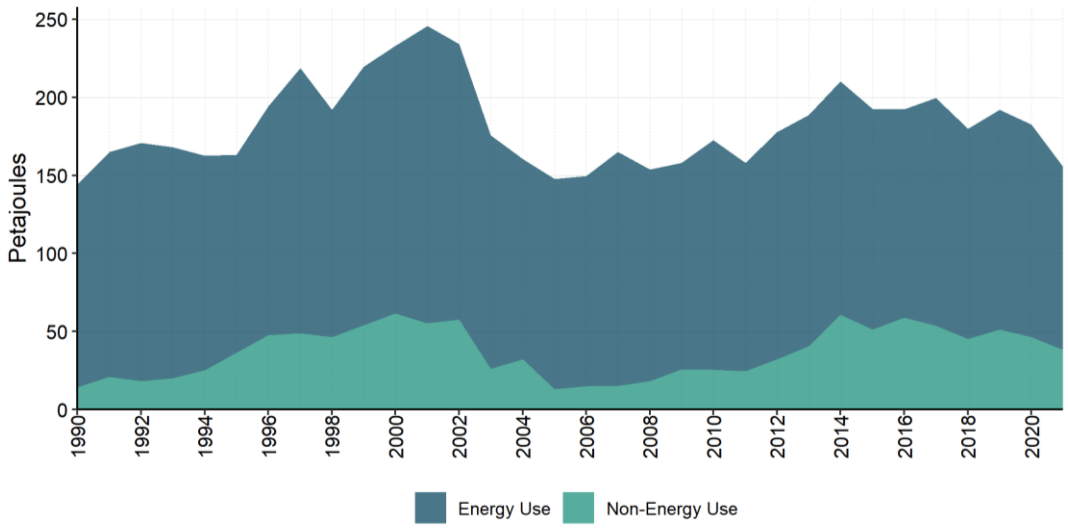
Emissions from synthetic gasoline production are reported in the *Manufacture of solid fuels and other energy industries* category. Synthetic gasoline production in New Zealand ceased in 1997.

The allocation of natural gas consumed for energy use versus non-energy use across time 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. The trend in natural gas use in the chemicals category can be explained partly by events in the methanol production industry in New Zealand.

Methanex New Zealand operates methanol production plants in the country and is a major gas user. Methanex significantly reduced its production in 2004 following deficient gas supply in 2003, but increased its capacity in 2008 and then further in 2012. Production at full capacity resumed in December 2013.

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 from 1990 to 2021



3.2.4 Carbon dioxide capture from flue gases and subsequent carbon dioxide storage

No CO_2 capture from flue gases and subsequent CO_2 storage occurred in New Zealand between 1990 and 2021.

3.2.5 Country-specific issues

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

Sectoral approach – Methanol production

Sector activity data do not include non-energy use of fuels, so we do not need to modify emissions to account for the sequestration of carbon in methanol. Emissions from the natural gas used as fuel are reported in the CRF category 1.A.2.c *Chemicals* in the Energy sector, and the emissions from the natural gas used as feedstock are described in chapter 4, 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, 2022). It covers energy statistics and includes 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.

For the most part, categories and fuels from the energy balance correspond directly with the categories and fuels in CRF table 1.A(b). A few special cases occur, as follows, where the structure of the CRF table does not align with New Zealand's energy balance.

- In the New Zealand energy balance table, crude oil and refinery feedstocks are combined, whereas in CRF table 1.A(b) these are separate line items.
- In New Zealand, liquefied petroleum gas (LPG) is considered a primary fuel and indigenous production is included in the national energy balance as such. The CRF table does not allow entry of LPG production, so it is included in natural gas production and then allocated to liquefied petroleum gas via stock change.
- New Zealand's energy balance includes the production of synthetic gasoline from natural gas under energy transformation. The CRF table does not allow entry of synthetic gasoline transformation, so it is included in natural gas production and then allocated to gasoline via stock change.

These allocations allow a more meaningful comparison with the sectoral approach data for liquid and gaseous fuels.

3.3 Fuel combustion (CRF 1.A)

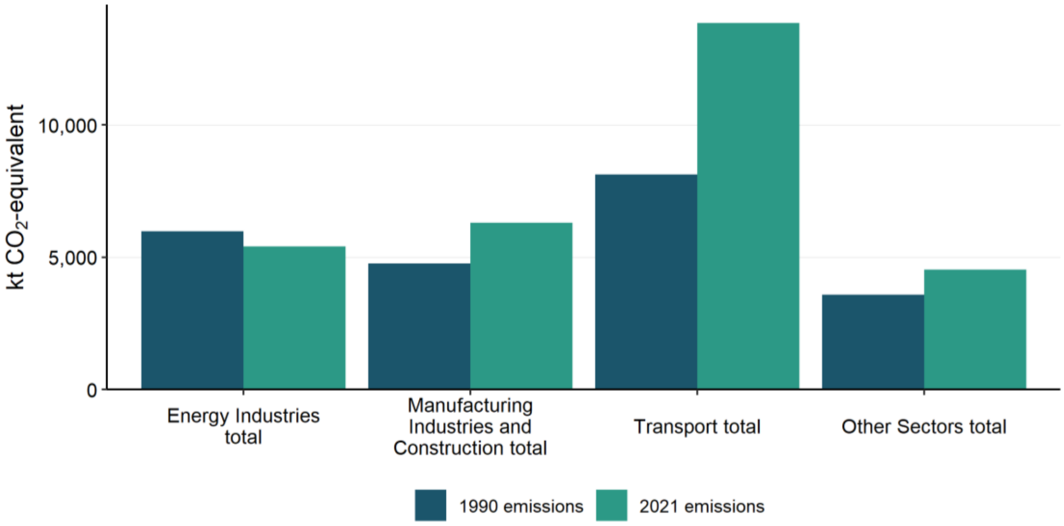
3.3.1 Sector-wide information

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 from 1990 to 2021



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

We source most of our liquid fuel consumption data for the Energy sector from the DPFI. This 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. The survey was originally conducted by Stats NZ, before MBIE took over this role in 2009.

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 bought fuel wholesale from oil companies and resold it to consumers. As a result, liquid fuel activity data were being over-allocated to the *Transport* category (where they were allocated by default). In contrast, most of the fuel purchased from these 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 and using these data to correctly allocate sales of liquid fuels by small resellers to the appropriate sector.

As a result of this recommendation, the Annual Liquid Fuel Survey was started in 2009 (for the 2008 calendar year). The survey found that these 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) details 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 mined and sold by coal producers in New Zealand. The three grades of coal surveyed are bituminous, sub-bituminous and lignite. This survey categorises coal sales by industry, recognising 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 high-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 various 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 several 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 estimated 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 known to be used by some local government councils. However, exploratory data collected in the past have indicated that such use only involves small quantities and produces insignificant emissions. Given this, MBIE has not focused on improving its methodology. As it is aware of some use, it continues to report a standard estimate introduced in 2006 to ensure there is no under-reporting.
- 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 produced emissions).

Gas biomass emissions estimates are based on electricity generation data

Biomass electricity generation data are collected for 15 individual plants. As of 31 December 2021, New Zealand gas biomass generation was known to include the following.

- Eleven landfill facilities generated a total of 33.1 megawatts (MW). These facilities are electricity only. (Some landfill gas was used to heat a swimming pool in Christchurch before the Canterbury 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 generated a total of 12.9 MW. These are all co-generation facilities that provide heat and electricity for the processing of sewage. Accurate information is not available on the exact type of generation plant used at these individual facilities, although they are 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 increase response rates. 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 (i.e., excluding parasitic load). These values are 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 IPCC 2006 default emission factors. These factors are:

- CO_2: 13.4 kt carbon/PJ or 49.17 kt CO_2/PJ
- methane (CH_4): 0.9 t/PJ
- nitrous oxide (N_2O): 0.09 t/PJ.

The CO_2 emission factor 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).

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, 2022). 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 category.

Emission factors

New Zealand emission factors are based on gross calorific values. A list of emission factors forCO_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, we use 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 Organisation for Economic Co-operation and Development and International Energy Agency assumptions to make these conversions, namely:

- gaseous fuels: Gross Emission Factor = 0.90 × Net Emission Factor
- liquid and solid fuels: Gross Emission Factor = 0.95 × Net Emission Factor
- wood: Gross Emission Factor = 0.80 × 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 2006 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 of New Zealand's 2013 submission (FCCC/ARR/2013/NZL, paragraph 32) (UNFCCC, 2014), the emission factors between 1990 and 2008 have been interpolated.

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 as 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 2021 from all fields, along with the production weighted average, are included in annex 4.

The annual gaseous fuel emission factor is calculated as an average of the emission factors of all natural gas fields in New Zealand, weighted by each field's relative production for the year. This method provides increased accuracy as it takes into account trends in gas field production rates over time (e.g., the decline in production from both the Maui and Kapuni gas fields and their replacement by other new gas fields like Pohokura). This emission factor fluctuates slightly from year to year, mainly due to the relative production volume at different gas fields.

Natural gas from the Kapuni gas field has a 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 (which is then vented) is reported under 1.B.2.c *Venting and flaring*.

Biomass

Emission factors for wood combustion are calculated from the IPCC 2006 default emission factor, and assume 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

After significant work to upgrade the oil and gas data system, data for naphtha, lubricants and petroleum coke have been disaggregated and are now reported separately in the reference approach.

The system for tracking and calculating emissions within the Energy sector was previously migrated to the R programming language. A further project to streamline and simplify the greenhouse gas reporting data system was completed in 2021. This project identified and addressed a number of minor inconsistencies and bugs. Several upstream data systems, including the energy balance tables, have also been translated into the R programming language.

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

3.3.3 Sector-wide planned improvements

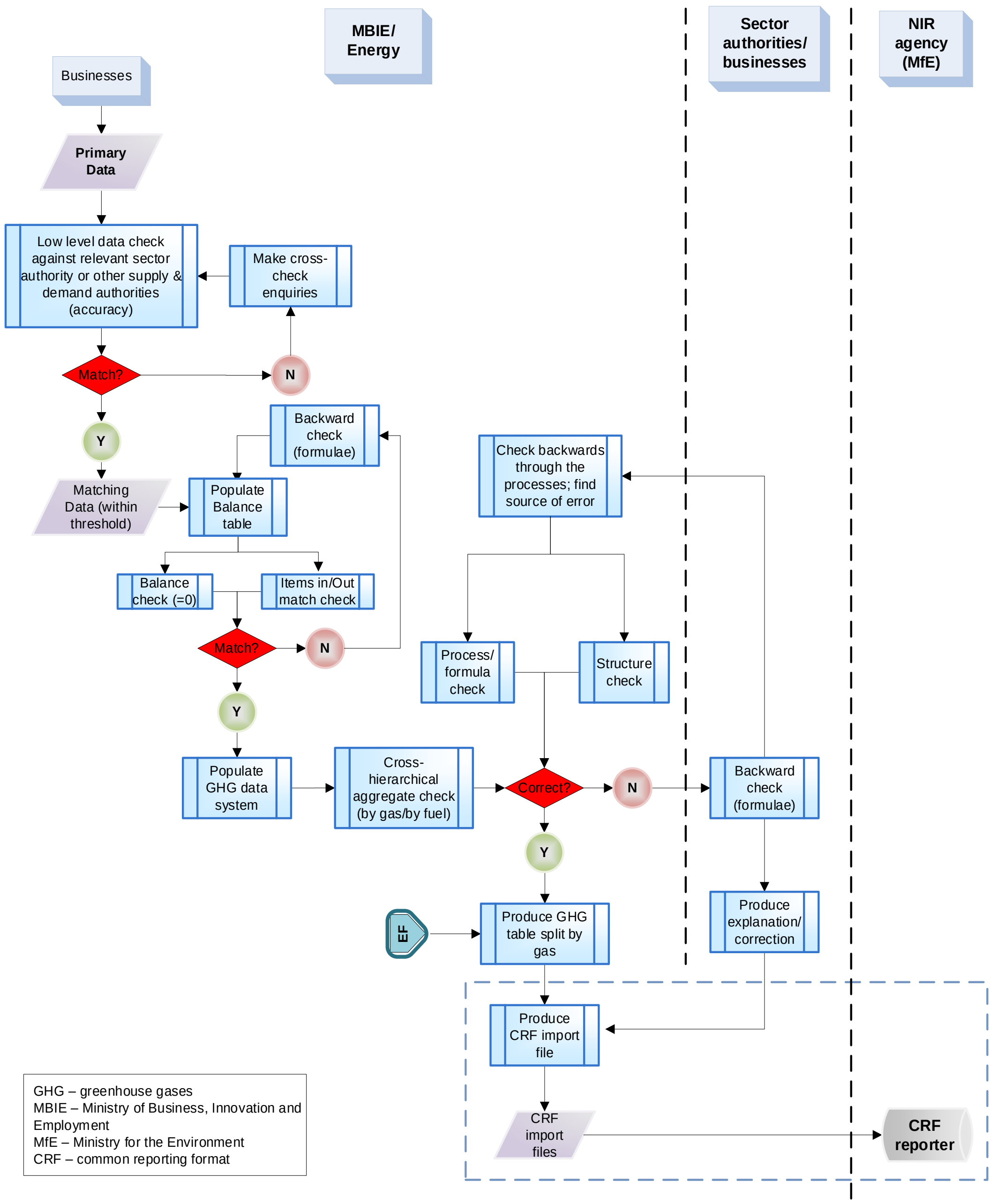
Work is progressing well on the construction of a new comprehensive fuel properties data management system. It is expected to be commissioned before New Zealand's next submission.

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

3.3.4 Sector-wide quality assurance and 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 and converted to gross values for comparability with the New Zealand energy system.

Figures 3.3.3, 3.3.4 and 3.3.5 show the upper, lower and middle IPCC 2006 default emission factor ranges, and compare the implied emission factors according to observed fuel consumption in New Zealand for the given year. Each fuel type falls within the IPCC default range, except for gaseous fuels. This is because, as discussed in section 3.3.1, CO_2 emission factors for New Zealand natural gas fields are established through gas composition analysis and are known to be high by international standards.

Figure 3.3.3 Carbon dioxide implied emission factor (IEF) – liquid fuel combustion from 1990 to 2021

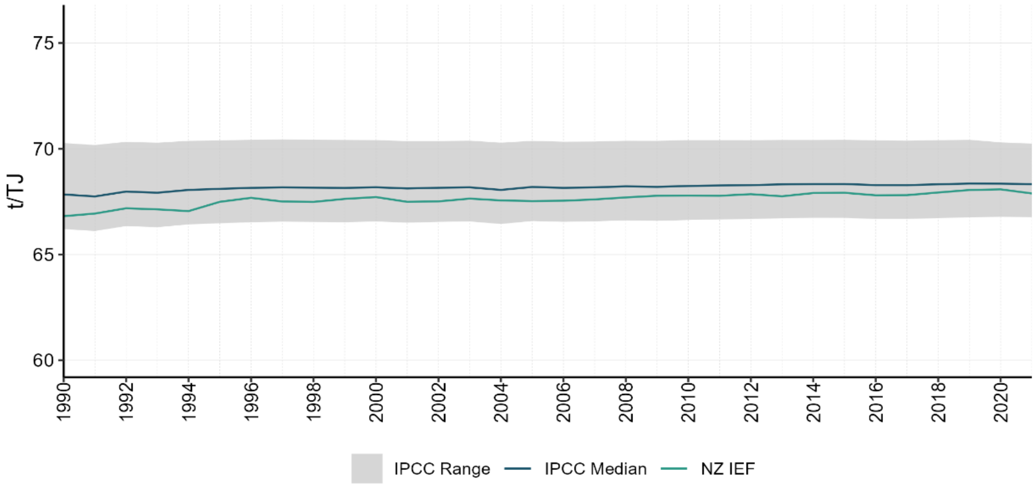


Figure 3.3.4 Carbon dioxide implied emission factor (IEF) – solid fuel combustion from 1990 to 2021

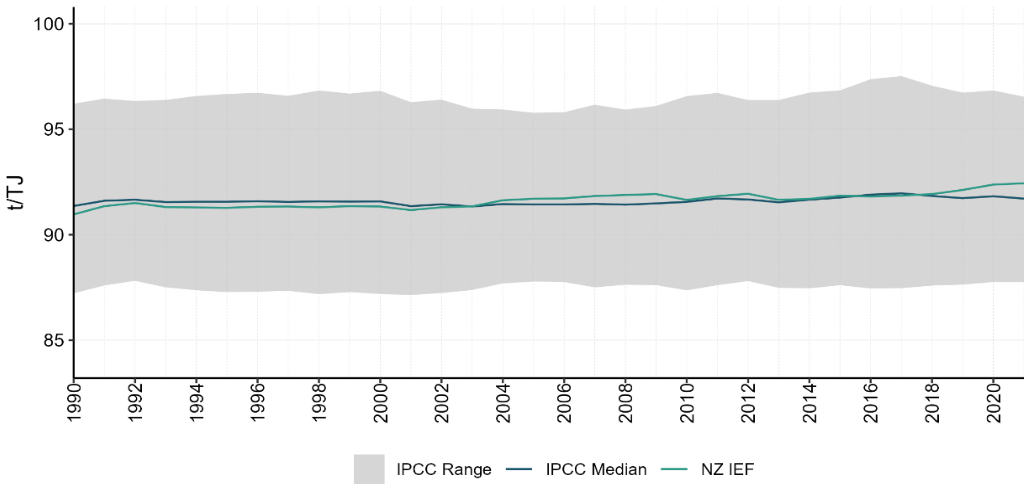
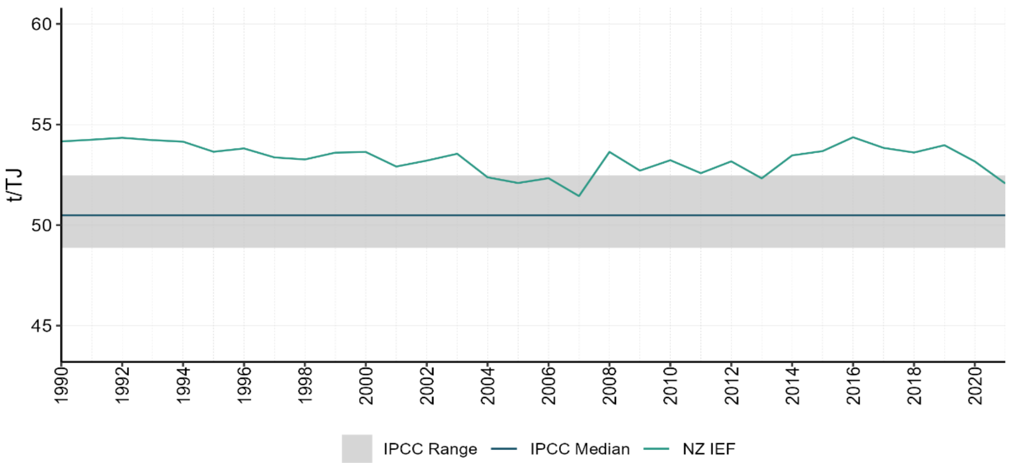


Figure 3.3.5 Carbon dioxide implied emission factor (IEF) – gaseous fuel combustion from 1990 to 2021



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 per cent to 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 of these gases 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 2006 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 emissions estimates for 2021

	Category	Activity data uncertainty (%)	Emission factor uncertainty (%)
CO_2	Liquid fuels	0.8	±0.5
	Solid fuels	4.6	±2.2
	Gaseous fuels	2.1	±2.4
	Fugitive – geothermal	5.0	±5.0
	Fugitive – venting/flaring	2.1	±2.4
	Fugitive – oil and gas production and transport	5.0	±100.0
	Fugitive – transmission and distribution	2.1	±100.0
CH_4	Liquid fuels	0.8	±50.0
	Solid fuels	4.6	±50.0
	Gaseous fuels	2.1	±50.0
	Biomass	50.0	±50.0
	Fugitive – geothermal	5.0	±5.0
	Fugitive – venting/flaring	2.1	±50.0
	Fugitive – coal mining and handling	4.6	±50.0
	Fugitive – transmission and distribution	2.1	±100.0
	Fugitive – oil and gas exploration and production	2.1	±100.0
	Fugitive – oil transportation	5.0	±50.0
N_2O	Liquid fuels	0.8	±50.0
	Solid fuels	4.6	±50.0
	Gaseous fuels	2.1	±50.0
	Biomass	50.0	±50.0
	Fugitive – venting/flaring	5.0	±100.0

To estimate activity data uncertainty, we use the percentage difference between annual calculated consumer energy from supply-side surveys and annual observed consumer energy from demand-side surveys. 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, 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 used in synthetic gasoline production. The excess CO_2 removed from Kapuni gas at the Kapuni Gas Treatment Plant has also been reported in the *Manufacture of solid fuels and other energy industries* category because of confidentiality concerns.

In 2021, emissions in category 1.A.1 *Energy industries* totalled 5,399.5 kt CO_2-e (17.3 per cent of the Energy sector emissions). Emissions from energy industries in 2021 were 587.3 kt CO_2e (9.8 per cent) lower than the 1990 level of 5,986.9 kt CO_2-e. Category 1.A.1.a *Public electricity and heat production* was the largest contributor to this sector, accounting for 4,416.6 kt CO_2-e of emissions from the *Energy industries* category in 2021. This is 926.5 kt CO_2e (26.5 per cent) higher than the 1990 level of 3,490.1 kt CO_2-e.

Changes in emissions between 2020 and 2021

Between 2020 and 2021, emissions from 1.A.1.a *Public electricity and heat production* decreased by 200.9 kt CO_2-e (4.4 per cent). This was largely because the share of electricity generated from renewable energy sources increased from 81.1 to 82.1 per cent over this period, due mainly to higher wind generation as several new wind farms came online during the year. The increased renewable generation displaced gas and coal-fired generation, which together decreased 5.2 per cent from 2020.

Key categories identified in the 2021 level and trend assessment for the *Energy industries* category are given in table 3.3.2.

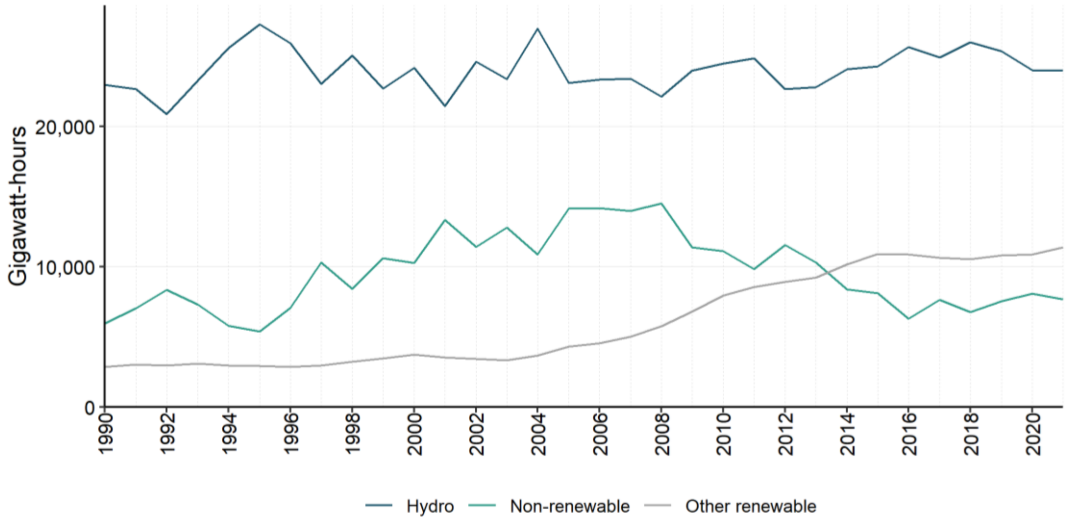
Table 3.3.2 Key categories for 1.A.1 *Energy industries*

	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 2021 calendar year, hydro generation provided 55.5 per cent of New Zealand's electricity generation. A further 18.4 per cent came from geothermal, 6.0 per cent from wind, 1.7 per cent from biomass and 0.5 per cent from solar. The remaining 17.8 per cent was provided by fossil fuel thermal generation plants using natural gas, coal and oil (MBIE, 2022).

Greenhouse gas emissions from the *Public electricity and heat production* category show large year-to-year fluctuations between 1990 and 2021. 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, when low rainfall affects most of New Zealand's hydro lake levels, any shortfall in hydroelectric generation is made up by increased 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 requires higher use of natural gas and coal.

Figure 3.3.6 New Zealand's electricity generation by source from 1990 to 2021



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

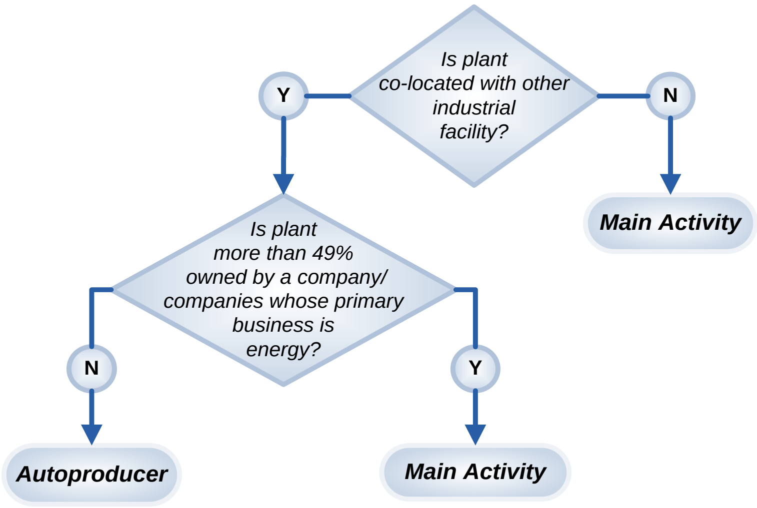
All thermal electricity generators provide figures to MBIE for the amount of coal, natural gas and oil used for electricity generation. Greenhouse gas emissions from geothermal electricity generation are reported under 1.B.2.d *Fugitive emissions – Geothermal*.

Around 5 per cent of New Zealand's electricity is supplied by co-generation (also known as combined heat and power) (MBIE, 2022). Most major co-generation plants are attached to large industrial facilities that consume the majority 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 in 1.A.1.a *Public electricity and heat production*, while emissions from other co-generation plants are included in 1.A.2 *Manufacturing industries and construction* (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

Petroleum refining in New Zealand occurs at only one site: the Marsden Point Oil Refinery, owned by Refining New Zealand. 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.

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

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. Historically, coal mines would use their own coal to fuel on-site water boilers. However, the last of these at the Stockton mine closed in the mid-1980s and, in the expert opinion of coal industry specialists, 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 CO_2 emission factor for natural gas fluctuates from year to year, reflecting the relative amount of gas produced from the various gas fields in a given year. New Zealand gas fields also have higher CO_2 content than most international gas fields. This is particularly evident in 1.A.1.a *Public electricity and heat production*.

Uncertainties and time-series consistency

Uncertainties in emissions and activity data estimates for this category are relevant to the entire *Fuel combustion* category (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

Revised 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 the manufacture of iron and steel, other non-ferrous metals, chemicals, pulp, paper and print, food processing, beverages and tobacco, and in other uses. Emissions from co-generation plants that do not meet the definition of co-generation as provided in the 2006 IPCC Guidelines are included in this category.

In 2021, emissions from the 1.A.2 *Manufacturing industries and construction* category accounted for 6,302.0 kt CO_2-e (20.2 per cent) of emissions from the Energy sector. Emissions from this category are 1,544.2 kt CO_2-e (32.5 per cent) higher than the 1990 level of 4,757.7 kt CO_2-e.

A decline in methanol production in 2003 to 2004 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, but then mothballed the Waitara Valley plant again in early 2021.

Changes in emissions between 2020 and 2021

Between 2020 and 2021, emissions from the *Manufacturing industries and construction* category decreased by 194.0 kt CO_2-e (3.0 per cent). This change was driven chiefly by a decrease in emissions from the *Chemicals* category, down 272.5 kt CO_2-e (17.6 per cent) from 2020. This drop in turn was mostly due to the closure of Methanex's Waitara Valley plant in response to gas supply constraints.

Key categories identified in the 2021 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		Trend	Level, trend
Food processing, beverages and tobacco – CO_2	Level	Level, trend	Level, trend
Non-metallic minerals – CO_2		Trend	
Other – mining and quarrying – CO_2	Level, trend		
Other – construction – CO_2*	Level, trend		
Other – other non-specified – CO_2	Level, trend	Trend	

Note: * This key category is calculated using emissions that do not distinguish by fuel type. However, it is known to comprise primarily liquid fuels.

Methodological issues

Some emissions from the use of solid fuels and gaseous fuels are excluded from this category because they are accounted for under the IPPU sector. In particular, other sectors account for the following emissions.

- 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 several 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, 2022) categorise industrial uses of energy using the Australian and New Zealand Standard Industrial Classification (ANZSIC) 2006. From 2009, MBIE started to collect more detailed information on the industry of fuel use in the various surveys used to compile its balance tables, which has allowed us to further disaggregate the *Manufacturing industries and construction* category. 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

Prior to 2010, coal use in the *Manufacturing industries and construction* category could not be further disaggregated, as no data existed to allow for more detailed categorisation. However, in 2010 MBIE implemented disaggregation for coal use in this category based on the improved industry use data. This disaggregation was applied from 2009 onwards, and the 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 the 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 allocations 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 2021

CRF category code	Manufacturing industries and construction category	%
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 is 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. As a result of this reallocation, emissions attributed to category 1.A.3 *Transport* decreased by around 20 per cent, and emissions attributed to other categories, such as 1.A.4.c *Agriculture/forestry/fishing*, increased 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. Proportions of liquid energy end use were then determined across the manufacturing industries. These proportions, 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 (see table 3.3.5). 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.

Table 3.3.5 Energy intensity values used to disaggregate liquid fuel use for manufacturing (gigajoules per gross domestic product index)

Category	Petrol	Diesel	Fuel Oil
Mining	2.4	1,117.9	19.6
Building and construction	30.5	334.8	2.7
Food processing	1.4	475.6	243.5
Textiles	0.9	12.8	158.6
Wood, pulp, paper and printing	1.1	199.5	43.7
Chemicals	0.2	36.3	2.0
Non-metallic minerals	0.7	587.4	263.9
Basic metals	1.2	88.1	0.4
Mechanical/electrical equipment	2.6	23.6	0.9
Industry unallocated	0.7	2.7	0.5

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 proportions are shown in figure 3.3.8, figure 3.3.9 and figure 3.3.10.

Figure 3.3.8 Proportions used for *Manufacturing industries and construction* category – Gasoline from 1990 to 2021

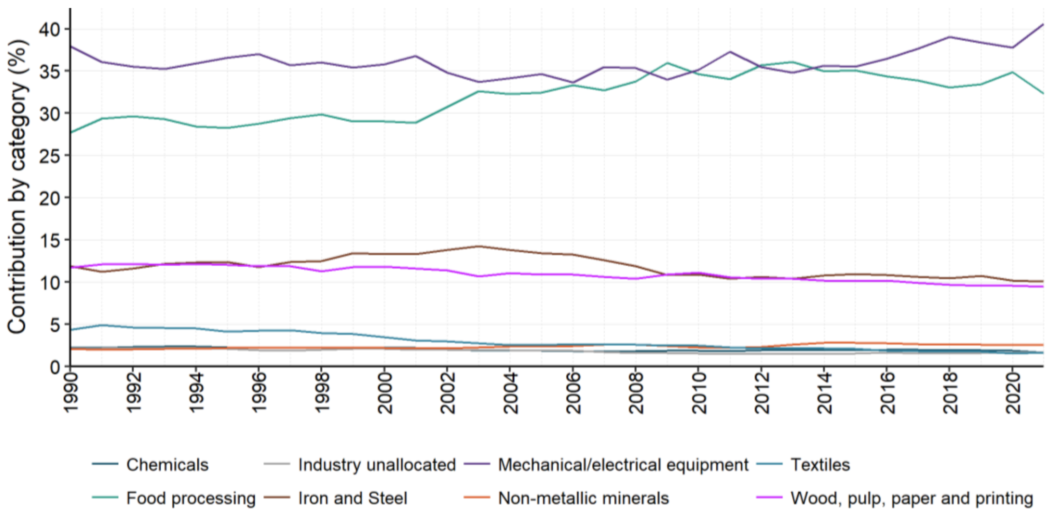


Figure 3.3.9 Proportions used for *Manufacturing industries and construction* category – Diesel from 1990 to 2021

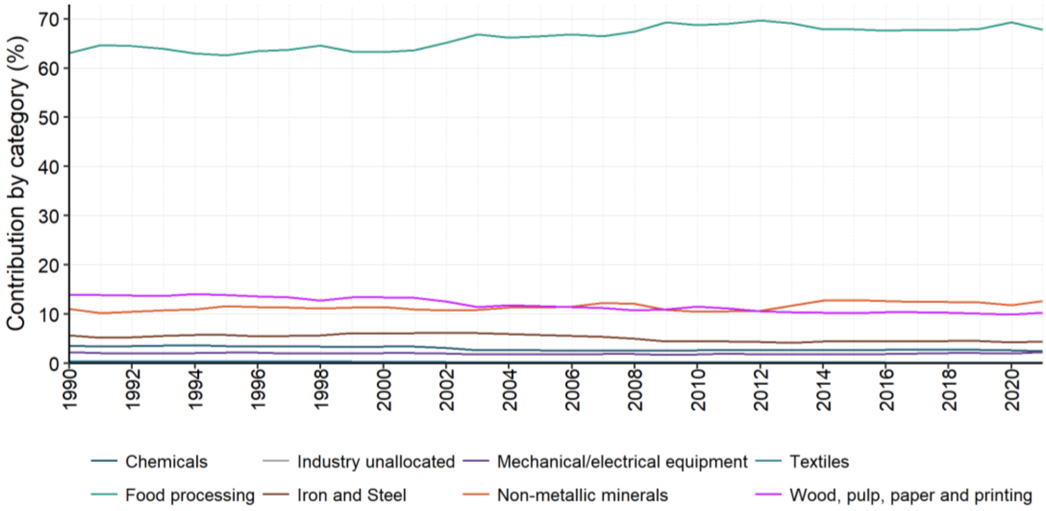
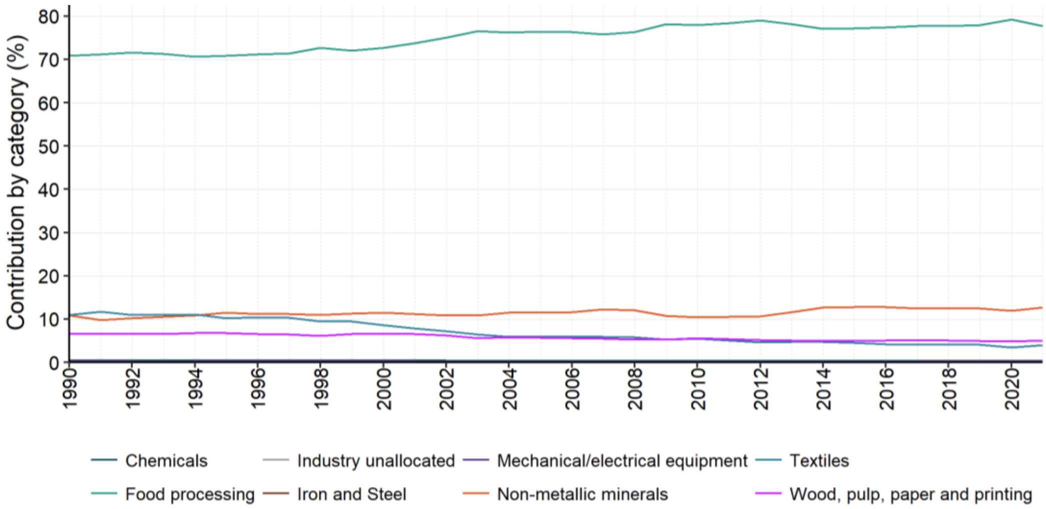


Figure 3.3.10 Proportions used for *Manufacturing industries and construction* category – Fuel oil from 1990 to 2021



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 before 2006. Several inconsistencies in sector reporting were found, along with a considerable amount of missing data for sectoral breakdowns. Inconsistencies from 2003 to 2005 were due to changes in survey design over time. Inconsistencies or missing data before 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 and production data were used along with assumptions about energy intensity and consumption of categories (to as detailed a level as possible).

Several categories are represented by only one or two major natural gas consumers: for some of these cases data from major consumers were directly used. 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.

Other fossil fuels

This category includes waste oil and tyre-derived fuel. Activity data are sourced from the NZ ETS.

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: this 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.

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. This approach 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 (reported under the IPPU sector) and non-methane volatile organic compounds.

Superphosphate fertiliser is commonly used in New Zealand to ensure that soil has a sufficiently high phosphorous content. It is manufactured from the reaction between sulphuric acid and phosphate rock.[32] During the process, the heat generated by the exothermic reaction between molten sulphur and oxygen is recovered in a waste-heat boiler to produce steam that is then used for process heating and to drive a steam turbine that produces electricity. The electricity is used on site and generally any excess is exported to the local power supplier.

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 improvements

A new fuel type, tyre-derived fuel, has been included under *Other fossil fuels*. A Tier 2 methodology was used to estimate CO_2 emissions based on an emission factor of 1,668 kilograms of CO_2 per tonne (the Annex I average), while Tier 1 methodologies were used for CH_4 and N_2O based on IPCC 2006 default emission factors for industrial wastes.

Source-specific recalculations

Some historical energy demand 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.

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.

[32] Phosphate rock: rock rich in the mineral fluorapatite, $Ca_5(PO_4)_3F$.

In 2021, category 1.A.3 *Transport* was responsible for 13,856.0 kt CO_2-e (44.4 per cent of emissions from the Energy sector). Emissions in 2021 were 5,729.8 kt CO_2-e (70.5 per cent) higher than the 8,126.2 kt CO_2-e emitted from the transport sector in 1990. The transport emissions profile in 2021 was dominated by emissions from category 1.A.3.b *Road transportation*. In 2021, road transport accounted for 12,654.9 kt CO_2-e (91.3 per cent) of total transport emissions. This is 5,825.8 kt CO_2-e (85.3 per cent) higher than the 1990 level of 6,829.1 kt CO_2-e.

Changes in emissions between 2020 and 2021

Between 2020 and 2021, emissions from transport increased by 654.1 kt CO_2-e (5.0 per cent). This increase was a rebound from the suppressed activity during 2020 due to COVID-19 restrictions.

Key categories identified in the 2021 level and trend assessment for the *Transport* category are given in table 3.3.6.

Table 3.3.6 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. Information on non-CO_2 emission factors can be found in annex 4, table A4.7.

Data collected by New Zealand's Ministry of Transport provide comprehensive information on vehicle-kilometres-travelled by vehicle class and fuel type from 2001 to 2016. 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 comprise cold and hot starts. Before 2001, insufficient data were available, so good practice guidance was used in choosing the splicing method to ensure timeseries consistency (splicing refers to the technique where different methods are combined to form a complete time series).

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

- manufactured in New Zealand[33] 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 nine 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 sub-fleets: the 'new vehicle fleet' and the 'used vehicle fleet'. This allocation is based on a vehicle's year of manufacture rather than when it is first added to the New Zealand fleet.

New vehicles are allocated an appropriate vehicle class from the COPERT 4 model (European Environment Agency, 2007), and used Japanese vehicles are 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.

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 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.

For the 2018 submission, the Ministry of Transport 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 this version of the guidebook. Moreover, detailed emission factors were provided for heavy-duty trucks in different gross vehicle mass bands.

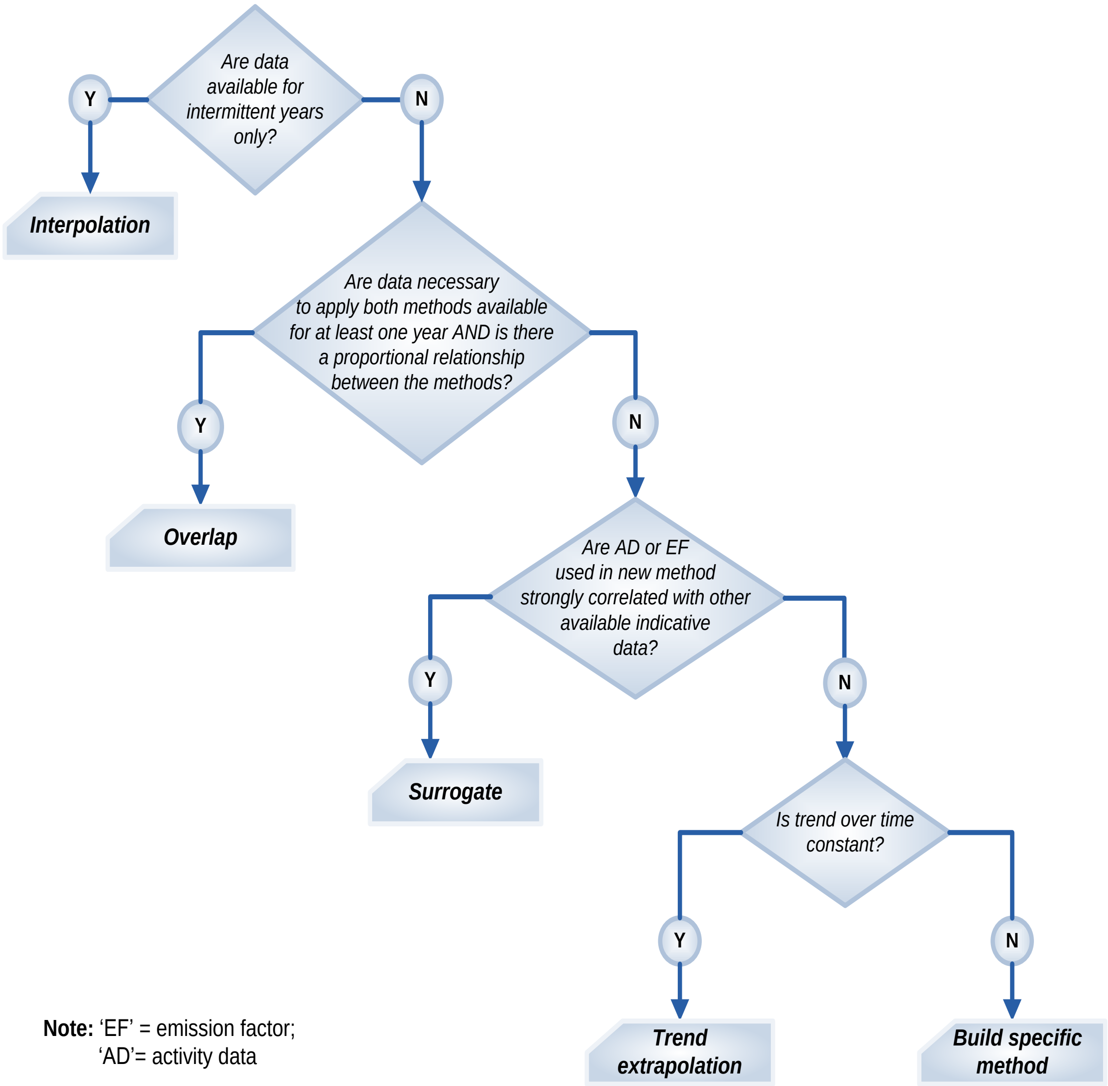
Time-series consistency

Insufficient data exist to apply the Tier 3 methodology between 1990 and 2000, so we have combined methods to form a complete time series (splicing). To establish the most appropriate splicing method, emissions were calculated using the Tier 1 methodology for the period 2001

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

to 2016. 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 emissions estimates from LPG, the relationship between Tier 1 and Tier 3 appears nearly constant for both N_2O and CH_4 from 2001 until 2002. As a result, the overlap method was used (IPCC, 2006), with:

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

Where: y_t is the recalculated emissions 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 emissions 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

Historically, the New Zealand Government encouraged the production and use of dual fuels (CNG–gasoline and LPG–gasoline) in transport as a strategy to reduce New Zealand's dependence on imported oil. New Zealand saw significant use of dual fuels in vehicles until 1987, when government subsidies were removed. Since then, dual fuel use has decreased, due to both the removal of subsidies and falling oil prices. The last recorded use of CNG in New Zealand was a Hamilton bus company, which continued using CNG in its bus fleet until 2017.

The vehicle-kilometres-travelled data provided by the Ministry of Transport allocate all 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 for gasoline, and correctly allocating dual fuel activity data between gasoline and LPG would result in a slight decrease in overall emissions. On this basis, we have not reallocated activity data for LPG-gasoline dual fuel vehicles due to a desire to be conservative when applying methods that would lead to net emissions reductions.

As another measure to ensure that we do not underestimate emissions, we have made an estimate of the fuel used in CNG buses. The remaining natural gas was then assumed to be combusted in converted light passenger vehicles, and an IPCC 2006 default emission factor was used to estimate the associated emissions.

Blended biofuels

Since 2007, some fuel retailers have sold small volumes of biogasoline and biodiesel blended with mineral oil products (data on these exist from 2007 onwards). These fuels are categorised under 1.A.3.b *Road transportation*. To ensure that liquid biofuel combustion is considered correctly in the inventory, we first calculate the energy split (i.e., gasoline as a share of combined gasoline and biogasoline or mineral diesel as a share of mineral diesel and biodiesel), and then multiply our new estimate by this factor to account for the biofuel proportion of the fuel. The emissions from the combustion of biofuels were then estimated using a Tier 1 methodology, as in previous inventories.

Biodiesel

Blended biodiesel has been disaggregated into biogenic and fossil fractions in our reporting. 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 is now included in the national total emissions.

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 *Manufacture of solid fuels and other energy industries* 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 (a form of highly refined kerosene) as propellants.

The specific categorisation of aerospace activity 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. While the 2006 IPCC Guidelines (volume 2, table 3.1.1) state that emissions from all remaining transport activities should be reported under 1.A.3.e *Other transportation*, 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 that it would raise concerns about commercial data confidentiality due to the small number of companies operating in the sector.

Activity data

1.A.3.a Civil aviation

MBIE currently collects data on domestic and international aviation fuel use through the DPFI. The respondents to this survey are New Zealand's four main oil companies: BP, Z Energy, ExxonMobil and Gull (Gull participates only in gasoline and diesel sales).

Our 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 have indicated that they allocate the fuel to international or domestic transport based on whether or not they are legally required to charge goods and services tax (GST) on the activity; GST is not applied 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, the domestic leg will attract GST so the fuel use will 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 is 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 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 for 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 this survey, emissions that would otherwise be reported in category 1.A.3.b *Road transportation* are allocated to the correct category. For time-series consistency, these reallocations were also made from 1990 to 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, the operator of national rail services in New Zealand, 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. Several 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.

MBIE receives import–export and excise data on liquid biofuels from the New Zealand Customs Service and sales data from major fuel companies. In December 2012 the Biofuel Sales Obligation was abolished and in June 2012 the Biodiesels Grant Scheme was removed. Following their removal, biodiesel use fell significantly and has remained relatively stagnant since.

1.A.3.c Railways

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

1.A.3.d Domestic navigation

Activity data for fuel oil use in 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 the Interislander ferry service) to obtain total diesel consumption in the *Domestic navigation* category. 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.

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 of the collection of these data coincided with this operator ceasing a 'fast ferry' service (which ran on MDO) between the North Island and South Island. The remainder of its fleet runs on fuel oil.

No significant quantity of diesel is used for commercial domestic navigation in New Zealand. Smaller quantities of diesel may be 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 emissions 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 United Nations Framework Convention on Climate Change 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 to 2000 has been updated to improve consistency between fuels and vehicle types.

Source-specific improvements

Revisions to the national energy balance have resulted in reallocation of liquid fuel activity data from *Transport* to the *Residential* category. A description of the change is provided in section 3.3.9.

A previous ERT recommendation was to:

> Continue to estimate the CO_2 emissions on the basis of 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.

This was implemented using the vehicle-kilometres-travelled data as the basis for the disaggregation. The Ministry of Transport has now provided estimates of CO_2 by mode based on its vehicle fleet data and incorporating estimates of vehicle fuel economy. This represents best practice and will greatly increase accuracy. These splits have been used to disaggregate the MBIE petrol and diesel fuel sales data between cars, light trucks, heavy trucks/buses and motorcycles.

This change has no impact on overall road transport emissions, but has resulted in reallocation between modes: the estimated petrol consumption by cars has decreased (average –165 kt CO_2 across the time series) while petrol consumption by light trucks has increased (average +201 kt CO_2 across the time series). The estimated diesel consumption by cars has decreased (average –1,106 kt CO_2 across the time series) while diesel consumption by heavy trucks/buses has increased (average +1,794 kt CO_2 across the time series).

Source-specific planned improvements

MBIE and the Ministry of Transport are considering 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 provided 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 2021, the *Fuel combustion – Other sectors* category accounted for 4,539.3 kt CO_2-e (14.5 per cent of the emissions from the Energy sector). This is 961.1 kt CO_2-e (26.9 per cent) higher than the 1990 value of 3,578.2 kt CO_2-e.

Changes in emissions between 2020 and 2021

Between 2020 and 2021, emissions from 1.A.4 *Other sectors* decreased by 106.5 kt CO_2-e (2.3 per cent).

Key categories identified in the 2021 level and trend assessment for the *Other sectors* category are given in table 3.3.7.

Table 3.3.7 Key categories for 1.A.4 *Other sectors*

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

Methodological issues

This category has no notable methodological issues.

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 in 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 ('Liquid fuels' under 'Activity data'), 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 3.3.8). The historical data are insufficient 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 to 2008.

Table 3.3.8 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 resellers rather than directly to end-users. As a result, some activity previously reported in the *Commercial* category has been reallocated to the Agriculture sector. This on-selling is assumed to continue across the time series from 1990 to 2021.

Several 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.

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).

Outdoor combustion of biomass (e.g., for bonfires, barbecues, campfires, pizza ovens, braziers or chimeneas, or in preparation for traditional methods of cooking food such as hāngī, umu and lovo) is common in New Zealand. 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 ('Gaseous fuels' under 'Activity data').

Other fossil fuels

Mixtures of fossil fuels are combined with a wide range of metal, organic and non-organic compounds in the formulation of fireworks. In New Zealand, most towns and cities hold public fireworks displays for 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. Fireworks are imported from overseas, generally China – there is no domestic production. Common fossil–carbon based fuels include carbon black, coal, asphaltum and gilsonite. In addition to CO_2, greenhouse gas emissions include CH_4 and N_2O.

The annual gross weight of imported fireworks was used as activity data. Emission factors were sourced from the Danish NIR.

Uncertainties and time-series consistency

Uncertainties in emissions 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

Emissions from fireworks have been estimated and included in the *Residential* category.

Revisions to the national energy balance have resulted in reallocation of liquid fuel activity data from *Road transportation* to the *Residential* category. In July 2021, the Energy Efficiency and Conservation Authority published the report *Off-road Liquid Fuel Insights: Quantifying Off-road Diesel and Petrol Use in New Zealand* (Energy Efficiency and Conservation Authority, 2021). The research provides a more detailed breakdown of off-road fuel use than was previously available, enabling better understanding of how fossil fuels are used in the off-road context.

A key recommendation of this report was that recreational marine use should be recorded as 'off-road' in future data. The research found the potential exists for 383 million litres of petrol and 50 million litres of diesel to be sourced through the retail network for recreational marine use annually. This was previously recorded as 'on-road' use in the official data, while its actual use is off-road. The recommendation to reallocate this fuel use was implemented and the national energy balance was revised. Recreational boating is considered a residential leisure activity and so fuel use has been allocated to the *Residential* category.

Source-specific planned improvements

No improvements are planned 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 2021, fugitive emissions from fuels accounted for 1,113.3 kt CO_2-e (3.6 per cent) of emissions from the Energy sector. This is 318.1 kt CO_2-e (22.2 per cent) lower than the 1990 level of 1,431.3 kt CO_2-e.

Changes in emissions between 2020 and 2021

Between 2020 and 2021, fugitive emissions from fuels decreased by 85.3 kt CO_2-e (7.1 per cent). This was primarily the result of decreased activity in category 1.B.2.c. *Venting and flaring.*

Key categories identified in the 2021 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 mines		Trend
Natural gas – Distribution		Trend
Venting – Gas	Level, trend	
Flaring – Combined	Trend	
Other – Geothermal	Level, trend	

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

Description

In 2021, fugitive emissions from the *Solid fuels* category accounted for 62.4 kt CO_2-e (0.2 per cent) of emissions from the *Fugitive emissions* category. This is 265.6 kt CO_2-e (81.0 per cent) lower than the 328.0 kt CO_2-e reported for 1990.

Between 2020 and 2021, fugitive emissions from the *Solid fuels* category decreased by 1.1 kt CO_2-e (1.7 per cent) due to decreased coal production.

New Zealand's fugitive emissions from the *Solid fuels* category are a by-product of coal mining operations. Methane is created during coal formation and released when coal is mined. The amount of CH_4 released during coal mining is dependent on the coal grade and the depth of the coal seam. Emissions also occur due to post-underground mining activities such as coal processing, transportation and use.

In 2021, New Zealand coal production was 2.9 million tonnes, similar to production levels in 2016 and 2017. Fewer than 20 active coal mines are operating in New Zealand, and as of 2021 none is underground. The two largest open-cast operations, at Stockton and Rotowaro, account for most national production. For further information and data on the coal mining industry, refer to *Energy in New Zealand* (MBIE, 2022).

At the end of 2021, no known flaring or capture of CH_4 was occurring 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 derived from Beamish and Vance is considered to be reliable because the emission factor (12.1 tonnes per kilotonne (t/kt)) is:

- well within the 2006 IPCC default range of 6.7–16.75 t/kt
- largely based on data for the most significant sub-bituminous coal mine in New Zealand (Huntly East mine), which was in continuous operation since 1988 and the most significant producing mine.

The emission factor for underground mining of bituminous coal is taken from the 2006 IPCC Guidelines. It is noted that any bituminous emission factor derived from Beamish and Vance (1992) would not be reliable, and should not be used, for the following reasons.

a) The derived emission factor (35.28 t CH_4/kt) is more than double the high default 2006 IPCC value. Using such an emission factor that is so far out of line with the default values would require a strong justification.

b) New Zealand already has the highest implied emission factor for underground mining among Annex I Parties. Dramatically increasing the emission factor 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 emission factors 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 is currently investigating whether there was any activity in this category. According to the 2006 IPCC Guidelines, mines of only a few acres in size should be disregarded, and 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. A mine plans database has been made available online (https://mineplans.nzpam.govt.nz), although this is still a work in progress. An online exploration database is also available (https://data.nzpam.govt.nz/GOLD/ system/mainframe.asp).

During 2021, a contractor was employed to review all the coal reports within MBIE's online coal mine databases and record the following details:

- mine name
- mine number
- coalfield

- mining method
- location of the mine (grid reference or coordinates)
- mine start year
- mine closure year
- details of production
- whether the mine was gassy (mentions of problems with gas)
- whether the mine was flooded or had water problems that would indicate it is now flooded.

A long list of historical mines was collated. Only 63 mines had information on whether the mine is flooded and only 30 mines had information on whether the mine was a gassy mine. Further data collection and processing are still required before we can make a meaningful assessment of fugitive emissions. In particular, we still need to collect:

- **elevation data** to determine likely flooded or unflooded status
- data on **mine size** to be used in applying a cut-off threshold.

We intend to complete this work in time for the 2024 submission.

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 open-cast 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

There were no recalculations made for the current submission.

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 2021, fugitive emissions from the *Oil and natural gas* category contributed 1,050.8 kt CO_2-e (94.4 per cent) to emissions from the *Fugitive emissions* category. This is 52.5 kt CO_2-e (4.8 per cent) lower than the 1990 level of 1,103.3 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 nearly 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 due to incomplete combustion.

Fugitive emissions also occur in transmission and distribution within the natural gas transmission pipeline system. However, these emissions are relatively minor compared 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 in the *Fugitive emissions* category because they are not the result of fuel combustion. 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 whose geothermal steam is not used 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 considered insignificant. Naturally occurring sites do not contribute any anthropogenic emissions.

In 2021, emissions from geothermal operations were 546.2 kt CO_2-e, which is 262.8 kt CO_2-e (92.7 per cent) higher than the 1990 level of 283.4 kt CO_2-e.

Between 2020 and 2021, emissions from geothermal sources decreased by 3.6 per cent. A steady decline in emissions has occurred over the past six years as the more recently developed fields have de-gassed.

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: this refinery has a hydro cracker rather than a catalytic cracker. Therefore, no emissions come from fluid catalytic cracking. New Zealand does, however, produce emissions 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 geothermal power companies. New Zealand has around 15 geothermal power stations and 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.

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 the atmosphere involves the following calculations.

Average discharge per hour is calculated as:

$$582.3 \frac{tonnes\ of\ steam}{hour} \ x \ \frac{0.612\ CO_2}{100} by\ weight\ of\ steam = 3.565 \frac{tonnes\ of\ CO_2}{hour}$$

And the total discharge per year is:

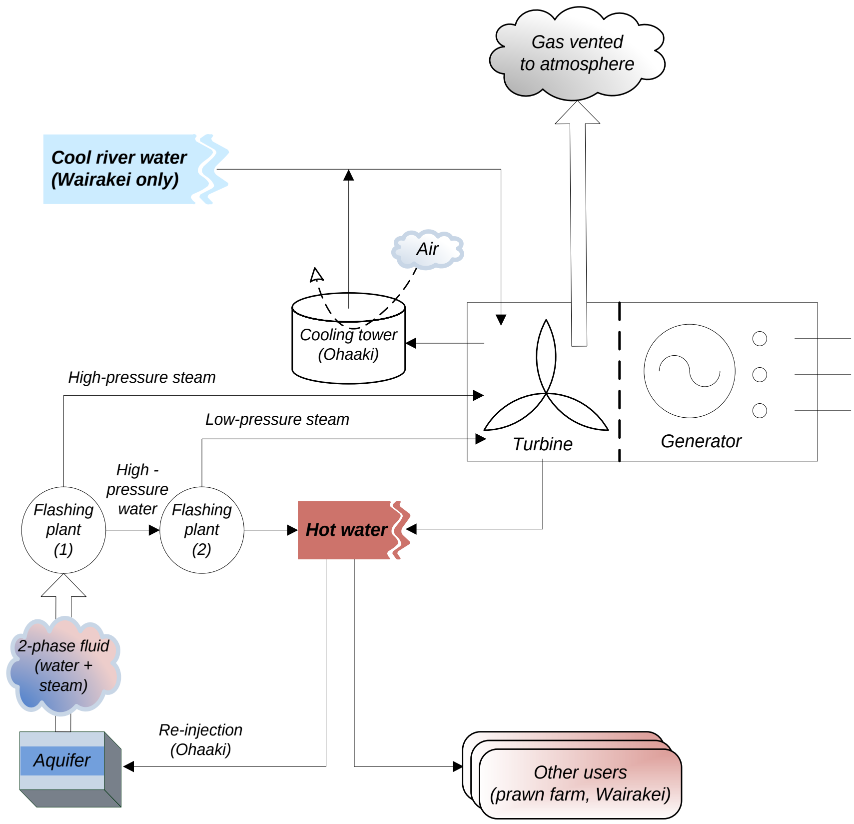
$$3.565 \frac{tonnes\,of\ CO_2}{hour} x8760 \frac{hours}{year}$$ = 31,230 tonnes of CO_2 per year.

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.

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.

The Climate Change (Unique Emissions Factors) Regulations 2009 outline requirements for participants in certain sectors to calculate a unique emission factor (UEF) and apply for approval to use it in place of a default emission factor to calculate and report on emissions. Users of geothermal fluid are eligible to apply for a UEF.

Operators could first apply for UEFs in 2010. MBIE received five applications relating to the use of UEFs for geothermal fluid for that calendar year. These five UEFs were approved and then adopted for the inventory after careful assessment of the impact on the level of emissions and the 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 default emission factors. Emissions from 2010 onwards are calculated using UEFs where available and field-specific default emission factors otherwise.

When several years of UEF data are available for comparison, the 1990 to 2009 emission factors for each affected field will be reviewed.

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, 2022). 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, 2022).

1.B.2.a.4 Refining

Activity data are total intake at New Zealand's sole oil refinery (MBIE, 2022).

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

Activity data are New Zealand's total consumption of gasoline (MBIE, 2022).

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 (reticulated natural gas in New Zealand is available only in the 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 Ltd). 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.

For this submission, New Zealand has implemented an improvement to the estimation of leakage from distribution networks, moving from a Tier 1 methodology to using more accurate industry data derived from models that represent a Tier 3 approach. Further details are given below under 'Source-specific revisions and improvements'.

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 natural gas flaring, losses, own use are reported directly by gas field operators.

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

In response to an ERT recommendation, flaring of refinery gas has been reallocated from 1.B.2.a *Oil* to 1.B.2.c *Venting and flaring*.

Emission factors

Unless noted otherwise, default IPCC emission factors have been used.

Uncertainties and time-series consistency

Time-series data from various geothermal fields vary in completeness, and some historical data are not available. 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 revisions and improvements

The methodology used to estimate fugitive emissions from natural gas distribution networks has been revised. The former methodology (Tier 2) used an assumed constant leakage rate of 1.75 per cent of total reticulated natural gas. This figure was derived by the Natural Gas Corporation in the mid-1990s and was found to be out of date. Recent engagement with industry experts has revealed that the current estimate of the leakage rate from the modernised distribution pipelines in New Zealand averages 0.35 per cent over the period 2017 to 2021.

The new estimates from industry represent a Tier 3 approach, using specific emission factors, assessed at the facility level. The industry emissions estimate model has been developed using a best practice MarcoGaz estimating template. It uses internationally published emissions rates (American Petroleum Institute Compendium of emissions rates) combined with company-specific asset knowledge and information to provide a bottom-up approach. Further, the industry is now completing annual asset-level leakage measurements to validate the emissions rates and estimates.

The Tier 3 methodology detailed above only applies from 2017 onwards. To preserve time-series consistency and avoid a step change between this and the previous method, we have employed data splicing: for previous years where estimates from the Tier 3 models are not yet available, the leakage rate is interpolated back to the 1990 value of 1.75 per cent.

Updated data sourced from field operators have been used to improve the accuracy of emissions estimates for geothermal activities.

Source-specific planned improvements

Updated estimates of distribution losses will be incorporated as and when Tier 3 estimates from industry models become available. This is dependent on sufficiently detailed and disaggregated information on the historical state of distribution network infrastructure and assets.

As the data set of verified UEFs 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 under 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 many 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. No fluorinated chemicals are produced 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 (62.8 per cent), fluorinated gases (33.3 per cent) and smaller amounts of CH_4 and N_2O. The major categories in the IPPU sector are *Iron and steel production*, *Refrigeration and air conditioning*, *Aluminium production* and *Cement production*. Coal and natural gas are also 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.

2021

In 2021, emissions in the IPPU sector contributed 4,609.6 kilotonnes carbon dioxide equivalent (kt CO_2-e), or 6.0 per cent, of New Zealand's gross greenhouse gas emissions.

The largest 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 ozone depleting substances (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.

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*.

The emissions by category are shown in table 4.1.1.

1990–2021

Emissions from the IPPU sector in 2021 were 1,029.7 kt CO_2-e (28.8 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 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. In 2020 and 2021 the increase was offset by reduced emissions due to COVID-19 restrictions and the progressive shutdown of the Marsden Point oil refinery. 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.

2020–2021

Between 2020 and 2021, emissions from the IPPU sector increased by 26.7 kt CO_2-e (0.6 per cent).

This change was the result of a recovery to normal rates of production and emissions from the *Metal industry* and other categories, following plant shutdowns related to COVID-19 restrictions in 2020. New Zealand had a national lockdown in force from 26 March to 27 May 2020.

Emissions from the Marsden Point oil refinery, however, remained at lower levels as the company prepared to shut the plant down in March 2022.

Table 4.1.1 New Zealand's greenhouse gas emissions for the IPPU sector by category in 1990 and 2021

Source category	Emissions (kt CO_2-e) 1990	Emissions (kt CO_2-e) 2021	Difference (kt CO_2-e) 1990–2021	Change (%) 1990–2021	Share (%) 1990	Share (%) 2021
Mineral industry (2.A)	561.9	529.2	–32.7	–5.8	15.7	11.5
Chemical industry (2.B)	203.0	139.1	–63.9	–31.5	5.7	3.0
Metal industry (2.C)	2,670.2	2,310.6	–359.6	–13.5	74.6	50.1
Non-energy products from fuels and solvent use (2.D)	25.2	42.4	17.2	68.5	0.7	0.9
Product uses as substitutes for ODS (2.F)	–	1,483.0	1,483.0	–	–	32.2
Other product manufacture and use (2.G)	119.7	105.3	–14.4	–12.0	3.3	2.3
Total	**3,579.9**	**4,609.6**	**1,029.7**	**28.8**	**–**	**–**

Note: Columns may not sum due to rounding.

Figure 4.1.1 New Zealand's annual emissions from the IPPU sector from 1990 to 2021

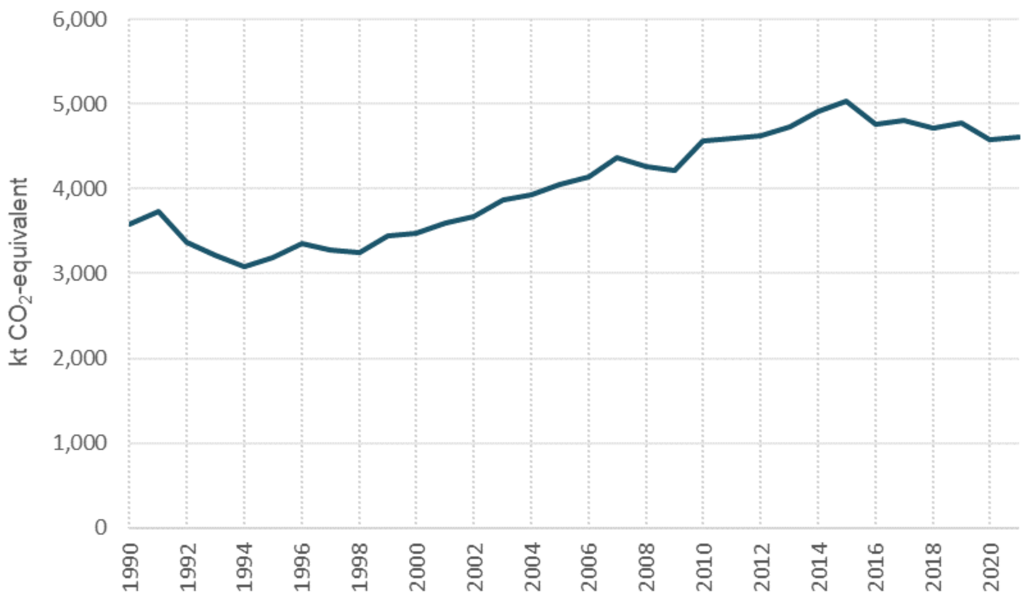
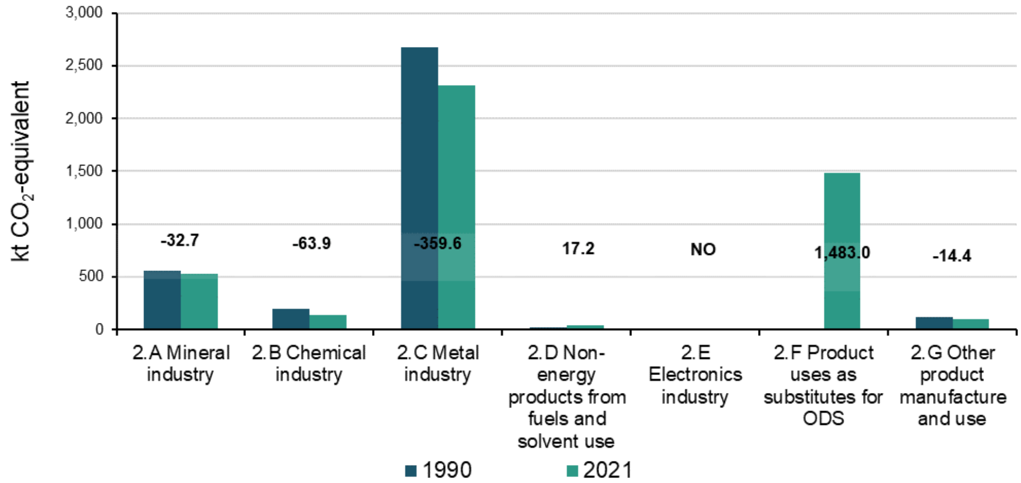


Figure 4.1.2 **Change in New Zealand's emissions from the IPPU sector from 1990 to 2021**



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.B.10	Chemical Industry – Other (please specify)	CO_2	T1
2.C.1	Metal Industry – Iron and Steel Production	CO_2	L1, T1
2.C.3	Metal Industry – Aluminium Production	CO_2	L1
2.C.3	Metal Industry – Aluminium Production	PFCs	T1
2.F.1	Product Uses as Substitutes for ODS – Refrigeration and Air Conditioning	HFCs	L1, T1

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.

The small scale of New Zealand's industry sector means some activities are only carried out by one or two companies. Information these companies provide in response to surveys is often subject to an obligation of confidentiality, so that their activity data or emissions cannot be published. These confidentiality concerns have several implications for reporting of activity data and emissions.

- Activity data for cement, steel and glass production 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.
- Emissions from gas used for energy purposes in ammonia production are reported in the *Manufacturing industries and construction* category in the Energy sector (CRF 1.A.2.c) where this information can be aggregated with other companies. Only chemical feedstock gas is reported in the *Chemical industry* category. Total energy use for the ammonia–urea plant is not disclosed.
- Data on emissions from hydrogen making at the Marsden Point oil refinery are reported in the *Chemical industry* category. This means that data from New Zealand's only industrial hydrogen-making process, which is smaller in scale than refining, are aggregated and kept confidential.

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

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

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 in 2006 (CRL Energy, unpublished(a)). Emissions and activity data have been extrapolated for the years since that time.

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* category, reflecting the quality of data provided by survey respondents, and have been updated as needed 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 the primary data source. Verification is done over time as ETS returns are verified by the Environmental Protection Authority (EPA), the agency that administers the NZ ETS.

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 or other publicly available information, where possible, and anomalous data followed up and checked.

4.1.7 Recalculations and improvements

For this submission, amounts of refrigerant added to equipment in the *Refrigeration and air conditioning* category were re-estimated to better account for changes in stocks held by importers and users.

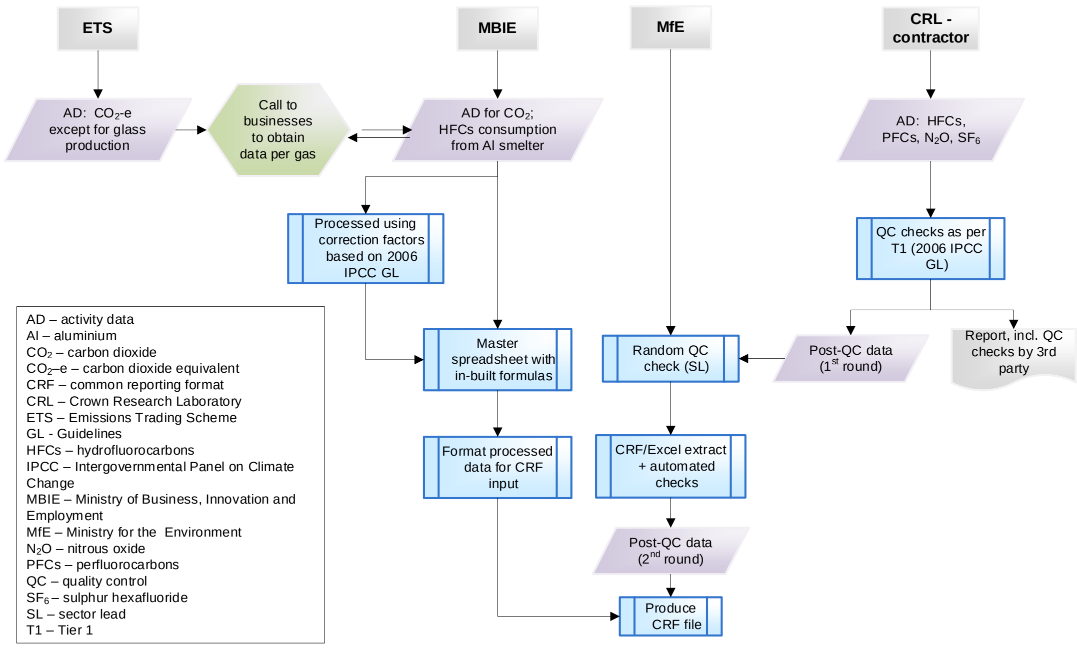
Expert review team comments

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.

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* 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 under 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 Whangārei. 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. The New Zealand cement industry produces clinker from the calcination of limestone and processes it into Portland cement or 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 under 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* category. Emissions from this use of mineral inputs are reported in the *Mineral industry* category (see section 4.2.2) to aggregate data and protect the confidentiality of data provided by these 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 and trend assessment).

In 2021, the *Mineral industry* category accounted for 529.2 kt CO_2-e (11.5 per cent) of emissions from the IPPU sector. This is 32.7 kt (5.8 per cent) below the 1990 emissions. Cement and lime production have not resumed historical levels following COVID-19 restrictions, which reduced production in 2020. Production of cement, lime and glass containers had previously increased over time, with a peak in 2015 of 876.3 kt CO_2-e. Emissions decreased after 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, 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 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 encompasses 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 2021, the *Cement production* category accounted for 369.6 kt CO_2-e (69.8 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 making cement 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 2021, the *Lime production* category accounted for 103.7 kt CO_2-e (19.6 per cent) of emissions from the *Mineral industry* category. The activity data used are the amounts of burnt lime produced, reported as tonnes of pure calcium oxide (CaO), as required in NZ ETS returns. This measure is used regardless of whether the lime is subsequently hydrated to make calcium hydroxide ($Ca(OH)_2$).

Activity 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 CRF 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, 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 early 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 and updated for the years 2007 to 2009 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 to 2021, 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 under 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* category (from 2010), the methods used are specified in the Climate Change (Stationary Energy and Industrial Processes) Regulations 2009. 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 the Climate Change (Stationary Energy and Industrial Processes) Regulations 2009, NZ ETS participants that 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 2006 IPCC Guidelines (IPCC, 2006a) but is described as country specific in the CRF because of a minor discrepancy: NZ ETS participants are not required to report separately very small amounts of kiln dust or MgO.

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* 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), except ceramics for which there is substantial uncertainty in the activity data and in the composition of clay. Cement kiln dust is not relevant for 2017 to 2021 because the cement plant now operating reports no significant kiln dust produced. 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 (CO_2)	±1	±1
Cement kiln dust (CO_2)	±1	±5
Cement (SO_2)	±1	±40
Lime (CO_2)	±2	±2
Glass (SO_2)	±5	±10
Glass (NMVOC)	±5	±50
Ceramics (CO_2)	±50	±20
Other uses of soda ash (CO_2)	±3	±2
Other uses of limestone (CO_2)	±3	±2

Time-series consistency

In previous inventory submissions, the reported activity data for lime production have not been fully consistent through the time series because of the change to using NZ ETS data and the use of different calculation methods for these emissions. A consistent approach, based on the methods that companies are required to use for NZ ETS reporting, is now applied for the entire time series.

4.2.4 Source-specific QA/QC and verification

For this submission, data for all CO_2 emissions in the *Mineral industry* category underwent Tier 1 quality checks in the preparation of this inventory. The only key category is CO_2 emissions from *Cement production* (level and trend assessment).

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 (the Ministry for the Environment) will make use of the resulting information to verify the emissions data where possible.

4.2.5 Source-specific recalculations

For lime production, the activity data reported were revised in the previous submission, following a recommendation by the ERT to make the time series more consistent between NZ ETS data and the earlier reporting approach. The pure chemical content of the lime produced (CaO and MgO, net of impurities, which are typically 2 per cent to 3 per cent) is now reported for the entire time series.

There are no recalculations for the 2023 submission.

4.2.6 Source-specific planned improvements

The inventory agency has worked with the companies in the *Mineral industry* category to improve transparency and confidence in the data provided. Concerns about the confidentiality of data provided by the cement and glass companies remain a barrier to improving transparency further.

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 was made at the Marsden Point oil refinery until the refinery closed in March 2022. Carbon dioxide 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. The emissions of CO_2 reported in this category arise from the fraction of chemical feedstock CO_2 that is not recovered for urea production. Emissions from combustion at this site are reported separately in the Energy sector (CRF 1.A.2.c). Nearly 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 under 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 reported in the *Non-energy products from fuels and solvent use* category (CRF 2.D.3).

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 under the Energy sector (CRF 1.A.1). 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 under 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* category in 2021 were 139.1 kt CO_2-e (3.0 per cent) of emissions from the IPPU sector. This is 63.9 kt CO_2-e (31.5 per cent) below the 1990 level. The reduction has occurred from 2020 and has been driven by a decrease in emissions from the Marsden Point oil refinery due to COVID-19 restrictions. Subsequently, the refinery company decided to close the site and outputs remained low as they prepared for its closure.

The only key category is CO_2 emissions from the *Other* category (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 amounts 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. There are also significant CO_2 emissions from gas used for combustion, which are reported under the Energy sector in the *Manufacturing industries and construction* category (CRF 1.A.2.c) and aggregated with other data. This method has been used to allow data on the total gas used at the plant to remain confidential.

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 any separate 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 2006 IPCC Guidelines do not provide a method for estimation of any CO_2 emissions from this process (IPCC, 2006a). Any small amounts of chemical process CO_2 emissions from the methanol production process are included under 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 not been used since 2014.

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	Type of gas	Emission factor
Superphosphate fertiliser production	SO_2	1.5 kg per tonne of H_2SO_4
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 category, as shown in table 4.3.2.

Table 4.3.2 Uncertainty in emissions from the *Chemical industry* 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 (NO_x 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 mainly due to changes in refinery gas composition. Other implied emission factors in this category only reflect the default emission factors used.

4.3.4 Source-specific QA/QC and verification

For this submission, data for all CO_2 emissions in the *Chemical industry* category underwent Tier 1 quality checks in the preparation of this inventory. The only key category is CO_2 emissions from *Other* (hydrogen production) (trend assessment).

4.3.5 Source-specific recalculations

There are no recalculations for this category.

4.3.6 Source-specific planned improvements

There are no planned improvements for this category.

4.4 Metal industry (2.C)

4.4.1 Description

The main emissions in the *Metal industry* category in New Zealand are from iron and steel production (from iron sand and historically from recycled scrap steel) and from aluminium production. New Zealand has no production of coke, sinter or ferroalloys.

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.

Until 2015, Pacific Steel Limited 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, production in New Zealand is now focused on newly produced iron rather than 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, resulting in CO_2 and PFC emissions.

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* category are CO_2 emissions from *Iron and steel production* (level assessment) and from *Aluminium production* (level assessment), and PFCs from *Aluminium production* (trend assessment).

Emissions from the *Metal industry* category in 2021 were 2,310.6 kt CO_2-e (50.1 per cent) of emissions from the IPPU sector. This is 359.6 kt CO_2-e (13.5 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.

The New Zealand Steel site was closed from 26 March to 27 April 2020, due to COVID-19 restrictions, reducing output for the year by approximately 11 per cent. Output recovered to normal levels for 2021. Aluminium production in 2020 and 2021 was approximately 5 per cent lower than 2019.

4.4.2 Methodological issues

Choice of activity data

Iron and steel production (2.C.1 and 2.C.1.a)

In 2021, the *Iron and steel production* category accounted for 1,718.1 kt CO_2-e (74.4 per cent) of emissions from the *Metal industry* category. The activity data (tonnes of steel produced) provided to MBIE came from two steel producers up to 2015 and now come from one; they are regarded as commercially confidential and are reported as confidential in the CRF.

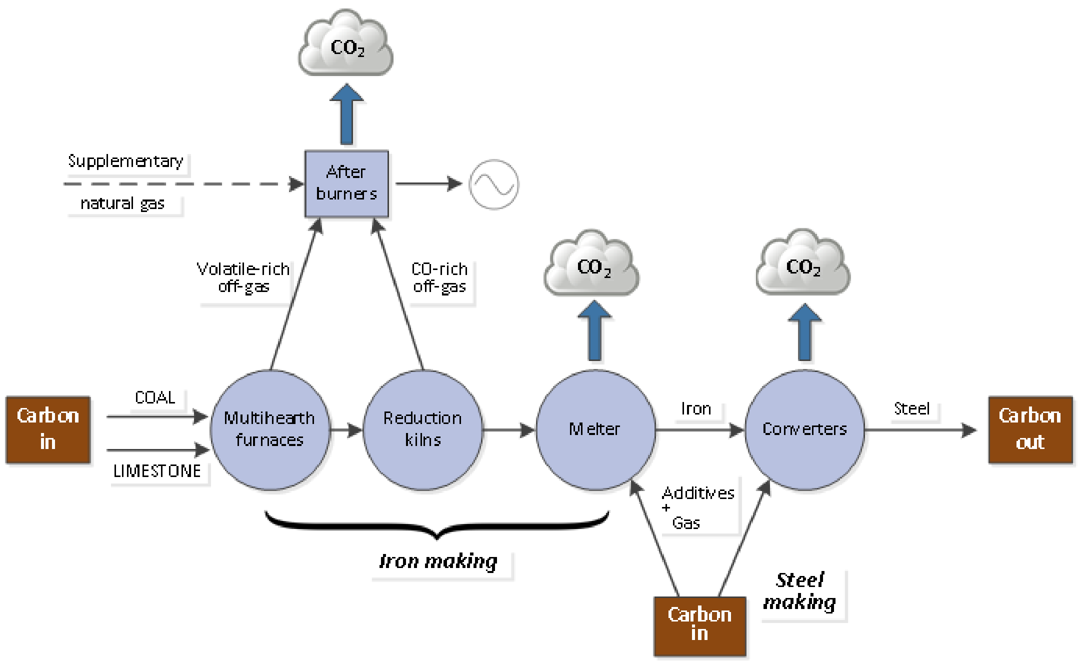
Most of the CO_2 emissions from the *Iron and steel production* category are produced through the production of iron from titanomagnetite iron sand. Nearly all of the emissions in this process come from the use of sub-bituminous coal as a reducing agent. There is no carbon in the iron sand used by New Zealand Steel Limited (see 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
Total	**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 multi-hearth 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. Emissions from supplementary natural gas used in this plant are reported under the Energy sector (1.A.2.a). New Zealand Steel reported in the past (CRL Energy Ltd unpublished(b)) that there were no detectable methane emissions from this plant. No updated information is currently available.

Much smaller amounts of CO_2 are derived from limestone added to the multi-hearth 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 under the Energy sector.

In 2021, the *Aluminium production* category accounted for 592.5 kt CO_2-e (25.6 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 2021, the CO_2 and PFC emissions data and activity data were 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* 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, and the carbon in steel produced is subtracted.

Emissions from the production of steel by Pacific Steel were also estimated using a 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 to 2008 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 Tier 2 method (IPPC, 2006a). 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* 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 2021. This method is applied in the reporting requirements the company now uses in its NZ ETS returns.

There is no history of direct measurement of PFC emissions at the smelter, so site-specific slope coefficients (required for the use of Tier 3) are not currently available.

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 method 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. Data on the duration of anode effects are not available for the years 1990 to 1992 and for those years a Tier 1 method is used, with the default emission factors of 0.4 kilograms CF_4 and 0.04 kilograms C_2F_6 per tonne of aluminium.

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)). For magnesium casting, the uncertainty of ±100 per cent represents the very approximate activity data (SF_6 usage) available. This activity was already historical when the data were collected.

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	±30
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 until about 1998. Since that time 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
PFCs remain relatively static in 2001, 2003 and 2006	Increased emissions from restarting the cells

The activities of lead-acid battery recycling and use of SF_6 in a magnesium foundry ceased during the time series resulting in zero emissions after 1999 and 2015 respectively.

4.4.4 Source-specific QA/QC and verification

The three key categories in the *Metal industry* category are CO_2 emissions from *Iron and steel production* (level and trend assessment), *Aluminium production* (level assessment), and PFCs from *Aluminium production* (trend assessment). The data for all direct emissions in this category underwent Tier 1 quality checks in the preparation of this inventory.

4.4.5 Source-specific recalculations

There are no recalculations for this category.

4.4.6 Source-specific planned improvements

There are no planned improvements for this 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* 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 under 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* category in 2021 were 42.4 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 not available for the years before 2011, 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 to 2021.

Paraffin wax use (2.D.2)

A small amount of paraffin wax is imported into New Zealand. There are 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. There was no use of urea catalysts before 2008.

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

Three main bitumen production companies that provide materials for road paving are operating in New Zealand. 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 to 2021 in the absence of any updated information.

Choice of methods

Tier 1 methods (IPCC, 2006a, 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.

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 for these categories.

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 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
Use of urea-based catalysts in transport	±50	±10
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 category, the activity data have been extrapolated and emission factors are defaults. The implied emission 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

For the previous submission, averaging the data for lubricants in recent years resulted in a small recalculation of emissions affecting 2018. There are no recalculations for this submission.

4.5.6 Source-specific planned improvements

This 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 category.

4.7 Product uses as substitutes for ODS (2.F)

4.7.1 Description

HFCs are used in a wide range of equipment and products, including refrigeration and air conditioning systems and aerosols. Small amounts of PFCs have also been used in these applications in some years. No HFCs or PFCs are manufactured in New Zealand. PFCs are also emitted from the aluminium-smelting process and these emissions are reported in the *Metal industry* category (2.C.3.b).

The use of HFCs in New Zealand began in 1992 and has increased since the mid-1990s when chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) began to be phased out under the Montreal Protocol. The Ozone Layer Protection Act 1996 set out a programme for phasing out the use of ODS in New Zealand. New Zealand is a signatory to the Kigali Amendment to the Montreal Protocol and is now phasing down the consumption of HFCs. The phase-down is being implemented through a permitting system for imports, which began on 1 January 2020.

In 2021, emissions in the *Product uses as substitutes for ODS* category were 1,483.0 kt CO_2-e or 32.2 per cent of emissions from the IPPU sector. This was an increase of 38.4 kt CO_2-e (2.7 per cent) from the 2020 level of 1,444.6 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 the *Refrigeration and air conditioning* category (level and trend assessment) were identified as a key category.

4.7.2 Methodological issues

Choice of activity data

New Zealand imports substantial amounts of new HFCs, mainly for use as refrigerants, both in bulk and in factory-charged equipment. Both bulk chemical and equipment charged in New Zealand are exported, but on a much smaller scale.

Most of the activity data for the *Product uses as substitutes for ODS* 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 (Verum Group, unpublished).

Data on bulk imports and exports of refrigerant, and factory-charged imported and exported equipment, were obtained using a survey. Detailed information on the supplies and banks of chemical in each sub-application was obtained from survey questionnaires and follow-up calls to request specific data. The survey included:

- 15 companies known to be significant importers and distributors of HFCs and PFCs
- approximately 75 manufacturers, exporters, importers and significant users of air conditioning and refrigeration systems and equipment
- importers, service agents and installers of vehicle air conditioners, and their trade association

- the three companies that supply fire protection equipment
- five foam blowing companies and their suppliers
- the government pharmaceutical purchasing agency (Pharmac)
- aerosol importers.

Equipment sales data are also sourced from the Energy Efficiency and Conservation Authority for equipment reported under New Zealand's mandatory energy efficiency labelling scheme. Import data are sourced from Stats NZ and from the EPA for information derived from the NZ ETS and climate change levy.

Refrigeration and air conditioning (2.F.1)

These 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.

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 less accurate than the data on total amounts of each chemical imported. It is consistently difficult to attribute bulk chemical accurately to each of the six specific sub-applications.

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. Significant stockpiling of refrigerant gases occurred in anticipation of NZ ETS obligations in 2013. Stockpiling also appears to have occurred in other years, in response to various price and policy changes. Stock changes are an important factor in applying the mass balance approach to calculate emissions.

Care is also needed to avoid double counting of chemical that is sold more than once by wholesalers and other owners before it is used.

An additional challenge is incomplete or inaccurate data on the imports of refrigerant in pre-charged equipment. Total reported imports do not appear to fully account for the quantities in equipment that is sold, as indicated by New Zealand's mandatory product labelling scheme. The number of vehicles imported is known accurately (Mobile air conditioning) but there is significant uncertainty in the quantities of refrigerant in each vehicle due to the variety of new and second-hand models imported.

As a result of these challenges, many assessments must be made to attribute activity data for each HFC over time and across sub-applications. These are documented in the report by Verum Group (unpublished) and in the stock models used to calculate emissions.

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 are provided by Waka Kotahi 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 wide variety of vehicles, many of them used cars, and it is not feasible to obtain accurate and up-to-date statistics on their refrigerant charge. Based on this earlier trend, the average charges in new vehicles added to the fleet are assessed to reduce by 2.0 per cent per year for 2010 to 2021. Discussion with importers in 2018 indicated that the ongoing trend to reduce these charges has continued (Verum Group, unpublished).

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 the annual survey. Survey data indicated increasing use of commercial HFC mixes up to 2019. During 2020 and 2021 foam companies have moved to the increasing use of hydrofluoroolefin (HFO) blowing agents. 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 have imported and supplied 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 have provided data on the amount imported in equipment in response to the annual survey. There have been no new installations in 2020 or 2021. Current stocks and recovered chemical are used to replace leakage.

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, if they have used any propellant, have used HFCs. 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. A small proportion use HFC-227ea. 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. Pharmac supplies annual data on the sales of MDIs, measured as millions of doses for HFC and non-propellant inhalers.

An approximate weighted average is used to estimate emissions per dose for each propellant. This average amount of propellant per dose has changed over time due to a changing mix of inhaler types (120 and 200 dose inhalers) as shown in table 4.7.2.

Table 4.7.2 Average emissions per dose in metered dose inhalers (milligrams)

Propellant	Inhalers using HFC-134a	Inhalers using HFC-227ea
1995–2015	81.4	66.9
2016	80.2	68.1
2017	79.5	68.5
2018	78.3	70.3
2019	77.9	73.5
2020	77.5	83.2
2021	76.9	87.8

HFC-134a is the predominant HFC propellant used in non-medical aerosols in New Zealand. A small amount of HFC-152a has been used from 2015. A very small amount of HFC-43-10mee was reported in 2020 and 2021, mixed with HFC-134a in a specialised aerosol product.

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 the aerosol cans that are imported and sold in New Zealand use hydrocarbon propellants, while only a few specialised applications use HFCs.

Information on the importation, manufacture and use of non-MDI aerosol products has been sourced from the survey data supplied by importers, from the one New Zealand aerosol manufacturer that previously used HFC-134a and from their industry association.

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; for example, they accounted 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 proportions 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) from 2001 to 2016
- phasing down by 0.1 per cent each year from 2017 to 2019, driven by introduction of HFOs
- remaining at 0.7 per cent for 2020
- 0.6 per cent in 2021 due to a further increase in the use of HFOs.

For all non-MDI aerosol products using HFC-134a as the propellant, the average propellant charge is assessed to be 84 grams.

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* 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.

Annual sales and the charge in new equipment are calculated as shown in box 7.3 in the 2006 IPCC Guidelines (IPCC, 2006a) (see box 4.1). Total charge of new equipment includes equipment that is later exported.

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.

The mass balance approach uses equation 7.9 in the 2006 IPCC Guidelines (IPCC, 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*. For commercial and industrial refrigeration, where the required data are available, the models distinguish and calculate separately:

- recovery for destruction
- recovery for reuse of the refrigerant.

Country-specific assessments for the lifetime of equipment have been made to calculate the 'original total charge of retiring equipment'. These assessments include progressive retirement of air conditioning equipment in years 8 to 19, and dehumidifiers in years 6 to 15. The analysis also takes account of the impact of the 2011 Canterbury earthquake, which resulted in emissions from demolition of damaged buildings in the following years.

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

Table 4.7.3 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 2007–2021
	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 2007–2021
	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). Insufficient data are available to further subdivide aerosol products by sub-application and 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. For each chemical, use of the Tier 2b method means that emission factors only affect the attribution of emissions among these five sub-applications, not the total emissions. Attribution to any one sub-application is subject to high uncertainties and may, consequently, be subject to significant apparent year-to-year variations.

These emission factors are detailed in the report by Verum Group (unpublished) and in the stock models used to calculate emissions.

For *Mobile air conditioning*, the model distinguishes between leakage that is replaced in regular servicing (3.0 per cent of the bank each year) and refrigerant that leaks, but is not replaced because owners do not have the air conditioning units serviced. The overall average amount of loss for the fleet is assessed to be 15±10 per cent; that is, at any time a notional 'average vehicle' will have 85±10 per cent of the charge that it would have if there was no leakage. There is also some uncertainty in the proportion of bulk imports of HFC-134 used in *Mobile air conditioning* as opposed to the other sub-applications.

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. Fire protection systems have a long life and retirements are rare. Based on information from the system suppliers, it is assessed that all refrigerant present on decommissioning is recovered.

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 with some use of expert judgement.

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 and is updated annually to reflect the share of different equipment types in the latest reported year. Uncertainties in this category have also been estimated for each sub-application. However, these reflect the uncertain attribution of emissions between sub-applications, which does not contribute to the overall uncertainty given for this category.

Table 4.7.4 New Zealand's uncertainties in product uses as substitutes for ozone depleting substances

Category	Uncertainty in activity data (%)	Uncertainty in emission factors (%)
Refrigeration and air conditioning	±24	NA
Foam blowing agents	±12	±50
Aerosols	±25	±10
Fire protection	±30	±30

Note: NA = not applicable.

Time-series consistency

There is substantial variation over the time series due to the introduction and increasing use of HFCs as replacements for CFCs and HCFCs. In previous submissions, year-to-year variation in the calculated emissions from refrigeration and air conditioning has been driven by changes in stocks from year to year. Recalculations made for this submission have reduced this apparent variance.

Calculated annual HFC emissions have increased at a consistent rate from 1,073 kt CO_2-e in 2010 to 1,483 kt CO_2-e in 2021. The banks of HFCs in operating equipment are also increasing over time, particularly in air conditioners. Future emissions will depend on the maintenance and eventual retirement of this equipment.

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 (level and trend assessment). 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 Stats NZ. The former Ministry of Economic Development compiled a detailed breakdown of bulk HFCs using these 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 became unavailable after that year.

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 2022 submission, the amounts of R134a and R404A added to the banks for industrial and commercial refrigeration and stationary air conditioning from 2007 to 2016 were re-estimated to better account for changes in stocks held by importers and users. A significant proportion was assigned to stocks rather than additions to the bank, resulting in recalculations for 2018 and 2019.

For this submission, the modelling methods used have been improved to allow recovery for destruction and recovery for reuse to be shown separately. This allows more accurate assessment of emissions when reuse needs to be considered. Separate estimates are now made for stocks in cool-stores and in other industrial refrigeration facilities, which were previously considered together.

Data collected for this submission showed a 76 per cent increase in imports of refrigerants in pre-charged equipment, mainly household heat pumps. This, and other changes in 2021 data, has resulted in a reassessment of stock numbers and retirements in earlier years.

Other reassessments have been made for this submission.

- The emission factor for *Transport refrigeration* has been adjusted from 50 per cent to 35 per cent, which is the mid-range IPCC estimate.
- The emission factor for *Stationary air conditioning* has been adjusted from 20 per cent to 10 per cent, for HFC-134 only, because this refrigerant is typically used in large units that will experience lower leakage rates.
- Differences between import data and Energy Efficiency and Conservation Authority sales data have been resolved with an assessment that stocks have been building up over time.
- Improved information has indicated a greater age range for domestic refrigerators, of 10 years to 24 years.
- The weighted average charge in MDIs has been reassessed for 2016–20, reflecting changing sales numbers for the two types of inhalers.
- Minor reassessments and calculation changes in the *Foam blowing agents* and *Fire protection* categories have had a negligible effect on emissions.

Recalculation of stocks has also indicated more recovery of HFC-134a than previously estimated. This has an indirect effect on *Mobile air conditioning* emissions because it is partly attributed to vehicle air conditioning units. The result is a small reduction (2.1 kt CO_2-e) in estimated 2020 emissions.

The total impact of these recalculations is to decrease the 2020 emissions by 35.5 kt CO_2-e.

4.7.6 Source-specific planned improvements

No specific improvements are planned for this category. There are still some unexplained year-to-year variations in emissions from the *Refrigeration and air conditioning* category, which is an indication that further improvements can be made by better accounting for stockpiling of bulk chemical. Future submissions will continue to address this issue.

4.8 Other product manufacture and use (2.G)

4.8.1 Description

The *Other product manufacture and use* category in New Zealand comprises emissions from:

- use of SF_6 as an insulant and 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 2021, emissions from the *Other product manufacture and use* category totalled 105.3 kt CO_2-e or 2.3 per cent of emissions from the IPPU sector. This is a decrease of 14.4 kt (12.0 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. This included all significant electricity companies, equipment manufacturers and industrial electricity users. 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 have been imported into New Zealand from 2011, for use in a specialised type of eye surgery. The importer provided information on the amount imported: between 0.1 kilograms and 0.3 kilograms per year.

Enquiries to importers and the tyre industry have indicated that there is no use of SF_6 in New Zealand for other applications such as double-glazed windows, 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 Stats NZ 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 (Verum Group, unpublished).

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 2019. 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 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 loss rates have been used, where 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 has become progressively more accurate (Verum Group, unpublished). 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.

Losses on disposal are assessed as 95.0 per cent if a service agent is not used, and 5.0 per cent when service agents carry out the disposal and implement good recovery practices. No recovery of SF_6 was reported before the year 2000.

Other

Emissions of SF_6 and other gases for all other applications are assumed to be prompt, and an emission factor of either 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 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	±20	±30
Medical and other product use (SF_6)	±80	–
Medical and other product use (PFCs)	±80	–
N_2O from other product uses	±15	–

Time-series consistency

The implied emission factors for the *Electrical equipment* category have declined, due to improvements both in data quality and in the actual management of SF_6 utilisation and recovery by Transpower and other users over time. Recovery did not occur before 2000. Imports of SF_6 and N_2O for other purposes have varied 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

Minor errors in reported SF_6 stocks and disposal emissions in the *Electrical equipment* category were corrected in the previous submission.

There are no recalculations for the 2023 submission.

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 may enable the consistent use of Tier 2 or Tier 3 methods for this category in future submissions.

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Chapter 5: Agriculture

5.1 Sector overview

Emissions summary

2021

In 2021, emissions from the Agriculture sector totalled 37,786.1 kilotonnes carbon dioxide equivalent (kt CO_2-e), representing 49.2 per cent of New Zealand's gross emissions in 2021.

Enteric fermentation was the main source of Agriculture emissions, contributing 73.7 per cent (27,859.0 kt CO_2-e) of the sector's emissions. *Agricultural soils* (19.4 per cent) was the second largest source followed by *Manure management* (4.4 per cent). *Urea application* and *Liming* contributed 1.5 per cent and 0.9 per cent respectively. *Field burning of agricultural residues* contributed the remaining 0.1 per cent.

Methane (CH_4) emissions from *Enteric fermentation* contributed 36.3 per cent of New Zealand's gross emissions, and nitrous oxide (N_2O) emissions from the *Agricultural soils* category contributed 9.5 per cent of New Zealand's gross emissions.

New Zealand reports emissions from Tokelau, which is a dependent territory of New Zealand. Tokelau emissions 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 emissions for Tokelau.

1990–2021

In 2021, New Zealand's Agriculture sector emissions were 13.4 per cent (4,474.1 kt CO_2-e) above the 1990 level (33,312.0 kt CO_2-e) (table 5.1.1).

Table 5.1.1 Trends and relative contribution of New Zealand's agricultural greenhouse gas emissions by category between 1990 and 2021

Category	Emissions (kt CO_2-e) 1990	2021	Change (%) 1990–2021	Difference (kt CO_2-e) 1990–2021	Share (%) of sector 1990	2021
Enteric fermentation (CRF 3.A)	26,960.4	27,859.0	3.3	898.6	80.9	73.7
Manure management (CRF 3.B)	771.7	1,680.5	117.8	908.8	2.3	4.4
Rice cultivation (CRF 3.C)	NO	NO	–	–	–	–
Agricultural soils (CRF 3.D)	5,216.8	7,315.2	40.2	2,098.3	15.7	19.4
Field burning of agricultural residues (CRF 3.F)	27.4	22.6	–17.5	–4.8	0.1	0.1
Liming CO_2 emissions (CRF 3.G)	296.5	355.6	20.0	59.2	0.9	0.9
Urea application CO_2 emissions (CRF 3.H)	39.2	553.2	1,311.4	514.0	0.1	1.5
Other carbon-containing fertilisers (CRF 3.i)	NE	NE	–	–	–	–
Total	**33,312.0**	**37,786.1**	**13.4**	**4,474.1**	**100**	**100**

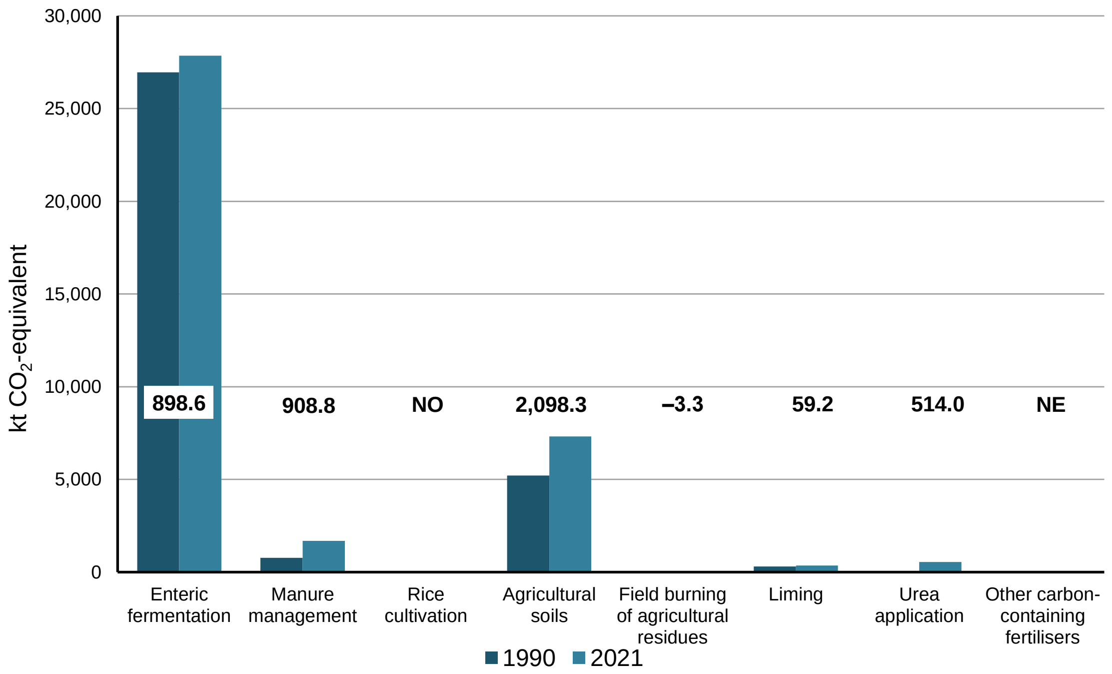
Note: NO = not occurring, NE = not estimated. Percentages presented are calculated from unrounded values.

The greatest contributions to the increase since 1990 are a 40.2 per cent (2,098.3 kt CO_2-e) increase in N_2O emissions from *Agricultural soils* and a 117.7 per cent (849.9 kt CO_2-e) increase in CH_4 emissions from *Manure management* (figure 5.1.1).

The increase in N_2O emissions from *Agricultural soils* is primarily a result of increased application of synthetic nitrogen fertiliser by around 644 per cent since 1990. This is partly due to an increase in dairy farming, as well as increased use on farms.

The increase in emissions from *Enteric fermentation* is driven by an increase in dairy cattle numbers, which is partially offset by a decrease in beef cattle and sheep numbers. The change in animal populations since 1990 reflects the relative financial returns in each sector (it has been more profitable to farm dairy cattle than beef cattle or sheep in New Zealand over the reporting period). Stock numbers have also been reduced as a result of several voluntary initiatives driven by agricultural sector groups, which have focused on improving livestock genetics and championing the uptake of more sustainable farming practices. Alongside this, changes in New Zealand's regulatory environment, especially regarding improvements to freshwater quality have also likely led to reductions in stock numbers.

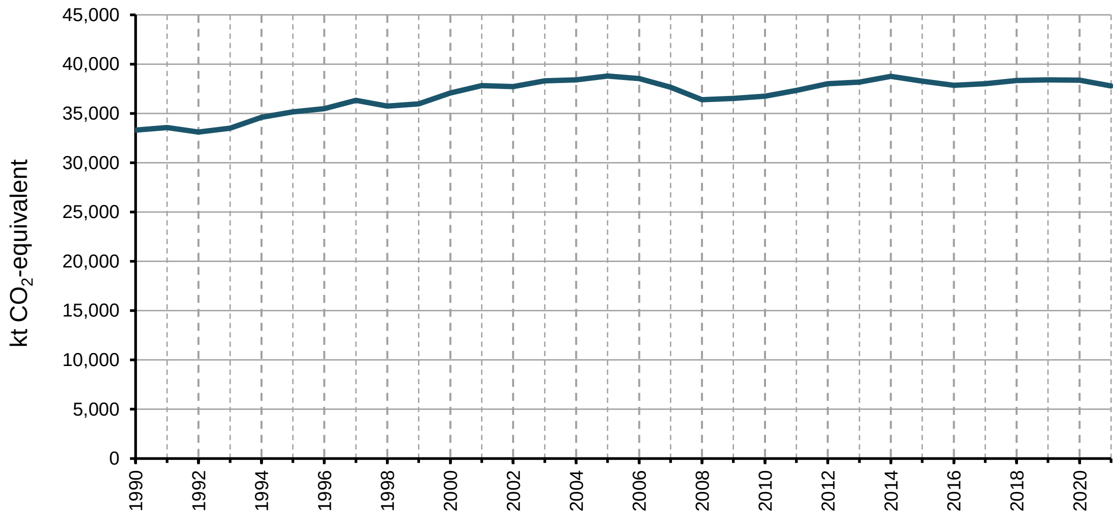
Figure 5.1.1 Change in New Zealand's emissions from the Agriculture sector from 1990 to 2021



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

Agriculture emissions most recently peaked at 38,755.2 kt CO_2-e in 2014, corresponding with a peak in dairy cattle (and total cattle overall) numbers. Prior to 2014, Agriculture emissions were at their highest in 2005 (38,794.31 kt CO_2-e) but dropped by around 1,000 kt CO_2-e during the Global Financial Crisis (2007–08) and another 1,000 kt CO_2-e during the 2008 nationwide drought. Agriculture emissions have remained slightly below the 2014 peak in the years 2015 to 2021. This is partly due to a drop in the profitability of dairy (relative to other primary sector exports) since 2015 and a continued fall in the sheep population (figure 5.1.2).

Figure 5.1.2 New Zealand's Agriculture sector emissions from 1990 to 2021



2020–2021

Between 2020 and 2021, total Agriculture emissions decreased 1.5 per cent (574.1 kt CO_2-e), largely due to a decrease in emissions from dairy cattle, sheep and synthetic nitrogen fertiliser. Specifically:

- dairy cattle emissions decreased by 1.3 per cent (236.9 kt CO_2-e) due to a decrease in the dairy cattle population
- synthetic nitrogen fertiliser emissions decreased by 9.5 per cent (177.9 kt CO_2-e) due to a decrease in fertiliser use
- sheep emissions decreased by 1.8 per cent (160.6 kt CO_2-e) due to a further decrease in the sheep population.

Emissions from other activities had minor increases and were not enough to offset the overall decrease in agricultural emissions. Some of these increases include:

- beef cattle emissions, which increased by 0.7 per cent (48.9 kt CO_2-e) due to a slight increase in the beef cattle population
- urea emissions, which increased by 2.1 per cent (11.2 kt CO_2-e) due to a small increase in the use of urea.

5.1.1 New Zealand farming practices and trends

Agriculture is a major component of the New Zealand economy, and exports from agricultural products comprised around 63.6 per cent of the total free-on-board value of merchandise exports in 2021 (Stats NZ, 2022). The production of agricultural products in New Zealand is helped by the favourable temperate climate and access to freshwater and highly productive soils. Typical farming practices in New Zealand include the use of year-round outdoor pastoral grazing systems and nitrogen inputs through nitrogen fixation by legumes, complemented (if required) by synthetic nitrogen fertiliser and supplementary feeds. The common use of outdoor pastoral grazing systems means New Zealand's agricultural production is more sensitive to climatic events affecting feed production than countries that use intensive grain-fed systems and indoor feedlots.

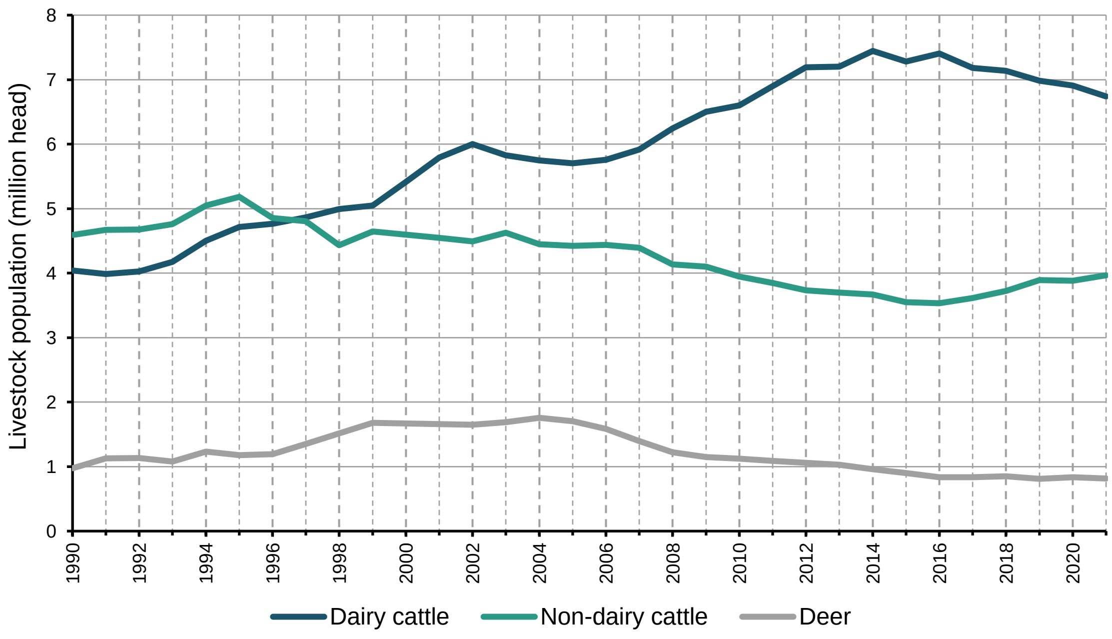
Intensive housing of major ruminant livestock species rarely occurs in New Zealand. Farmers may temporarily take animals off regular grazing areas to prevent damage to soils and limit any subsequent loss in pasture growth, although most off-paddock sites are also outside. This means New Zealand has a much lower proportion of agricultural emissions from *Manure management*, compared with other Annex I Parties, because most manure is deposited directly onto pastures. For further information about New Zealand's agricultural farming conditions, see section 2.9 (National circumstances, Agriculture) of New Zealand's Eighth National Communication (Ministry for the Environment, 2022).

Trends in emissions from the Agriculture sector are largely driven by the populations of the ruminant livestock categories (dairy cattle, beef cattle, sheep and deer). In 1990 and 2021 respectively, 94.1 per cent and 90.0 per cent of agricultural emissions originated from these ruminant livestock categories.

Agriculture activities use around 42 per cent of New Zealand's total land area (Stats NZ, 2017). Since 1990, the proportions of the main livestock categories farmed in New Zealand have changed (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. Between 1990 and 2021, the land area used for sheep, beef and deer grazing has decreased by 37.2 per cent (4,636,191 hectares) (Beef + Lamb New Zealand Ltd, 2022), while the area used for dairy farming has increased by 67.4 per cent (689,970 hectares) (LIC and Dairy NZ, 2021). However, since 2015, the total land under dairy production has remained static while the national herd has decreased season to season.

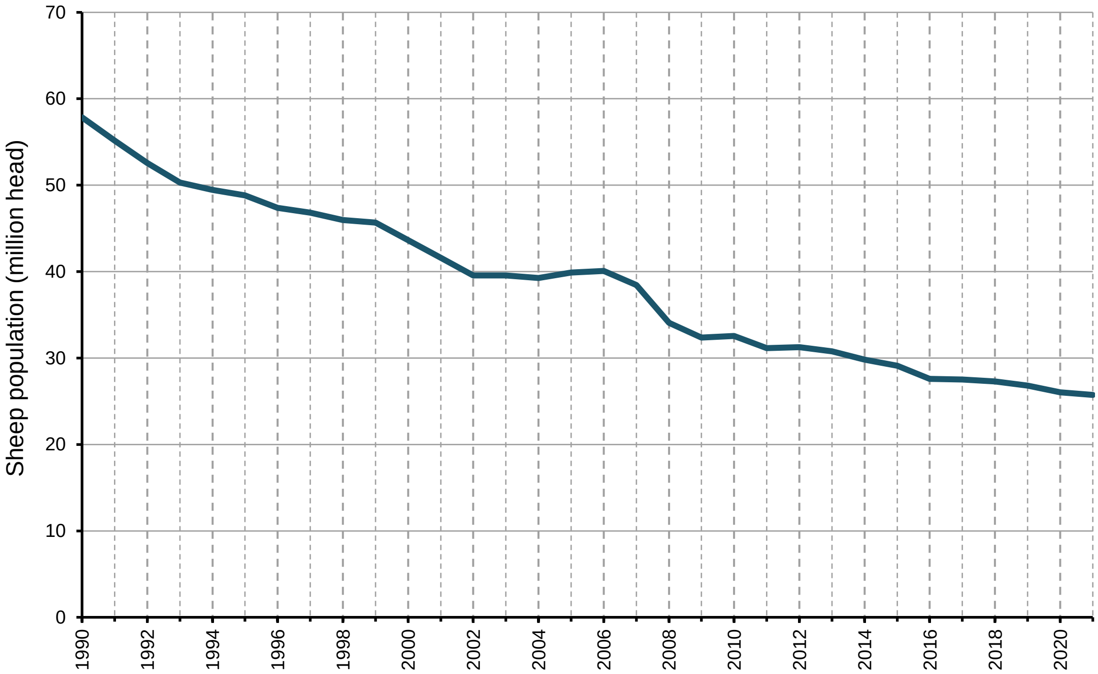
The use of synthetic nitrogen fertiliser in the Agriculture sector has increased by nearly 644.1 per cent since 1990, although total use has decreased in recent years. Total emissions from synthetic nitrogen fertiliser (including CO_2 from urea) have increased from 0.9 per cent (1990) to 6.0 per cent (2021) of agricultural emissions. The more cost-effective approach of using nitrogen fertiliser to boost pasture growth for feed (relative to the cost of other supplementary feeds) is largely responsible for this increased uptake.

Figure 5.1.3a Populations of New Zealand's dairy cattle, beef cattle and deer from 1990 to 2021 (June year ending)



Source: Stats NZ

Figure 5.1.3b Population of New Zealand's sheep from 1990 to 2021 (June year ending)



Source: Stats NZ

Effect of productivity improvements and climatic events on implied emission factors

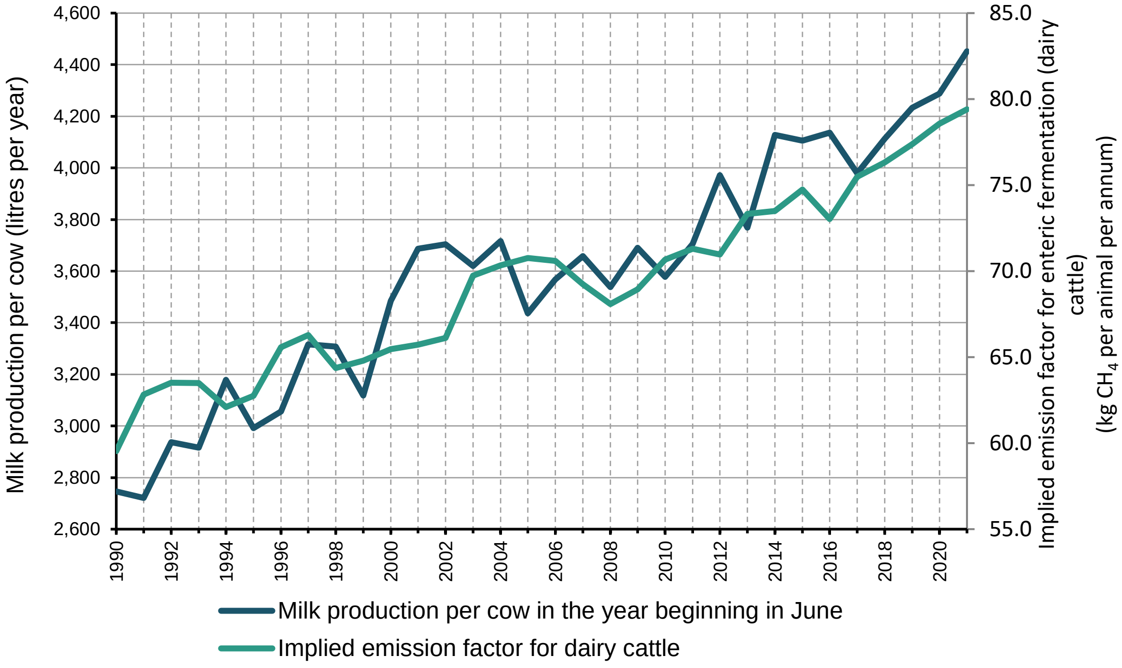
A gradual increase has occurred in the implied CH_4 and N_2O emission factors[34] per head of the major livestock species farmed in New Zealand. This trend reflects the increased levels of productivity (milk and meat yield per head) achieved by New Zealand farmers between 1990 and 2021. Increases in animal liveweight and milk yield per animal require increased feed intake to meet higher energy demands, which results in higher CH_4 and N_2O emissions per animal (i.e., higher implied emission factors (IEFs)). The increased levels of productivity have also caused emissions per unit of product (i.e., milk and meat emissions intensity) to steadily decrease since 1990.

The use of year-round outdoor pastoral grazing systems means New Zealand production is dependent on the quantity and quality of pasture grown on land managed by farmers, as well as the use and/or availability of any supplementary feeds. Pasture growth is strongly influenced by weather and climatic events, such as droughts and floods, however, the maritime climate is generally favourable for pastoral agriculture. These factors can cause changes in per-animal productivity and mean that IEFs can be noticeably different in adjacent years. For example, in 2008, a major nationwide drought affected both livestock numbers and animal performance, resulting in lower livestock emissions and overall agricultural emissions (see figure 5.1.2). The livestock population and IEFs started to increase after the drought, once seasonal growing conditions improved, and farmers restored herd and flock numbers.

An example of this is included in figure 5.1.4, which overlays milk production per milking dairy cow with the IEFs (enteric fermentation) for dairy cattle from 1990 to 2021. The figure shows that, while per cow productivity has trended upward, there is a significant amount of inter-annual variability (influenced by climatic conditions and international product prices). It also shows that the IEFs are affected by these changes in productivity.

[34] 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 in that species and sector.

Figure 5.1.4 **Dairy milk productivity and implied enteric fermentation methane emission factors for dairy cows from 1990 to 2021**



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

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 *(Beef)* Cattle	CH_4	L1, T1
3.A.2	Other (please specify) – Sheep	CH_4	L1, T1
3.A.4	Other Livestock – Deer	CH_4	L1
3.A.4	Other Livestock – Goats	CH_4	T1
3.B.1.1	Option A – Dairy Cattle	CH_4	L1, T1
3.D.1.1	Direct N_2O Emissions from Managed Soils – Inorganic N Fertilisers	N_2O	L1, T1
3.D.1.3	Direct N_2O Emissions from Managed Soils – Urine and Dung Deposited by Grazing Animals	N_2O	L1, T1
3.D.1.4	Direct N_2O Emissions from Managed Soils – Crop Residues	N_2O	L1
3.D.1.6	Direct N_2O Emissions from Managed Soils – Cultivation of Organic Soils	N_2O	L1, T1
3.D.2.1	Indirect N_2O Emissions from Managed Soils – Atmospheric Deposition	N_2O	L1
3.D.2.2	Indirect N_2O Emissions from Managed Soils – Nitrogen Leaching and Run-off	N_2O	L1
3.G	Agriculture – Liming	CO_2	L1
3.H	Agriculture – Urea Application	CO_2	L1, T1

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* (CH_4) and *Manure management* (CH_4 and N_2O)). In New Zealand, the predominant species (in terms of population numbers) are sheep, followed by dairy cattle, beef cattle and deer. New Zealand breeds are selected to perform 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 calculating emissions. For example, 90.0 per cent of New Zealand's livestock emissions come from *Dairy cattle*, *Non-dairy* (beef) *cattle*, *Sheep* and *Deer* ('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 with some Tier 2 components. As such, most of New Zealand's reported agricultural emissions are calculated using a Tier 2 methodology. 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 *(Beef)* 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	CS		
	Non-Dairy *(Beef)* 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						
	Synthetic Fertilisers			T2	CS		
	Animal Manure Applied to Soils			T1, T2	CS		
	Sewage Sludge Applied to Soils			NA	NA		
1	Other Organic Fertilisers Applied to Soils			NA	NA		
	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		

	Source category	CH_4		N_2O		CO_2	
		Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
	Indirect Emissions						
2	Atmospheric Deposition			T1, T2	D		
	Nitrogen Leaching and Run-off			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.

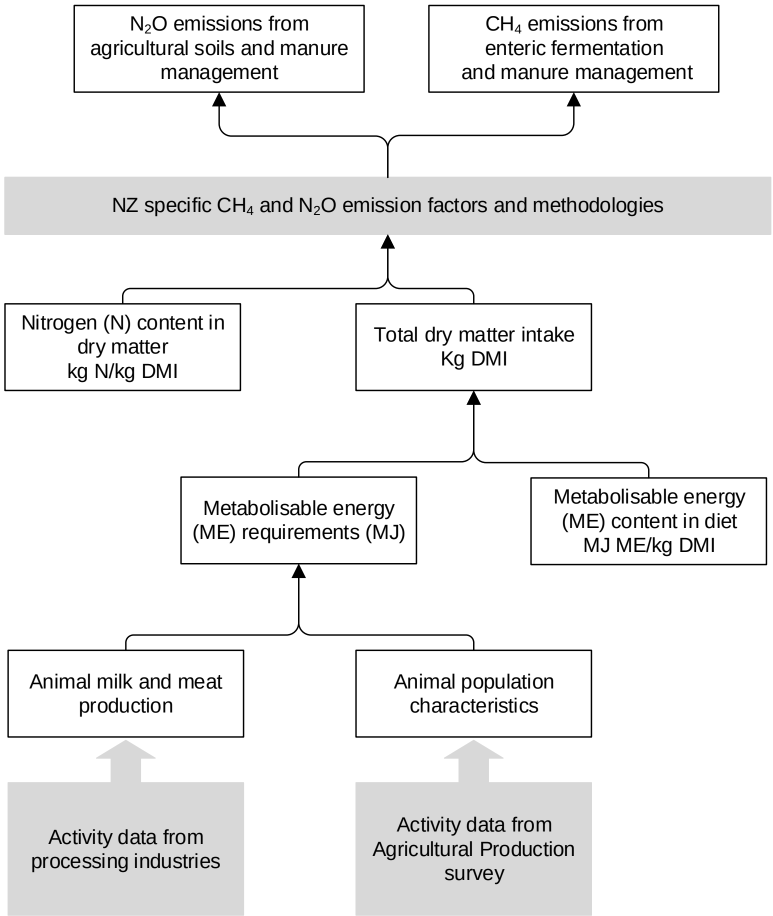
Further technical details on emissions calculations are provided in the inventory methodology document on the Ministry for Primary Industries (MPI) website (www.mpi.govt.nz/dmsdocument/13906-detailed-methodologies-for-agricultural-greenhouse-gas-emission-calculation) and in the methodological issues section for each category in this document. The approach for determining livestock nutritional and energy requirements, which is required to calculate *Enteric fermentation* emissions and nitrogen excreted by livestock as the precursor for calculating *Manure management* (and some *Agricultural soils* emissions), is described in the following paragraphs.

Description of the Tier 2 model for determining emissions from energy requirements for major ruminant livestock categories

New Zealand uses a Tier 2, process-based model to calculate emissions from the major livestock categories (Clark et al., 2003). Components of the national Agriculture inventory model are constantly being improved through findings from new international and commissioned domestic research. The thoroughly researched country-specific emission factors and monthly data for livestock populations, animal productivity and feed quality mean New Zealand's model is close to a Tier 3 inventory. However, data that inform pasture and non-pasture feed quality are not as comprehensive as would be required to report at a Tier 3 level. Figure 5.1.5 outlines the current Tier 2 methodology used to estimate emissions for the four major livestock categories.

Agricultural production (meat, milk and wool) and livestock population data are combined in the model with data on the total metabolisable energy (ME) content of the animal's diet. To calculate CH_4 emissions from enteric fermentation, the production data are used to determine the dry-matter intake (DMI) required to meet total annual productivity levels for each of the livestock categories and are then multiplied by a country-specific CH_4 emission factor per unit of DMI. *Manure management* emissions are primarily CH_4 from manure deposited directly onto pasture, but also N_2O as that manure breaks down due to the processes of nitrification, denitrification, volatilisation and leaching. Information on the nitrogen content of feed is multiplied with the DMI previously calculated to determine quantity of animal nitrogen intake and subsequent nitrogen excretion after allowing for nitrogen in growth and milk production.

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 quantity of livestock emissions has a linear relationship with DMI, which is a function of livestock energy requirements and the energy concentration of the feed:

$$DMI = \frac{ME_{TOTAL}}{E}$$

Where: DMI is the dry-matter intake (kg $year^{-1}$)

ME_{TOTAL} is the total metabolisable energy requirement of the animal (kJ), and

E is the energy concentration in the feed (kJ/kg DMI).

Calculating metabolisable energy requirements (ME_{TOTAL})

For dairy cattle, beef 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). The CSIRO 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. Further, the CSIRO algorithms consider animal liveweight and production requirements based on the rate of liveweight gain, gender, milk yield and physiological state. All calculations are performed monthly. 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 (ME_{TOTAL}) 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 milk fat percentage, and liveweight gain for dairy and beef production respectively) and physiological state (e.g., growing, gestating (ME_C) 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 day^{-1}).

And:

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

Where: K is the coefficient that accounts for differences in fasting heat production across species (CSIRO, 1990). This value is 1.0 for sheep and 1.4 for all cattle and deer (CSIRO, 2007)

S is the coefficient that accounts for differences in basal metabolic rate between males and females. This value is 1.0 for females and castrates and 1.15 for entire mature males (CSIRO, 2007)

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 (ME_{BASAL}), and

E_{GRAZE} is the additional energy expenditure of livestock in cold stress.

For further details, see the inventory methodology document on the MPI website (www.mpi.govt.nz/dmsdocument/13906-detailed-methodologies-for-agricultural-greenhouse-gas-emission-calculation).

Monthly diet energy (E) concentration

In New Zealand, dairy cattle, beef 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 species are used in the Agriculture inventory model. This diet is typically supplemented with feeds of various types, such as hay and silage, and a range of different crops and crop wastes. Data on the concentration of pasture are reported in the inventory methodology document (Pickering et al., 2022, 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 across the livestock emission source categories, a single enhanced livestock population characterisation and DMI estimate is produced by the Tier 2 model. The enhanced livestock characterisation and DMI is used 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 in the *Agricultural soils* category.

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 and hence DMI. Animal population data are collected by Stats NZ. Productivity data for dairy are provided jointly by the Livestock Improvement Corporation (LIC, a farmer-owned cooperative) and DairyNZ, with other data provided by industry organisations such 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 from all major meat processors 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 end 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 calendar year and ending on 30 June of the next year. To calculate emissions for a single calendar year (January–December), the calculated emissions 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 are the only livestock type where emissions are currently calculated on a sub-national regional area basis represented by regional council areas. This allows the inventory to take into account regional differences in productivity for dairy livestock as a result of New Zealand's microclimates and management systems (Clark, 2008a). A regional emissions assessment is not carried out for other livestock types because regional productivity data are currently unable to be accurately collected at the sub-national level and integrated into the national population data.

Animal population data

Stats NZ collects animal population data on a sub-national 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 2022) and the survey is conducted in the interim years. The only difference between these two processes is the sample size. The census attempts to gather information from the entire target population, and the survey attempts to gather information from a representative random sample of that population. Further details about the scope and accuracy of the Stats NZ Agricultural Production data collection are provided in annex 3, section 3.1.

The timing of Stats NZ final data releases (June the year after the survey) and the inventory submission deadlines mean data from an MPI *Expectations Report* (see chapter 10, section 10.1.3 for more detail) have been used in the 2023 (1990 to 2021) submission. The 2023 submission results will be updated with final data from Stats NZ in the 2024 (1990 to 2023) submission. This affects 2022 livestock population data only, which are needed to estimate emissions for the 2021 year.

The New Zealand Agriculture inventory uses a country-specific population characterisation for pasture-based livestock compared with the default recommended by the Intergovernmental Panel on Climate Change (IPCC) for Tier 2 inventories (IPCC, 2000, 2006). The full list of categories for the major livestock populations can be found in annex 3, table A3.1.2, and in the inventory methodology document on the MPI website (www.mpi.govt.nz/dmsdocument/13906-detailed-methodologies-for-agricultural-greenhouse-gas-emission-calculation).

For the purposes of emissions data reporting, '*Dairy cattle'* category encompasses all cattle that support the milking dairy herd. In addition to dairy heifers, this includes calves, young growing non-lactating heifers, dry cows and dairy bulls. All other cattle in New Zealand are characterised as beef cattle. These include beef breeding lactating cows used for producing slaughter animals, such as calves, dry cows, bulls and all slaughter classes. A proportion of male and female calves not required for dairy replacements are transferred into the beef herd and are slaughtered for meat consumption, generally at 18 to 24 months of age.

A detailed livestock population model is used to calculate monthly populations for dairy cattle, beef 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), Suttie (2012) and Burggraaf et al. (2022). Populations within a given year are adjusted on a monthly basis to account for births, deaths and transfers between age groups. For example, because most lambs are born and slaughtered between August and May, their numbers do not appear in the June census or survey data. Additionally, male and female dairy calves not necessary for replacements are usually slaughtered at four days of age or transferred to the beef herd. The monthly population model ensures that the calculated feed demand more accurately reflects the status of each livestock category at a particular time of the year. Average national estimates of monthly birth and death dates and rates are used, which are based on expert opinion and limited published data. In reality, these vary across the country, between farming species, climates and between farming systems.

Animal productivity data

Animal productivity data are obtained from LIC and DairyNZ, Beef + Lamb New Zealand Ltd and Deer Industry New Zealand. Slaughter statistics are collected by MPI and used as a proxy to establish changes in animal liveweight over time (www.mpi.govt.nz/resources-and-forms/economic-intelligence/data/). 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 beef cattle and breeding bulls, is collected at irregular intervals from small survey populations. For years when data are 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 in the New Zealand dairy statistics reports. These data are collectively compiled by LIC and DairyNZ.

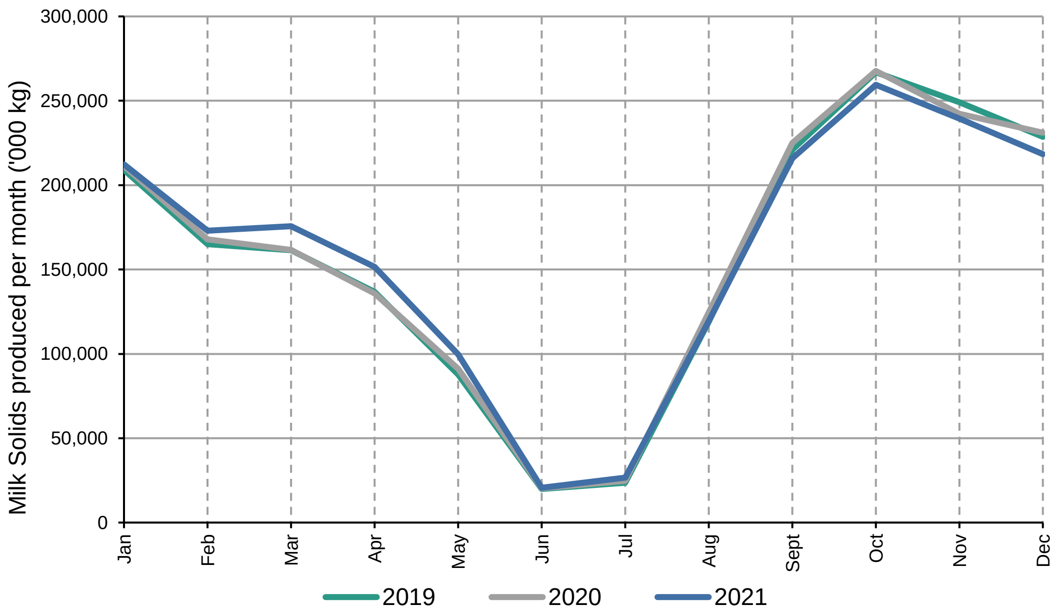
Data on New Zealand's total milk production are taken from the amount of milk processed through New Zealand dairy factories for both the export and domestic markets. Data on individual animal production are sourced from the Dairy Industry Good Animal Database (DIGAD), maintained by DairyNZ. Dairy farmers 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. These meters are regularly calibrated and audited. Milk samples from individual farms are also independently tested for milk solids, milk fat percentage 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 assessed 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 earlyAugust 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), representing the seasonal nature of forage growth.

New Zealand's dairy production per animal is lower than in 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.

Annual milk yields per animal have been obtained and reported as additional data in the CRF tables for Annex I country inventories by dividing the total milk produced by the total number of milking dairy cows and heifers.

Figure 5.1.6 National monthly milk production in New Zealand from 2019 to 2021



Source: Dairy Companies Association of New Zealand (2022)

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 to 2003, annual milk yield per cow was determined by the following equation:

$$Litres\ per\ cow = \frac{Mean\ milk\ fat\ (kg/cow) \cdot 100}{\%\ milk\ fat}$$

From 2004 onwards, productivity data have been collected by LIC at a similar regional level as the livestock population data collected by Stats NZ. In some instances, the regional level data provided by LIC are disaggregated more than required. MPI officials allocate this to other regions so that it lines up with the population data, that is, districts identified under the region 'Central Plateau' are allocated to the 'Bay of Plenty'. This is a straightforward process because the districts provided by LIC clearly fall within the specified regional boundaries that the Stats NZ data are based upon.

In the 2020/21 season, nearly 76 per cent of all dairy cattle in milk were tested by LIC for milk production, along with milk fat and protein levels (LIC and DairyNZ, 2021). LIC also does genetic testing to identify superior breeding stock and their genetic background. Genetic improvement has contributed to the productivity improvements in the New Zealand dairy cattle herd (LIC, 2009).

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, some of which comprise several regional council regions. Data from the livestock improvement regions were appropriately apportioned to regional council areas. Liveweights before 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 about 9 per cent of the weight of the average cow at birth and to reach 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 (two months of age) 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 industry data (Clark et al., 2003), that the average mature weight of a breeding dairy bull is 500 kilograms as of 1 January 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 New Zealand 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 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 (2021) reported the proportions of different breeds in the New Zealand dairy herd in 2020 as:

- Holstein–Friesian/Jersey crossbreed (49.6 per cent)
- Holstein–Friesian (32.5 per cent)
- Jersey (8.2 per cent)
- Ayrshire (0.4 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 nearly 7.8 per cent lighter than a Holstein–Friesian (LIC and DairyNZ, 2021) 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.

Beef cattle: The principal source of information for estimating productivity for beef cattle is livestock slaughter statistics provided to MPI by meat processors, which are also used to estimate the liveweight of beef cattle at slaughter, assuming killing-out percentages[35] of 55 per cent. All growing beef animals are assumed to be slaughtered at two years of age,[36] 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 around 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 only began to separate carcass weights of adult dairy cows and adult beef cows in 2016 (MPI, 2022). Therefore, several assumptions[37] 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 provided to MPI by meat processors are used to estimate the liveweights of adult sheep and lambs at slaughter, assuming killing-out percentages of around 40 per cent for ewes and 45 per cent for lambs (Thomson et al., 2010). Lamb liveweights at birth are assumed to be 9 per cent of the adult ewe weight, with all lambs assumed to be born on 11 September (Thomson et al., 2010). Growing breeding and non-breeding ewe hoggets are assumed to reach full adult size when subsequently mated at an age of 20 months. Adult wethers (castrated male sheep) 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 provides estimates of the total wool production from 1990 to 2021 from which the individual fleece weight is estimated (Beef + Lamb New Zealand Ltd, 2022).

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35 Percentage of carcass weight in relation to liveweight.

36 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.

37 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).

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 of milk over 120 days, an average daily lactation yield of 1.7 litres of milk per day (Suttie, 2012).

Minor livestock categories

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 3, section A3.1.2, table A3.1.4).

The populations of goats, horses and swine are reported using data from the Stats NZ Agricultural Production Census and the inter-census Agricultural Production Survey. Data on the population of alpacas before 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 Stats NZ.

A small number of buffalo are farmed in New Zealand. Stats NZ advised that, in 2011, there were 192 buffalo. Because the buffalo livestock are used for producing milk, they are reported within the dairy herd, so the notation key 'IE' (included elsewhere) is used.

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 populations of animals are extremely small relative to the major livestock categories.

Poultry is further classified into three categories: broiler chicken,[38] layer hens and other poultry. Stats NZ 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 are used as suggested by Fick (2010). Stats NZ 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. In 2015, it was estimated only 739 ostriches were in the country. Other poultry manure management emissions are included and calculated. 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-bearing animals.

38 Also known as 'meat chickens', which tend to be larger breeds with higher muscle content.

5.1.5 Recalculations

Agricultural emissions research

New Zealand invests in a comprehensive research programme to develop technologies and practices to reduce biological greenhouse gas emissions from Agriculture. This is facilitated through the following.

- The New Zealand Agricultural Greenhouse Gas Research Centre (NZAGRC), which was established in 2009. Its 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), which was established in 2003 by New Zealand agricultural sector organisations and private companies in partnership with Government. It funds research, primarily into mitigation technologies and management practices for ruminants but also to provide information to improve on-farm greenhouse gas inventories. The PGgRc was funded in partnership between the Government, through the Ministry of Business, Innovation and Employment and agriculture sector parties. Funding from the Ministry of Business, Innovation and Employment has since ceased and the PGgRc now largely operates on funding from industry.
- New Zealand is one of the founding members of the Global Research Alliance on Agricultural Greenhouse Gases (GRA), which facilitates international research collaboration to study means of increasing global food production while reducing agricultural greenhouse gas emissions. This includes building capability, improving greenhouse gas inventories in developing countries, and facilitating the transfer of technologies and knowledge between members. New Zealand has hosted the GRA Secretariat since its establishment in 2009 and coordinates New Zealand's contribution, largely through the NZAGRC.
- New Zealand's Greenhouse Gas Inventory Research Fund aims to support continuous improvement of the Agricultural Greenhouse Gas Inventory to improve the accuracy and reduce uncertainty of emissions reporting and forecasting. This is required under the United Nations Framework Convention on Climate Change (UNFCCC).
- The Centre for Climate Action on Agricultural Emissions was recently established to accelerate the research, development and commercialisation of tools and technology to reduce emissions. It aims to achieve this via two main components:
  - Centre for Climate Action joint venture, a long-term partnership between the Government and industry partners to drive a targeted research programme and support the pathway and uptake of new tools and technologies
  - enhancing the NZAGRC via additional investment.

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.

He Waka Eke Noa – Primary Sector Climate Action Partnership

He Waka Eke Noa forms part of New Zealand's actions towards its Climate Change Response (Zero Carbon) Amendment Act 2019 targets and nationally determined contributions under the Paris Agreement. Government has set into law a target for net zero greenhouse gas emissions by 2050, with biogenic CH_4 having a separate target of a 10 per cent and 24 per cent to 47 per cent reduction below 2017 levels by 2030 and 2050 respectively.

In October 2019, the Government announced the formation of the Primary Sector Climate Action Partnership (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 nationwide scheme for the Agriculture sector to measure, manage and price agricultural greenhouse gas emissions by 2025. During 2022, the He Waka Eke Noa Partnership delivered a set of recommendations on farm-level pricing and held a series of public consultation meetings with farmers and other stakeholders seeking feedback on the proposal.

As a legislative requirement under the Climate Change Response (Zero Carbon) Amendment Act 2019, the Government published a report on the proposed pricing system on 21 December 2022. Final decisions on the pricing system will be made by Cabinet (government senior ministers) in early 2023.

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.

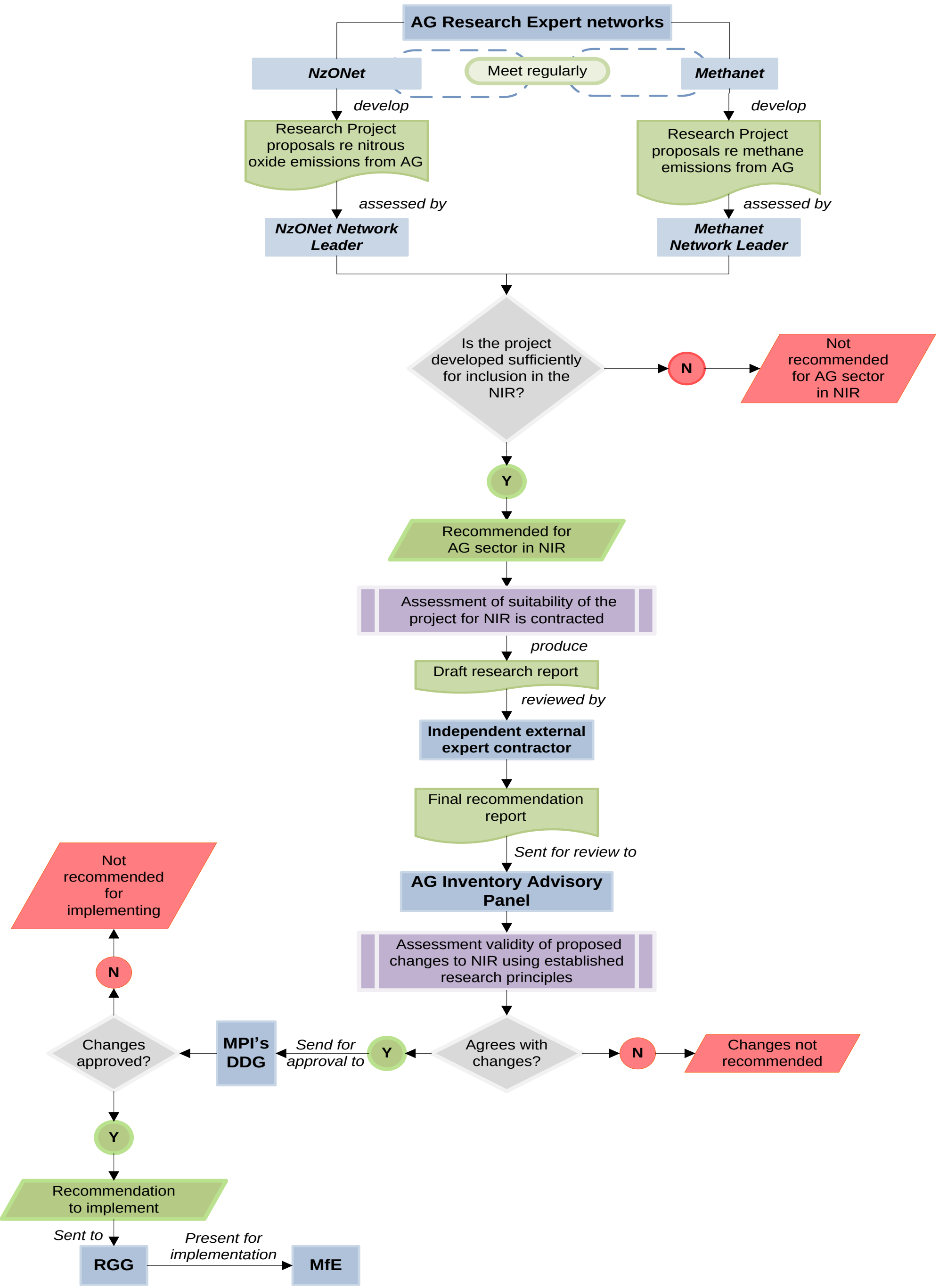
Domestically, New Zealand has a network of scientific experts in the fields of CO_2, CH_4 and N_2O emissions. Research findings are presented annually at the Greenhouse Gas Inventory Research Workshop. New inventory research ideas raised by the research community inform decisions for future inventory 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 relating 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. A standard peer review report template is used.

If the report recommends changes are made to the inventory, a briefing and the final report are sent to the Agriculture Inventory Advisory Panel, which currently 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.[39] The Panel is independent of policy and industry influences and has been formed to give independent advice on whether changes to the Agriculture section of the National Inventory Report are scientifically robust, justifiable, and internationally defensible. The Panel assesses if the proposed changes have been appropriately researched, using recognised scientific principles and practices, and if there is sufficient scientific evidence to support the recommended changes.

Changes recommended by the Panel must be approved by the Deputy Director-General (Policy and Trade) at MPI, as well as the Reporting Governance Group (RGG) which is Chaired by MfE and leads the reporting, modelling and projections of emissions and removals across government and all sectors. Further details of the RGG are provided in chapter 1, section 1.2.2.

[39] Methanet and NzOnet contain experts on methane (CH_4) and nitrous oxide (N_2O) respectively. These advisory groups 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, develop a collaborative approach to improve the quality of CH_4 and N_2O emission data, and build and maintain inventory research capability.

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 – October 2022

The Panel meeting was held on 26 October 2022 and considered the following potential inventory changes:

- the adoption of new $Frac_{LEACH}$ values for grassland and synthetic nitrogen fertiliser
- the inclusion of supplementary (non-pasture) feeds for dairy cattle, sheep, and beef cattle
- an update to the within-year *Dairy cattle* population modelling.

The Panel recommended the use of new $Frac_{LEACH}$ values for grassland and synthetic nitrogen fertiliser based on the work of Welten et al. (2021). Following on from the 2021 Panel meeting where a new $Frac_{LEACH}$ value was recommended for nitrogen applied to cropping systems, the Panel required further follow up by MPI officials to ensure the modelling work was also suitable for grassland. The Panel also recommended that the synthetic nitrogen fertiliser $Frac_{LEACH}$ value be adjusted based on the grassland and cropping values because it is applied to both systems.

For the second proposed change, the Panel recommended the inclusion of supplementary (non-pasture) feeds. Until now, the inventory has assumed that all Tier 2 livestock are 100 per cent pasture fed due to a lack of reliable, national level data on supplementary feeds. New research collated the use and quality of several other feeds at a national level of each animal type, which are now able to be accounted for.

Finally, the Panel also recommended an update to the within-year *Dairy cattle* population modelling. This includes several improvements to the way in which the monthly dairy cattle population is modelled, to better reflect what is occurring on-farm. It also includes export animal data for beef cattle, which were previously unaccounted for or incorrectly attributed to animal losses.

All of the changes made have been backdated to the 1990 baseline. Further details on these changes are outlined in sections 5.2.5 and 5.5.5 (source-specific recalculations), as well as chapter 10 (all recalculations).

The briefings, reports, supporting documentation and minutes of the 2022 Panel meeting (as well as Panel meetings for previous years) are available on the MPI website (www.mpi.govt.nz/news-and-resources/statistics-and-forecasting/greenhouse-gas-reporting/agricultural-inventory-advisory-panel).

Recalculations approved for the 2023 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 implemented all of the recommendations in its 2023 annual inventory submission.

The implementation of these improvements has resulted in the estimate of Agriculture sector emissions in 2020 being 2.7 per cent lower in the 2023 submission than they would otherwise be without the changes.

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 Stats NZ 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 Stats NZ ensures that statistical data are aligned with changes in agricultural management practices in the primary industries sector. Capturing this data is required to be able to track changes in emissions as a result of mitigation and shifts in farm management in the inventory.

The team responsible for the Agriculture inventory preparation also maintains relationships with industry bodies that provide additional data, such as Beef + Lamb New Zealand Ltd, DairyNZ, Deer Industry New Zealand, the Poultry Industry Association New Zealand and the Fertiliser Association of New Zealand. This also includes LIC, which is a farmer-owned cooperative.

As part of the quality control procedures, the inventory is reviewed by MPI personnel with expertise in climate change policy, international policy, climate change science and livestock farming policy. The review ensures that the inventory clearly explains the sources of agricultural emissions in New Zealand as well as the trends in emissions from year to year. The results from the inventory also inform domestic and international climate change policy.

MPI's 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 titled 'New Zealand's National Inventory System Guidelines for Compiling New Zealand's Greenhouse Gas Inventory'. This document provides domestic guidelines for the National Inventory Report sector leads to follow, including the decisions under the UNFCCC, Kyoto Protocol and the Paris Agreement. The document also includes New Zealand's quality-assurance and quality-control plan, which is followed by all inventory 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 *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006) and 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 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 re-checked 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 (MfE).

QA/QC area	Details of QA/QC procedure
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 MfE 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 MfE.
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 corrected for in the 2019 (1990–2017) submission.
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 and research

MPI has commissioned several projects aimed at further improving New Zealand's Agriculture inventory.

Short-term studies (around one year) include:

- developing a gene flow sub-model for sheep, to account for CH_4 reductions in the national flock due to the introduction of low-CH_4 rams (see section 5.2.6)
- developing a national repository of relative genetic merit of New Zealand sheep (see section 5.2.6)
- improving emissions estimates from minor animal categories (see section 5.2.6)

- undertaking a pork industry survey of manure management systems (see section 5.3.6)
- examining inventory methodology for the incorporation of CO_2 absorption through enhanced rock weathering (see section 5.5.6)
- reviewing N_2O emissions from non-manure components of organic fertilisers (see section 5.5.6)
- investigating N_2O emissions from nitrogen fertilisers and whether more disaggregated emission factors for non-urea nitrogen fertilisers are needed (see section 5.5.6)
- improving accounting for emissions attributed to venison and velvet from deer (below).

Longer-term studies (more than one year) include:

- measuring the CH_4 emissions from feed supplemented dairy cows (see section 5.2.6).
- determining the impact of pasture having the grass species kikuyu (*Pennisetum clandestinum*) on enteric fermentation emissions (see section 5.2.6)
- undertaking integrative greenhouse gas evaluation of forages (see section 5.2.6)
- improving information on feeding practices in dairy farming systems (see section 5.2.6)
- updating data on the use of different manure and effluent management systems in New Zealand dairy farms (see section 5.3.6)
- improving organic soils activity data and providing for the implementation of the IPCC 2013 Wetland Supplement (IPCC, 2014) (see section 5.5.6)
- quantifying N_2O emissions from eutrophic lakes as a result of pollution from agricultural runoffs and wastewater discharge (see section 5.5.6)
- increasing measurements of N_2O in spring and summer to develop N_2O emission factors for dung and urine (EF_3), which vary by season (see section 5.5.6)
- modelling pasture quality data using remote sensing in the form of hyperspectral imaging (below)
- developing a database of greenhouse gas activity data for whenua Māori (below)
- top-down measuring and modelling of methane emissions as a verification tool (below)
- continuing work to improve activity data, including through the annual collection of agricultural data by Stats NZ.

New Zealand also intends to review the recent publication of the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2019), and investigate changes to methodology and emission factors for Agriculture, where appropriate. Ongoing research into organic soils is being conducted with the aim of enabling the implementation of the IPCC 2013 Wetland Supplement (IPCC, 2014).

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 planned improvement 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)).

Remote sensing of pasture data

This project will seek to use remote sensing technologies to estimate pasture quality (i.e., metabolisable energy, N content and digestibility). Physical sampling of sites is expensive and time consuming, and limits the amount of comprehensive farm-scale data that are available through New Zealand. Through the use of airborne hyperspectral imaging, this project will undertake a proof-of-concept to illustrate efficacy of mapping farm-scale pasture quality data compared with traditional methods.

Splitting emissions between venison and velvet in the deer industry

Current deer industry emissions intensity values attribute all greenhouse gas emissions to venison production. Population statistics suggest that between 25 per cent and 35 per cent of the current deer population now directly supports velvet production. This project will conduct a population-based study, including reassessment of liveweight of various stock classes, and develop a methodology to allocate deer industry emissions to the production of velvet and venison.

Greenhous gas activity data for whenua Māori

This project will work to develop a database of activity and emission data for whenua Māori (Māori land). Māori have significant agricultural interests across New Zealand and current calculations of emissions are applied across the country, irrespective of land ownership and management differences. This will allow New Zealand to more accurately account for agricultural greenhouse gas emissions at a national level, while also helping to understand the implications of domestic policies on Māori land owners.

Top-down modelling of methane emissions as a verification tool

Accurate and regular reporting of CH_4 is vital to New Zealand's efforts to monitor and reduce anthropogenic greenhouse gas emissions. This research aims to provide regular reporting of regional CH_4 emissions using both ground-based observations and observations from satellites. This will be valuable as a verification tool for the current bottom-up methodology, while also providing a more up-to-date reporting mechanism that could be provided to other stakeholders across New Zealand.

5.2 Enteric fermentation (CRF 3.A)

5.2.1 Description

Methane is produced predominantly by ruminants as a by-product of enteric fermentation, which is the digestive process that breaks down consumed plant material in the rumen under anaerobic conditions. A portion of the plant material is fermented in the rumen to simple fatty acids, hydrogen, CO_2 and CH_4. The gases from this process are released by eructation (burping) and exhalation by the animal. The amount of CH_4 released is dependent on the type, quality and quantity of feed consumed, and energy expenditure of the animal. Energy expenditure depends on the type, age, weight, health and production of the animal, as well as whether the animal is pregnant (and the stage of pregnancy).

Methane emissions from the *Enteric fermentation* category from *Dairy cattle, Non-dairy* (beef) *cattle* and *Sheep* were identified as among the largest key categories for New Zealand in the 2021 level assessment, and were also assessed as key categories in the trend assessment. The

Enteric fermentation category from deer was also assessed as an additional key category in the level assessment, and the *Enteric fermentation* category from goats as an additional key category in the trend assessment. 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 27,859.0 kt CO_2-e, representing 36.3 per cent of New Zealand's gross emissions and 73.7 per cent of Agriculture emissions in 2021. The major livestock categories contributing to *Enteric fermentation* are:

- *Dairy cattle* (48.0 per cent of *Enteric fermentation*)
- *Sheep* (28.8 per cent of *Enteric fermentation*)
- *Non-dairy* (beef) *cattle* (21.3 per cent of *Enteric fermentation*)
- *Deer* (1.7 per cent of *Enteric fermentation*).

Trends

Emissions from *Enteric fermentation* increased 3.3 per cent (898.6 kt CO_2-e) between 1990 and 2021. Since 1990, there have been changes in the relative sources of emissions within the *Enteric fermentation* category (see table 5.2.1). Large increases in CH_4 emissions from *Dairy cattle* (122.6 per cent increase in *Enteric fermentation* emissions between 1990 and 2021) have been partially offset by decreases in emissions from *Non-dairy* (beef) *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 2021

	Emissions (kt CO_2-e)		Change from 1990		Share of Enteric fermentation category (%)		Share of total Agriculture sector (%)	
Livestock category	1990	2021	%	kt CO_2-e	1990	2021	1990	2021
Dairy cattle	6,012.9	13,382.5	122.6	7,369.6	22.3	48.0	18.1	35.4
Non-dairy *(beef)* cattle	5,861.6	5,944.0	1.4	82.3	21.7	21.3	17.6	15.7
Sheep	14,407.4	8,011.9	–44.4	–6,395.4	53.4	28.8	43.2	21.2
Deer	429.0	468.3	9.2	39.3	1.6	1.7	1.3	1.2
Minor livestock	249.5	52.4	–79.0	–197.1	0.9	0.2	0.7	0.1
Total	**26,960.4**	**27,859.0**	**3.3**	**898.6**	**100**	**100**	**80.9**	**73.7**

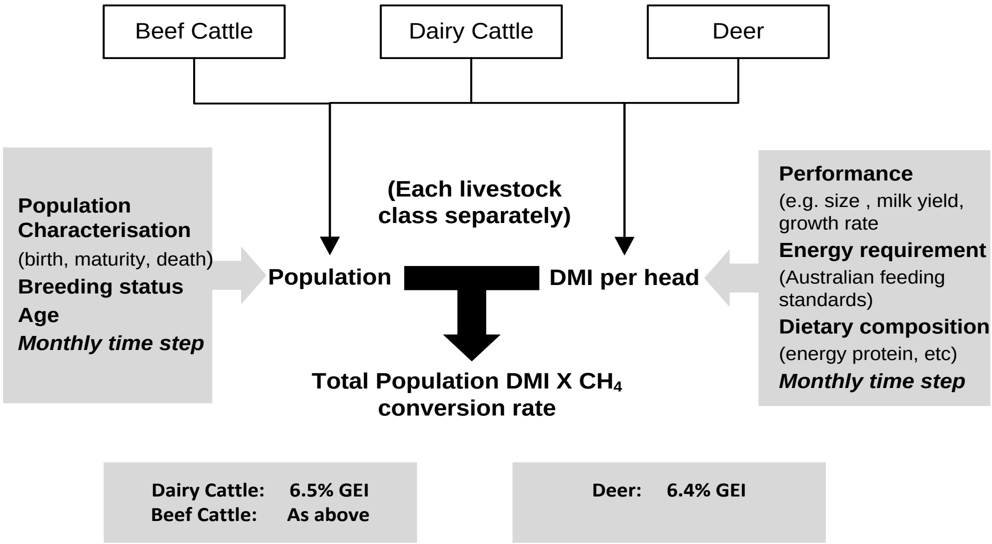
Note: Percentages presented are calculated from unrounded values.

5.2.2 Methodological issues

Emissions from Non-dairy (beef) cattle, Dairy cattle and Deer

The total amount of enteric CH_4 emitted by *Non-dairy* (beef) *cattle, Dairy cattle* and *Deer* is calculated using a CH_4 conversion factor for emissions per unit of dry matter feed intake in kilograms of DMI per livestock category (see figure 5.2.1). The enhanced 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 for *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 the methodology outlined in a peer reviewed paper published by Swainson et al. (2016). The study confirmed that DMI alone has the largest influence on CH_4 emissions and that pasture quality (as measured by the ME content) has a small but statistically significant effect on emissions from sheep less than one year of age.

Swainson et al. (2016) 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[40] 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[41] 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 of age (i.e., lambs)

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

ME is the metabolisable energy concentration of diet 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/head/day)

class refers to the different categories of sheep greater than one year of age (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 total diet (pasture and non-pasture feed) are calculated by New Zealand's Tier 2 inventory model (see section 5.1.3).

Methane measurement and modelling

New Zealand uses country-specific methodology and emission factors for estimating enteric fermentation CH_4 emissions per kilogram of dry matter feed intake (i.e., DMI) for several reasons. First, the data requirements for existing digestion models[42] are less relevant to New Zealand's predominantly pasture-based systems. Existing digestion models have been largely derived from animals fed indoors on diets unlike the grass-based diets fed to New Zealand livestock. Further, these existing models have a lower predictive power when compared against empirical experimental data derived from New Zealand research (Clark et al., 2003).

Since 1996, New Zealand scientists have been measuring CH_4 emissions from grazing (non-housed) cattle and sheep initially using the sulphur hexafluoride (SF_6) tracer technique (Lassey et al., 1997; Ulyatt et al., 1999). In recent years, New Zealand-based research has used closed-circuit respiration chambers, which are considered the gold standard for assessing CH_4

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

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

[42] 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).

emissions from livestock. These have been used to derive respiration-chamber-based measurements of CH_4 emissions for sheep and, more recently, an expanded programme for dairy and beef cattle.

To obtain New Zealand-specific values (or algorithms for sheep emissions), all relevant published and unpublished New Zealand-specific data were collated and used to derive average values for CH_4 emissions from different categories of livestock (Clark et al., 2003; Swainson et al., 2016). 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 DMI)	21.6 × DMI	$21.977 \times DM^{0.765}$	$11.705 \times e^{0.5ME} \times DMI^{0.734}$
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: DMI = dry matter intake; Y_m = methane yield, ME = metabolisable energy.

The adult cattle value is applied to all dairy and beef cattle, irrespective of age. The value for deer is calculated based on the average value for adult cows and the (now defunct) CH_4 emission rate for adult ewes[43] (Clark et al., 2003). This is due to (i) a lack of country-specific data for deer and (ii) that their liveweights are around halfway between cattle and sheep, both of which have emission factors based on robust, country-specific research. No CH_4 emissions are assumed to arise from very young animals during the time that their diet only consists of milk.

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 each category) for dairy cattle, non-dairy (beef) cattle, sheep and deer. New Zealand experiences significant inter-annual variability in these IEFs, which is explained further in section 5.1.1. In table 5.2.3, *Milking dairy cattle* is a subset of *All dairy cattle* and only includes mature dairy cows that are being milked. *All dairy cattle* includes milking cows as well as calves, dairy bulls and other dairy cattle not being milked.

Table 5.2.3 New Zealand's implied emission factors for enteric fermentation from 1990 to 2021

Year	All dairy cattle (kg CH_4 per animal per annum)	Milking dairy cattle (kg CH_4 per animal per annum)	Non-dairy *(beef)* 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	59.5	75.1	51.0	10.0	17.6
1991	62.8	75.0	52.6	10.1	18.1
1992	63.5	78.8	53.4	10.1	18.8
1993	63.5	79.9	54.2	10.3	19.2
1994	62.1	81.8	54.7	10.5	19.0
1995	62.7	81.5	54.1	10.4	19.7
1996	65.6	82.5	55.9	10.7	19.9
1997	66.3	84.2	56.9	11.1	20.2

43 Value was used in earlier versions of the National Inventory Report (21.25 grams methane per kilogram dry-matter intake).

Year	All dairy cattle (kg CH_4 per animal per annum)	Milking dairy cattle (kg CH_4 per animal per annum)	Non-dairy *(beef)* 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)
1998	64.4	81.1	57.2	11.2	20.3
1999	64.8	80.2	55.7	11.1	20.5
2000	65.5	87.7	57.8	11.5	20.8
2001	65.7	89.4	58.8	11.6	20.7
2002	66.1	88.9	58.6	11.6	20.8
2003	69.7	87.8	58.2	11.5	20.8
2004	70.3	87.0	59.2	11.8	21.1
2005	70.8	84.9	59.8	11.8	21.5
2006	70.6	86.1	60.9	11.7	21.7
2007	69.2	86.1	60.1	11.6	21.8
2008	68.1	88.9	59.6	11.8	22.0
2009	68.9	89.8	59.0	12.0	22.2
2010	70.7	88.3	59.0	11.6	22.2
2011	71.3	92.0	59.8	11.9	22.4
2012	71.0	92.6	60.7	12.0	22.5
2013	73.3	92.1	59.7	11.9	22.2
2014	73.5	95.9	59.4	12.1	22.4
2015	74.7	92.3	60.1	12.1	22.5
2016	73.0	93.4	60.6	12.3	23.0
2017	75.5	91.3	60.2	12.3	22.9
2018	76.3	94.8	59.2	12.5	22.9
2019	77.4	94.9	59.8	12.5	23.4
2020	78.6	96.6	60.8	12.5	23.1
2021	79.4	97.0	60.0	12.5	23.0

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 fermentation* emissions in 2021. 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 2021, the goat population declined from 1,062,900 to 116,666. This was largely driven by a decrease in demand for goat fibre and meat. New Zealand uses a country-specific emission factor for goats for enteric fermentation of 7.4 kg CH_4 head^{-1} year^{-1} for 1990 and 8.5 kg CH_4 head^{-1} year^{-1} 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 2021, the emission factor is calculated based on the 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 (Burggraaf et al., unpublished). The emission factor in 2021 was calculated to be 9.0 kg CH_4 head^{-1} year^{-1}.

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. The country-specific emission factor for enteric fermentation (1.06 kg CH_4 head^{-1} year^{-1}) 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 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 representative 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 swine age classes and categories. Additionally, the average value of GEI was adjusted for population and further verified against national animal welfare standards.

The New Zealand emission factor for swine is lower than the IPCC (2006) default for developed countries.[44] The IPCC (2006) default value for swine is based on average values derived from 1980s Western German swine production and population statistics and is not representative of New Zealand swine systems. In particular, the default value 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^{-1} year^{-1}) is used to estimate emissions from this livestock category.

Llamas and alpacas: The IPCC (2006) default value (8 kg CH_4 head^{-1} year^{-1}) is used to estimate emissions from this livestock category.

Mules and asses: The IPCC (2006) default value is used (10 kg CH_4 head^{-1} year^{-1}) to estimate emissions from this livestock category.

5.2.3 Uncertainties and time-series consistency

To ensure consistency across emission categories, a single enhanced 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 data. Information on the uncertainties and time-series consistency for the livestock population data is included in section 5.1.4 and annex 3, section 3.1.

Methane emissions from enteric fermentation

Kelliher et al. (2009) calculated the uncertainty of enteric fermentation CH_4 emissions for sheep and cattle using a Monte Carlo approach. This superseded a previous analysis undertaken by Clark et al. (2003). The analysis expressed the coefficient of variation according to the

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

standard deviation of the CH_4 yield. Kelliher et al. (2009) calculated the uncertainty by expressing the coefficient of variation according to the standard deviation of the CH_4 yield using a larger sample of measurements (relative to the previous analysis). The analysis was restricted to 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 (see table 5.2.4).

Table 5.2.4 New Zealand's uncertainty in the annual estimate of enteric fermentation emissions for 1990 and 2021, 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)	Range of uncertainty (kt CH_4/annum)
1990	1,078.4	905.9	1,251.0	345.1
2021	1,114.4	936.1	1,292.7	356.6

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 very small proportion of total CH_4 emissions.

Uncertainty in the annual CH_4 estimate is dominated by variance in the measurements of the 'CH_4 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 (Clark et al., 2003).

5.2.4 Source-specific QA/QC control and verification

Methane from *Enteric fermentation* from *Dairy cattle*, *Non-dairy* (beef) *cattle* and *Sheep* was identified as a key category (level and trend assessment). Methane from *Enteric fermentation* from *Goats* is a key category in the trend assessment, and from *Deer* in the level 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 per animal 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 dairy 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 CH_4 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 all cattle, sheep and deer are Tier 2 and are based on the 2006 IPCC Guidelines (IPCC, 2006). Table 5.2.5 shows a comparison of the New Zealand-specific 2020 IEFs for enteric fermentation with the IPCC Tier 1 Oceania default value, the IPCC Tier 2 net energy-based value and the Australian-specific 2019 IEF for dairy cattle, beef 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, 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* (beef) *cattle* and *Sheep*

	Dairy cattle (kg CH_4/head/year)	Non-dairy (beef) 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 2020 value[45]	95.7	51.2 (pasture) 67.2 (feedlot)	6.7
New Zealand-specific IEF 2021 value	79.4 (all dairy cattle, including calves) 97.0 (mature milking cattle only)	60.0	12.5

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

Dairy cattle: New Zealand's 2021 IEF for all dairy cattle, including calves, is lower than the IPCC Tier 1 Oceania default value and the Australian-specific IEF. New Zealand's 2021 IEF for mature milking cattle is higher than the IPCC Tier 1 Oceania default value and the 2020 Australian-specific IEF.

Although New Zealand's predominantly pasture-based system is similar to Australian dairy cattle management, the lower IEF value could be explained by New Zealand's higher proportion of lower liveweight cattle breeds. The 2017 Australian dairy herd comprised 74 per cent Holstein; other breeds include Jersey, Brown Swiss, Ayrshire, the Australian Red and the Illawarra (DataGene Limited, 2018). In 2020, 49.6 per cent of New Zealand's cow population comprised a Holstein–Friesian/Jersey crossbreed, 32.5 per cent are Holstein–Friesian and 8.2 per cent are Jersey (LIC and DairyNZ, 2021).

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 2021 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* (beef) *cattle: The New Zealand-specific 2021 IEF for *Non-dairy* (beef) *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

45 As reported in volume 1 of Australia's National Inventory Report 2020 on greenhouse gas accounts (Commonwealth of Australia, 2022). Note that the Australian-specific beef cattle IEF value is calculated from a population-based weighted average of pasture and feedlot IEF values from beef cattle.

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 outdoor pastoral-based farming systems.

Sheep: New Zealand's 2021 IEF for sheep is higher than the IPCC Tier 1 default value and higher than the 2020 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 most lambs, 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 total annual enteric CH_4 emissions because emissions are calculated monthly, but it does not include the lamb population when estimating the IEF. This results in the 2021 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 2021 sheep IEF. The difference can be explained by the same rationale as put forward for cattle.

Verifying regional methane emissions using inverse modelling techniques

New Zealand has invested in developing country-specific methods and emission factors to estimate CH_4 emissions from ruminant animals, given their contribution to gross greenhouse gas emissions in the New Zealand inventory. Present CH_4 emissions can be robustly calculated from estimates of animal populations, DMI and emission factors, but it is challenging to verify the efficacy of mitigation technologies in the field. A possible solution is inverse modelling of emissions, based on atmospheric greenhouse gas measurements from a network of observing stations, combined with models that describe the pathway the air took before arriving at the station to infer regional to national greenhouse gas emissions or uptake. The inversion is conducted by taking all existing data, the initial estimates of regional CH_4 (a priori), observations and back trajectory modelling, to infer what the regional emissions of CH_4 were.

In Geddes et al. (2021), atmospheric inverse modelling was tested on regional and national emission estimates for 2011 to 2013 and 2018 using data collected from the National Institute of Water and Atmospheric Research observing stations at Lauder, Central Otago, and Baring Head, Wellington region. The emission estimates from this research are underpinned by several key resources: (i) an initial estimate of monthly CH_4 emissions and distributions; (ii) atmospheric CH_4 measurements at an inland and a background (baseline CH_4 levels) site; (iii) an atmospheric transport model that describes the pathway air took before arriving at the observing sites; and (iv) an inverse method that estimates the best combination of emissions to match the available data.

Due to the atmospheric observing network's insensitivity to North Island CH_4 emissions, calculated emissions for the South Island using the inverse model were more robust than North Island estimates. For the South Island, estimated emissions using this technique were found to be comparable with those reported using inventory methods and data. The analysis showed that the atmospheric observations are adding new information that can be used to validate and enhance the Agriculture inventory. The inverse approach has the potential to shed light on seasonal and inter-annual variability and detect emission changes.

The accuracy of these estimates will be improved by the addition of more observations, the installation of additional sites, and further quality control. An expansion of New Zealand's national CH_4 observing network from two to eight sites is under way through the CarbonWatch NZ research programme. Satellites could also be a useful adjunct to allow further analysis of historical emissions and to constrain emissions where ground-based measurements are challenging (Geddes et al., 2021). In 2019, New Zealand's Ministry of Business, Innovation and Employment signed on to collaborate on MethaneSAT, a state-of-the-art satellite designed to detect global CH_4 emissions. It is currently scheduled for launch in October 2023 and will provide a valuable tool alongside the atmospheric observing network.

A project is planned to establish regular reporting of regional CH_4 emissions using top-down approaches (see section 5.1.7 for more details) from both ground-based observations and satellites enabling quarterly estimates of regional CH_4 emissions across New Zealand. Any relevant data can be incorporated into the reports, with the ground-based inversion adapted to provide relevant intercomparison.

5.2.5 Source-specific recalculations

Emissions estimates in the *Enteric fermentation* category reported in the 2023 submission have been affected by methodological improvements to (i) estimates of within-year *Dairy cattle* population change and (ii) to feed quality values to account for the use of non-pasture feed supplements.

Improved estimates of within-year Dairy cattle population change

Emissions estimates in all categories relating to *Dairy cattle* reported in the 2023 submission have been enhanced by a methodological update to estimates of within-year *Dairy cattle* population change.

The inventory models the *Dairy cattle* population of each production year (1 July to the following 30 June). Livestock population data derived from the Agricultural Production Survey for animals present on 30 June of each year for each region are used as a baseline. The number of animals present each month for the remainder of the production year (July to June) is then based on assumptions on timing and number of deaths, culling to slaughter and birth dates (with assumptions applied at a national level), along with the number present on 30 June the following year. Each of the four stock classes has a different set of methods, timing and assumptions.

Recent research carried out by AgResearch (Burggraaf et al., 2022) has used industry data to improve inventory population dynamics. A focus was placed on sources with data from 1990 to the present, in line with the timeline required for national greenhouse gas reporting. The study recommended improvements to population dynamics based on long-term averages in birth, death and slaughter timing, combined with monthly data for each year for heifer exports.

The following recommendations from Burggraaf et al., (2022) were implemented in the 2023 inventory submission:

- changing the weighted average calving and birth date from 1 August to 13 August
- adding 1 per cent to the growing heifers (0–1 years) population from birth (August) and then gradually losing these additional calves to then reach the June Agricultural Production Survey value
- subtracting monthly dairy cattle exports from the growing heifers (1–2 years) population. Exports are assumed to come from the not-in calf and not-lactating heifers
- including a 1 per cent death rate for growing heifers (1–2 years) spread across the year
- retaining stock in the growing heifers (1–2 years) class until 1 July. Previously, stock were moved into the mature milking cow population in May

- using a 16.9 per cent mortality rate for the national mature dairy cow population, which includes provision for replacement cull animals
- using the long-term average monthly cull distribution to determine the proportion of the starting population of mature cows still present each month.

Additionally, a change has also been made to the liveweight of growing heifers within the *Dairy cattle* population. It was previously assumed that all dairy calves (growing heifers 0–1 years) are born on 1 August and have a birth weight equal to 9 per cent of an adult dairy cow weight. The weight of these animals was increased linearly until they were 638 days old, at which point their weight was assumed to be 90 per cent of an adult dairy cow's. After 638 days, they joined the class of mature milking cows and made an instantaneous jump in weight to the full mature dairy cow weight.

In the improved calculation, it is assumed that all dairy calves (growing heifers 0–1 years) are born on 13 August and have a birth weight equal to 9 per cent of an adult dairy cow weight. The weight of these animals increases linearly until they are 730 days old, at which point their weight is assumed to be that of a mature dairy cow.

Implementing the 2023 changes caused estimated emissions from the *Enteric fermentation* category to decrease by 0.6 per cent (167.4 kt CO_2-e) in 1990 and 1.3 per cent (374.1 kt CO_2-e) in 2020 (see table 5.2.6).

Table 5.2.6 Comparison of the previous dairy population model and the improved dairy population model for emissions from *Enteric fermentation*

Emissions (kt CO_2-e)		1990	2020	Change in emission outputs between 1990 and 2020 (kt CO_2-e)	Percentage change in emission outputs between 1990 and 2020 (%)
Total emissions from *Enteric fermentation* (kt CO_2-e)	2023 (1990–2021) emissions estimate using previous population model	27,127.8	28,529.4	1,401.6	5.2
	2023 (1990–2021) emissions estimate using new population model	26,960.4	28,155.3	1,194.8	4.4
	Difference in emissions estimates compared with current inventory	−167.4	−374.1	−206.8	–
	Percentage difference in emissions estimates (%)	−0.6	−1.3	–	–

Use of non-pasture feed

Emissions estimates for *Dairy cattle*, *Non-dairy* (beef) *cattle* and *Sheep* have been improved by a methodological update to account for the use of non-pasture feed supplements. Previously, the inventory assumed that cattle and sheep consume only pasture to satisfy their energy requirements.

A recent report by Sangster (2022) makes recommendations for adjusting the feed quality values used in the inventory to account for the use of non-pasture feed. Adjusted feed quality values are calculated using a weighted average dependent on the consumption of supplementary feed by livestock.

The Agriculture inventory requires feed quality data to calculate CH_4. For the purpose of calculating emissions from *Enteric fermentation*, the key component of feed quality is ME used to calculate DMI.

Sangster (2022) uses the pasture feed quality values recommended by Giltrap and McNeill (2020). These pasture feed quality values were implemented in 2021, replacing values from research completed in the early 2000s (Litherland et al., 2002 and Ian Brooks (pers. comm.)). The feed quality values used for non-pasture feed supplements have been recommended by Calvert (unpublished).

Activity data on the consumption of non-pasture feed by livestock are provided by DairyNZ (MPI, 2019) and AbacusBio (MPI, 2017, 2018).

The 10 most commonly used non-pasture feeds were included in the analysis. These account for 90 per cent of non-pasture feed consumed by dairy cattle in 2019. To reduce the complexity of the analysis, and in recognition of the uncertainty in the source data, less common feeds were aggregated and assumed to have the same feed quality as pasture.

Implementing these changes resulted in estimated emissions from *Enteric fermentation* decreasing by 1.0 per cent (258.6 kt CO_2-e) in 1990 and 1.4 per cent (397.8 kt CO_2-e) in 2020 (see table 5.2.7).

Table 5.2.7 Comparison of the pasture quality values and adjusted feed quality values for emissions from *Enteric fermentation*

Emissions (kt CO_2-e)		1990	2020	Change in emission outputs between 1990 and 2020 (kt CO_2-e)	Percentage change in emission outputs between 1990 and 2020 (%)
Total emissions from *Enteric fermentation* (kt CO_2-e)	2023 (1990–2021) emissions estimate using pasture quality values	27,219.0	28,553.0	1,334.0	4.9
	2023 (1990–2021) emissions estimate using adjusted feed quality values	26,960.4	28,155.3	1,194.8	4.4
	Difference in emissions estimates compared with current inventory	–258.6	–397.8	–139.2	
	Percentage difference in emissions estimates (%)	–1.0	–1.4		

5.2.6 Source-specific planned improvements

New Zealand is carrying out ongoing research to improve estimates of CH_4 emissions from *Enteric fermentation*. The projects described below outline research focused specifically on the *Enteric fermentation* reporting category of the Agriculture inventory, although several cross-cutting, broader projects that will improve the accuracy of emissions estimates in multiple categories (including *Enteric fermentation*, *Manure management* and *Agricultural soils*) are described in section 5.1.7.

Methane emissions from forage supplemented dairy cows

This project will determine CH_4 emissions, using several measurement techniques, from early to mid-lactation dairy cows grazing pasture and supplemented with graded levels of concentrate feeds. This new data will be combined with relevant existing data from New Zealand and international databases on CH_4 emissions from dairy cattle fed pasture plus supplements. This will be used to determine if CH_4 emissions differ between dairy cattle fed (i) pasture alone or (ii) pasture with supplementation.

Impact of pasture kikuyu content on enteric methane emissions

Kikuyu grass is dominant in pastures during summer and autumn in Northland and other coastal areas within the upper North Island of New Zealand due to its drought tolerance. Global warming is expected to increase and spread the dominance of Kikuyu grass further. Preliminary research has shown it to produce more CH_4 per unit of organic matter intake; however, this has not been tested in New Zealand. This research will compare the composition of kikuyu grass against the default values used in the inventory. It will also estimate how the management of this pasture affects CH_4 production potential, using in vitro and modelling approaches.

Integrative greenhouse gas evaluation of forages

Forage rape (*Brassica napus*) and plantain (*Plantago lanceolata*) have been identified as forages with the potential to reduce CH_4 emissions per unit of dry matter eaten, as well as reducing the direct and indirect N_2O emissions from urine patches. The effect of growing and grazing these forages on soil carbon stocks is largely unknown. While previous studies have identified some emission reduction potential from their use, these findings need to be integrated across all greenhouse gases and whole-year operations, to quantify their overall emissions reduction potential, including implications for soil carbon. These forages are used differently in farming practice: forage rape is a crop grown in cultivated ground and used over short periods as supplemental feed. In contrast, plantain is commonly used in pasture mixes with grasses and legumes throughout the year.

Improving information on feeding practices in dairy farming systems

This research will estimate the number of dairy cattle in different farm systems and the likely timing and difference in diets between 1990 and present. Typical farming systems used in the New Zealand dairy sector are outlined by DairyNZ.[46]

Development of a gene flow sub-model for sheep to account for low-methane rams

Research in New Zealand during the past two decades has proven that breeding sheep with lower CH_4 emissions per unit of DMI is feasible. This project aims to develop a deterministic gene flow model for the New Zealand sheep industry that uses industry genetics data to provide a set of outputs relating to wide-scale commercial farm changes and the potential distribution of low CH_4 genes throughout the sheep population.

Development of a national repository of relative genetic merit of New Zealand sheep

The successful implementation of a gene flow model requires genetic activity data. This research will modify an existing industry database to enable commercial farmers to update their associated CH_4 breeding values. This will include standardising the way CH_4 breeding values are recorded, developing conversion between existing metrics and standard metrics, and implementation of the database.

Improving emissions from minor animal categories

Emissions from minor animal categories (*Goats*, *Horses*, *Mules and asses*, *Swine*, *Poultry*, *Llamas and alpacas*) are currently estimated using a Tier 1 methodology, with a combination of country-specific and IPCC default emission factors. This research will review key data

46 See the 'Five Production Systems' at www.dairynz.co.nz/business/the-5-production-systems/, for more information.

sources and parameters currently used to estimate some minor animal populations and their emissions output by assessing these data sets against other readily available data. The research will also identify possible improvements to the estimation of minor animal populations and their emissions.

Research will also aim to better characterise the goat industry, especially the split between meat and dairy goats. An important step is to develop a multi-year population model that provides an accurate reflection of changes in the meat and dairy goat sectors over time.

5.3 Manure management (CRF 3.B)

5.3.1 Description

Most 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 in 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 (anaerobic conditions). 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 cumulative amount of CH_4 produced over the inventory year. When manure is handled as a solid or deposited directly on pastures, it tends to decompose under aerobic conditions and less CH_4 is produced overall.

Nitrous oxide emissions from managed manure occur directly through the processes of nitrification and denitrification of nitrogen contained in the manure. Nitrous oxide is 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 manure N_2O emissions produced depends on the system of waste management and the duration of storage. In New Zealand, most manure is deposited directly on pasture by grazing animals, with little going into manure management systems.

Methane from *Manure management* from *Dairy cattle* (level and trend assessment) was identified as a key category for New Zealand in 2021.

Manure management contributed an estimated 1,680.5 kt CO_2-e, representing 4.4 per cent of Agriculture emissions in 2021. Estimated emissions from this category consist of:

- CH_4 emissions (93.5 per cent of *Manure management* emissions)
- N_2O emissions (6.5 per cent of *Manure management* emissions).

In 2021, N_2O emissions from *Manure management* totalled 108.6 kt CO_2-e (0.3 per cent of gross emissions from the Agriculture sector) (see table 5.3.1). In comparison, the combined direct and indirect N_2O emissions from organic fertilisers (spreading of animal manure) and manure deposited directly by grazing livestock reported in the *Agricultural soils* category totalled 7,315.2 kt CO_2-e in 2021 (19.4 per cent of emissions from the Agriculture sector).

Table 5.3.1 Trends and relative contribution of methane and nitrous oxide emissions under the *Manure management* category between 1990 and 2021

Manure management category	Emissions (kt CO_2-e)		Change from 1990		Share of *Manure management* category (%)		Share of total Agriculture sector (%)	
	1990	2021	%	Difference (kt CO_2-e)	1990	2021	1990	2021
Methane (CRF 3.B.(a))	722.0	1,571.9	117.7	849.9	93.6	93.5	2.2	4.2
Nitrous oxide (CRF 3.B.(b))	49.7	108.6	118.4	58.9	6.4	6.5	0.1	0.3

Table 5.3.2 shows the distribution of livestock waste across animal waste management systems in New Zealand. The Agriculture inventory assumes all beef cattle, sheep and deer manure is deposited directly onto pasture (there are minor instances where this does not occur). A small amount of excreta from dairy cattle (7.3 per cent) is stored in anaerobic lagoon waste systems (Rollo et al., 2017). 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 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[47] (%)	Pasture, range and paddock[48] (%)	Solid storage and dry lot (%)	Other (%)
Dairy cattle[49]	7.5	–	92.5	–	–
Non-dairy *(beef)* cattle	–	–	100.0	–	–
Sheep	–	–	100.0	–	–
Deer	–	–	100.0	–	–
Goats	–	–	100.0	–	–
Horses	–	–	100.0	–	–
Swine[50]	20.5	25.7	8.9	42.5	2.4
Poultry – broilers[51]	–	–	4.9	–	95.1
Poultry – layers[52]	–	–	5.8	–	94.2
Poultry – other[53]	–	–	3.0	–	97.0
Alpacas	–	–	100.0	–	–
Mules and asses	–	–	100.0	–	–

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

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

49 Calculated using 2018 data.

50 Hill (2012).

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

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

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

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* (beef) *cattle*, *Sheep* and *Deer*). This approach is based on the methods recommended by Saggar et al. (unpublished) and is consistent with the 2006 IPCC Guidelines.

Because New Zealand has detailed information on the dairy cattle population and its characteristics (such as feed intake), the IPCC (2006) Tier 2 methodology for dairy anaerobic lagoons is used. The Tier 1 methodology New Zealand uses for estimating emissions from various manure management systems of 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.

The following equation is used to determine the monthly FDM output for each livestock category (*Dairy cattle*, *Non-dairy* (beef) *cattle*, *Sheep* and *Deer*):

$$FDM = DMI \times (1 - DMD)$$

Where: FDM is faecal dry matter (kg head^{-1} month^{-1})

DMI is dry-matter intake (kg head^{-1} month^{-1}), 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 CH_4 from *Enteric fermentation* 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., 2017). A Tier 2 methodology derived from the 2006 IPCC Guidelines (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^{-1} month^{-1})

ASH is the ash content of manure, 0.08 (IPCC, 2006, default value)

B_0 is the maximum CH_4-producing capacity of manure variable by species and diet, 0.24 (IPCC, 2006; Oceania default value, verified by Pratt et al., 2012)

0.67 is the conversion factor for converting methane from cubic metres to kilograms (IPCC, 2006)

MCF is the methane conversion factor, 0.76 (IPCC, 2006, table 10.17, default for uncovered anaerobic lagoon, average annual temperature 15 degrees Celsius, verified by Pratt et al., 2012)

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 varies from around 0.92 to 1.04 g CH_4/kg (Saggar et al., unpublished; Sherlock et al., unpublished).

Non-dairy* (beef) *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). No New Zealand studies have been completed on CH_4 emissions from deer manure. Further information on the calculation of the manure CH_4 emission factor for deer is contained in section 7.1.4 of the Agriculture inventory methodology (Pickering et al., 2022.

Methane emissions from minor livestock categories

Manure CH_4 emissions from the minor livestock categories are calculated per $head^{-1}$, using country-specific and IPCC default emission factors.

Swine: New Zealand uses a country-specific emission factor of 5.94 kg CH_4 $head^{-1}$ $year^{-1}$ (Hill, 2012) for estimating CH_4 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 were used (equations 10.23 and 10.24 in the 2006 IPCC Guidelines (IPCC, 2006)) to determine a country-specific manure management emission factor. Further information on this is provided 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 $head^{-1}$ $year^{-1}$; *Layer hens* 0.016 kg CH_4 $head^{-1}$ $year^{-1}$; and *Other*[54] 0.117 kg CH_4 $head^{-1}$ $year^{-1}$. 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 of the 2006 IPCC Guidelines (IPCC, 2006)). The emission factors are 0.20 kg CH_4 $head^{-1}$ $year^{-1}$ for *Goats*, 2.34 kg CH_4 $head^{-1}$ $year^{-1}$ for *Horses* and 1.10 kg CH_4 $head^{-1}$ $year^{-1}$ for *Mules and asses*. These are the IPCC values for temperate developed countries.

Llamas and alpacas: No IPCC default value is available for CH_4 emissions from manure management for *Llamas and alpacas*. The emissions are calculated by assuming that the CH_4 emission factor from manure management for *Llamas and alpacas* for all years is equal to the CH_4 manure management IEF for *Sheep* in 1990. The *Llamas and alpacas* emission factor (0.10 kg CH_4 $head^{-1}$ $year^{-1}$) is not indexed to sheep over time because there are no data indicating that alpacas have had the productivity increases over time 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 that 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 $head^{-1}$ $year^{-1}$

(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 are calculated from the nitrogen intake less the nitrogen retained through digestion and contained within 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 a Tier 3 model for determining DMI (Clark et al., 2003; section 5.1.3). Monthly values for the nitrogen content of feed are provided by Giltrap and McNeill (2020).

[54] *Other* poultry generally consists of ostrich and emus, hence the higher emissions per head.

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, as well as non-dairy (beef) 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 animal DMI in New Zealand since 1990. Nitrogen excretion rates are also affected by adverse weather events, which affect the amount of DMI and can cause large changes in productivity and N_{ex} rates in adjacent years (see section 5.1.1).[55]

Table 5.3.3 Nitrogen excretion rates (N_{ex}) for New Zealand's major livestock categories from 1990 to 2021

Year	Dairy cattle N_{ex} (kg/head/year)	Non-dairy *(beef)* cattle N_{ex} (kg/head/year)	Sheep N_{ex} (kg/head/year)	Deer N_{ex} (kg/head/year)
1990	82.1	65.6	13.7	25.2
1991	86.3	67.7	14.0	26.0
1992	86.9	68.8	13.9	26.9
1993	86.6	70.1	14.4	27.4
1994	84.8	70.7	14.6	27.1
1995	85.8	70.0	14.4	28.01
1996	88.8	72.6	15.0	28.3
1997	89.2	73.9	15.7	28.7
1998	86.9	73.9	15.8	28.7
1999	87.2	72.2	15.7	29.0
2000	87.3	74.8	16.4	29.4
2001	86.9	76.0	16.5	29.3
2002	87.1	75.6	16.5	29.3
2003	91.4	75.2	16.5	29.3
2004	91.6	76.4	17.0	29.6
2005	91.0	77.4	17.1	29.9
2006	89.7	78.8	16.8	30.0
2007	88.7	77.6	16.5	29.9
2008	87.5	76.9	16.8	30.0
2009	88.4	76.2	17.3	30.2
2010	90.1	76.1	16.7	30.2
2011	89.7	77.2	17.1	30.5
2012	89.0	78.3	17.4	30.5
2013	91.7	77.0	17.3	30.2
2014	91.7	76.7	17.6	30.4
2015	93.0	77.5	17.6	30.6
2016	91.2	78.2	18.0	31.2
2017	94.6	77.6	18.1	31.1
2018	95.5	76.4	18.3	31.2
2019	96.2	77.3	18.4	31.8
2020	97.5	78.4	18.5	31.4
2021	98.5	77.3	18.3	31.3

55 For full details of how nitrogen excretion 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/dmsdocument/13906-Detailed-methodologies-for-agricultural-greenhouse-gas-emission-calculation).

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 nitrogen (N) head^{-1} year^{-1} (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 from meat processors.

Goats: New Zealand uses country-specific N_{ex} rates for goats to estimate N_2O emissions of 10.6 kg N head^{-1} year^{-1} for 1990 and 12.1 kg N head^{-1} year^{-1} 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^{-1} year^{-1} for broiler birds and 0.42 kg N head^{-1} year^{-1} for layer hens. Ducks, turkeys and other poultry types, such as ostriches, make up around 1 per cent of New Zealand's poultry population, and flock sizes are unclear because they are reported by Stats NZ under 'other poultry'. Therefore, the value of 0.60 kg N head^{-1} year^{-1} 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 or mules and asses, and the default N_{ex} rate for Oceania of 0.3 kg N per 1,000 kg of animal mass per day is used (IPCC, 2006, table 10.19).

***Llamas and alpacas*:** Because there is no IPCC default N_{ex} rate for *Llamas and 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., 14.1 kg head^{-1} year^{-1}). The alpaca emission factor is not indexed to sheep over time because no data are available 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).

Table 5.3.4 Nitrogen excretion (N_{ex}) rates for New Zealand's swine and goats from 1990 to 2021

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	2006	11.9	10.7
1991	10.7	9.2	2007	11.9	10.8
1992	10.8	9.3	2008	12.0	10.8
1993	10.8	9.5	2009	12.1	10.8
1994	10.9	9.5	2010	12.2	10.8
1995	11.0	9.6	2011	12.3	11.0
1996	11.1	9.8	2012	12.3	11.0
1997	11.2	9.9	2013	12.4	11.1
1998	11.2	9.9	2014	12.5	11.3
1999	11.3	9.9	2015	12.6	11.4
2000	11.4	10.2	2016	12.7	11.3

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)
2001	11.5	10.5	2017	12.8	11.3
2002	11.5	10.2	2018	12.7	11.4
2003	11.6	10.1	2019	12.7	11.3
2004	11.7	10.5	2020	12.7	11.4
2005	11.8	10.6	2021	12.7	11.3

Direct nitrous oxide emissions from manure management

Major livestock categories: For the major livestock categories (*Dairy cattle*, *Non-dairy* (beef) *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 in 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 in 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 systems (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 in 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 in 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 10.21) 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 in 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 in 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: $N_{vol-MMS}$ 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 are 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 in 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	0.40
Daily spread	Swine (Hill, 2012)	0.07
Solid storage and dry lot	Swine	0.30
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 enhanced 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*. 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 instead for the *Manure management* CH_4 emissions uncertainty.

Uncertainties for the livestock characterisation are also discussed in section 5.1.4 and annex 3, section 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 emissions uncertainty (Giltrap et al., unpublished).

As above, uncertainties for the livestock characterisation are discussed in section 5.1.4 and annex 3, section 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 2021 level and 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 2021 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 2020 Australian-specific IEF for *Dairy cattle*, *Non-dairy* (beef) *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, 10.23 and 10.24).

New Zealand has lower IEFs for CH_4 from *Manure management* for beef 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 2020 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 *(beef)* cattle	Sheep
IPCC Tier 1 Oceania default value (average temperature 15°C (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 2020 value[56]	15.32	4.83 (pasture) 3.47 (feedlot)	0.34
New Zealand-specific IEF 2021 value	8.67 (all dairy cattle, including calves) 10.86 (mature milking cows only)	0.83	0.14

5.3.5 Source-specific recalculations

Emissions estimates in the *Manure management* category reported in the 2023 submission have been affected by a methodological improvement to estimates of within-year *Dairy cattle* population change and a methodological improvement to feed quality values, to account for the use of non-pasture feed. For more detail on these changes, see section 5.2.5.

The implementation of the 2023 changes to estimates of within-year *Dairy cattle* population change caused estimated emissions from the *Manure management* category to decrease by 2.4 per cent (19.3 kt CO_2-e) in 1990 and 1.8 per cent (30.3 kt CO_2-e) in 2020 (see table 5.3.7).

The inclusion of non-pasture feed reported in the 2023 submission caused estimated emissions from the *Manure management* category to increase by 1.2 per cent (9.3 kt CO_2-e) in 1990 and decrease by 1.4 per cent (24.8 kt CO_2-e) in 2020 (see table 5.3.8).

56 As reported in Australia's *Common Reporting Format 2022*. Retrieved from unfccc.int/documents/478998 (11 January 2023). Note that the Australian-specific beef cattle IEF value is calculated from a population-based weighted average of pasture and feedlot IEF values from beef cattle.

Table 5.3.7 Comparison of the previous dairy population model and the improved dairy population model for emissions from *Manure management*

Emissions (kt CO_2-e)		1990	2020	Change in emission outputs between 1990 and 2020 (kt CO_2-e)	Percentage change in emission outputs between 1990 and 2020 (%)
Total emissions from *Manure management* (kt CO_2-e)	2023 (1990–2021) emissions estimate using previous population model	791.0	1,716.6	925.6	117
	2023 (1990–2021) emissions estimate using new population model	771.7	1,686.3	914.6	119
	Difference in emissions estimates compared with current inventory	−19.3	−30.3	−11.0	
	Percentage difference in emissions estimates (%)	−2.4	−1.8		

Table 5.3.8 Comparison of the pasture quality values and the adjusted feed quality values for emissions from *Manure management*

Emissions (kt CO_2-e)		1990	2020	Change in emission outputs between 1990 and 2020 (kt CO_2-e)	Percentage change in emission outputs between 1990 and 2020 (%)
Total emissions from *Manure management* (kt CO_2-e)	2023 (1990–2021) emissions estimate using previous pasture quality values	762.4	1,711.1	948.6	124.4
	2023 (1990–2021) emissions estimate using adjusted feed quality values	771.7	1,686.3	914.6	118.5
	Difference in emissions estimates compared with current inventory	9.3	−24.8	−34.1	
	Percentage difference in emissions estimates (%)	1.2	−1.4		

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.

Review of the methane conversion factor and manure management systems activity data for dairy cattle

This project was undertaken to review the methane conversion factor (MCF) for the calculation of CH_4 from manure deposited in anaerobic lagoons from dairy cattle. The aim of this research was to review and, if deemed necessary, revise the MCF to a suitable New Zealand-specific value or values to improve the accuracy of dairy cattle manure CH_4 emissions.

This was completed in 2022 and will be implemented alongside the results of a project collecting data on the use of manure management systems, including effluent storage lengths and mitigation technology application.

Pork industry survey

This project will redesign and update a survey that was previously sent out to the New Zealand pork industry, with the purpose of improving the accuracy of the data used to estimate emissions from swine. A large portion of the new survey will focus on the use of manure management systems in the pork industry and will be designed in a way that ensures the results are compatible with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories as well as the 2019 Refinement (IPCC, 2006, 2019).

In the 10 years since the initial survey was taken, the swine industry has evolved and progressed to the point that the data currently used in the methodology no longer accurately reflect that of the industry. This survey will provide more up-to-date information, leading to a more accurate estimate of emissions. This survey has recently been completed and the final recommendations will be considered for the 2024 submission.

Updating data on the use of different manure and effluent management systems in New Zealand dairy farms

A nationwide farm survey of dairy manure and effluent management practices will be carried out to collect information, including effluent storage lengths, farm off-paddock structure use, effluent soils separation and frequency of emptying effluent storage ponds. Previous research to determine whether the MCF for *Dairy cattle* needed to be updated highlighted the importance of effluent storage and management in resulting emissions. This new information will be vital in determining whether New Zealand can reliably update the MCF for dairy cattle.

5.4 Rice cultivation (CRF 3.C)

5.4.1 Description

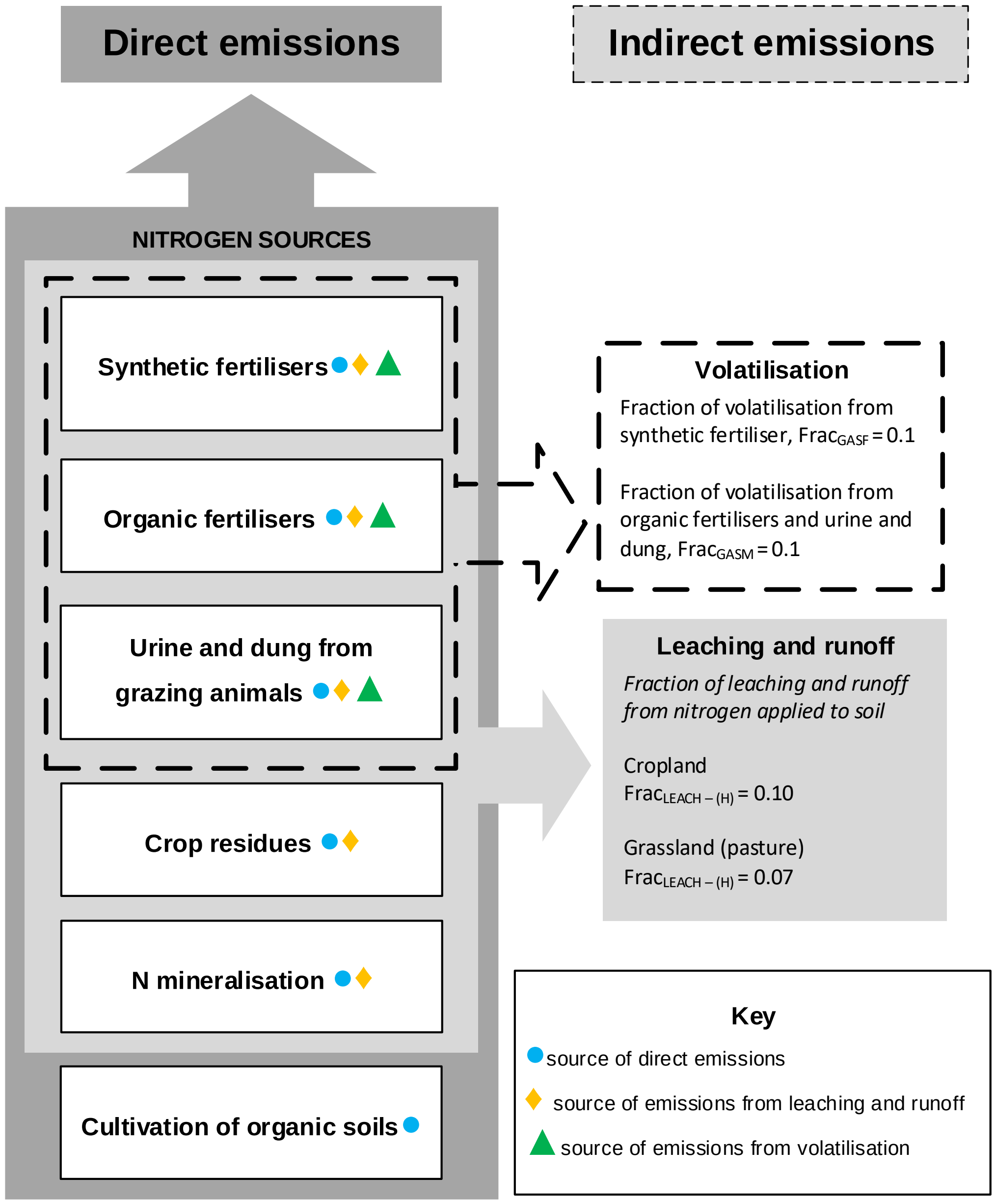
At present, there is no commercial rice cultivation in New Zealand. This has been confirmed with experts from Plant and Food Research, a New Zealand Crown research institute. The 'NO' (not occurring) notation is reported in the CRF tables.

5.5 Agricultural soils (CRF 3.D)

5.5.1 Description

Several categories contribute to N_2O emissions from *Agricultural soils* through 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 and organic fertilisers) or inorganic (synthetic nitrogen 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 within waterways.

Indirect emissions from livestock waste management systems are reported in section 5.3 (*Manure management*). Carbon dioxide emissions from lime and dolomite fertilisers are reported in section 5.8 (*Liming*), and CO_2 emissions from urea fertiliser are reported in section 5.9 (*Urea application*).

Agricultural soils contributed an estimated 7,315.2 kt CO_2-e, representing 9.5 per cent of New Zealand's gross emissions and 19.4 per cent of Agriculture emissions in 2021. The *Agricultural soils* category was the source of 92.2 per cent of New Zealand's total 2021 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): 48.0 per cent of emissions from *Agricultural soils*.
- Synthetic nitrogen fertiliser (level and trend assessment): 19.1 per cent of emissions.
- Volatilisation (level assessment): 11.7 per cent of emissions.
- Managed organic soils (level and trend assessment): 9.1 per cent of emissions.
- Leaching and runoff (level assessment): 7.6 per cent of emissions.
- Crop residues (level assessment): 3.5 per cent of emissions.

Trends

Emissions from *Agricultural soils* increased 40.2 per cent (2,098.3 kt CO_2-e) between 1990 and 2021. 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 from 1990 and 2021 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): 18.6 per cent (550.4 kt CO_2-e) increase.
- Synthetic nitrogen fertiliser (level and trend assessment): 507.4 per cent (1,168.6 kt CO_2-e) increase.
- Volatilisation (level assessment): 19.4 per cent (139.0 kt CO_2-e) increase.
- Management of organic soils (level and trend assessment): 1.3 per cent (8.7 kt CO_2-e) increase.
- Leaching and runoff (level assessment): 25.7 per cent (113.3 kt CO_2-e) increase.
- Crop residues (level assessment): 45.7 per cent (80.3 kt CO_2-e) increase.

Table 5.5.1 shows the trends and relative contribution of N_2O emissions from these categories between 1990 and 2021.

Table 5.5.1 Trends and relative contribution of nitrous oxide emissions from *Agricultural soils* categories between 1990 and 2021

Agricultural soils category		Emissions ($kt\ CO_2$-e) 1990	Emissions ($kt\ CO_2$-e) 2021	Change from 1990–2021 $kt\ CO_2$-e	Change from 1990–2021 %	Share of Agricultural soils category 2021 (%)	Share of total Agriculture sector 2021 (%)
Direct	Synthetic nitrogen fertilisers	230.3	1,398.9	1,168.6	507.4	19.1	3.7
	Organic fertilisers (animal manure spread on pasture)	35.8	73.8	38.0	106.2	1.0	0.2
	Pasture, range and paddock manure	2,959.6	3,510.0	550.4	18.6	48.0	9.3
	Crop residue	175.5	255.7	80.3	45.7	3.5	0.7
	Cropland nitrogen mineralisation from soil organic matter loss	0.0	0.1	0.1	287.5	0.0	0.0
	Management of organic soils	658.7	667.4	8.7	1.3	9.1	1.8
Indirect	Volatilisation	715.7	854.7	139.0	19.4	11.7	2.3
	Leaching and runoff	441.2	554.5	113.3	25.7	7.6	1.5
Total Agricultural soils		**5,216.8**	**7,315.2**	**2,098.3**	**40.2**	**100.0**	**19.4**

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 2006 IPCC Guidelines, 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; annex 3, tables A3.1.5, A3.1.6 and A3.1.7; 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 just over two thirds 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 synthetic fertiliser application (EF_1) and 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).

Recently, direct N_2O emission factors for dung and urine have been separated based on livestock type (for *Dairy cattle*, *Non-dairy* (beef) *cattle*, *Sheep* and *Deer*) and hill slope category based on research by Saggar et al. (2015) and van der Weerden et al. (2019, 2020) (see table 5.5.3). 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. Around 79 per cent of sloped land on sheep, beef and deer farms is classed as medium (12–24 degrees) or steep (greater than 24 degrees) sloped land (see annex 3, 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 emission 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 $EF_{3,PRP\text{-}URINE}$ for cattle, sheep and deer

Category		Emission factor		Source
3.D.1 Direct N_2O emissions				
Synthetic nitrogen fertiliser (urea)	$EF_{1\text{-}UREA}$	0.0059	kg N_2O-N/kg N	van der Weerden et al. (2016a, 2016b)
Organic fertiliser (dairy cattle manure)	$EF_{1\text{-}DAIRY}$	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	8.0	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	$EF_{3,PRP\text{-}MINOR}$	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	$EF_{3,PRP\text{-}DUNG}$	0.0012	kg N_2O-N/kg N	van der Weerden et al. (2019, 2020)
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 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, 2020)

Livestock type	Emissions factor by slope Flat and low sloped land (less than 12° gradient) $EF_{3,PRP\text{-}FLAT}$	Emissions factor by slope Medium and steep sloped land (greater than 12° gradient) $EF_{3,PRP\text{-}STEEP}$
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	Cropland $Frac_{LEACH-(H)}$	0.1	kg N/kg N	Welten et al. (2021)
	Grassland $Frac_{LEACH-(H)}$	0.08	kg N/kg N	Welten et al. (2021)
	Synthetic N fertiliser $Frac_{LEACH\text{-}(H)}$	0.082	kg N/kg N	Calculated based off of Welten et al. (2021)
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)	$EF_{3(PRP\text{-}DCD)}$	0.67	Clough et al. (2008)
Fraction of nitrogen from leaching and runoff with application of DCD	$Frac_{LEACH-(H)\text{-}DCD}$	0.53	Clough et al. (2008)
Volatilisation from synthetic nitrogen fertiliser coated with urease inhibitor (nBTPT)	$Frac_{GASF\text{-}UI}$	0.055	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})
- management 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. New Zealand commissioned research to review sources of organic waste and found that they are not of significant volume in New Zealand (van der Weerden et al., 2014). 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.

Van der Weerden et al., (2014) recommended a review of non-manure organic fertilisers within five years. A successful research proposal to undertake this review was received in 2022 and is currently under way (see section 5.5.6, for more detail).

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 (www.mpi.govt.nz/dmsdocument/13906-detailed-methodologies-for-agricultural-greenhouse-gas-emission-calculation).

Synthetic nitrogen fertiliser (CRF 3.D.1.1)

Anthropogenic N_2O emissions from synthetic nitrogen fertiliser are a relatively small proportion of total N_2O emissions, but have grown significantly since 1990. Most synthetic nitrogen fertiliser used in New Zealand is urea fertiliser applied to dairy pastures 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

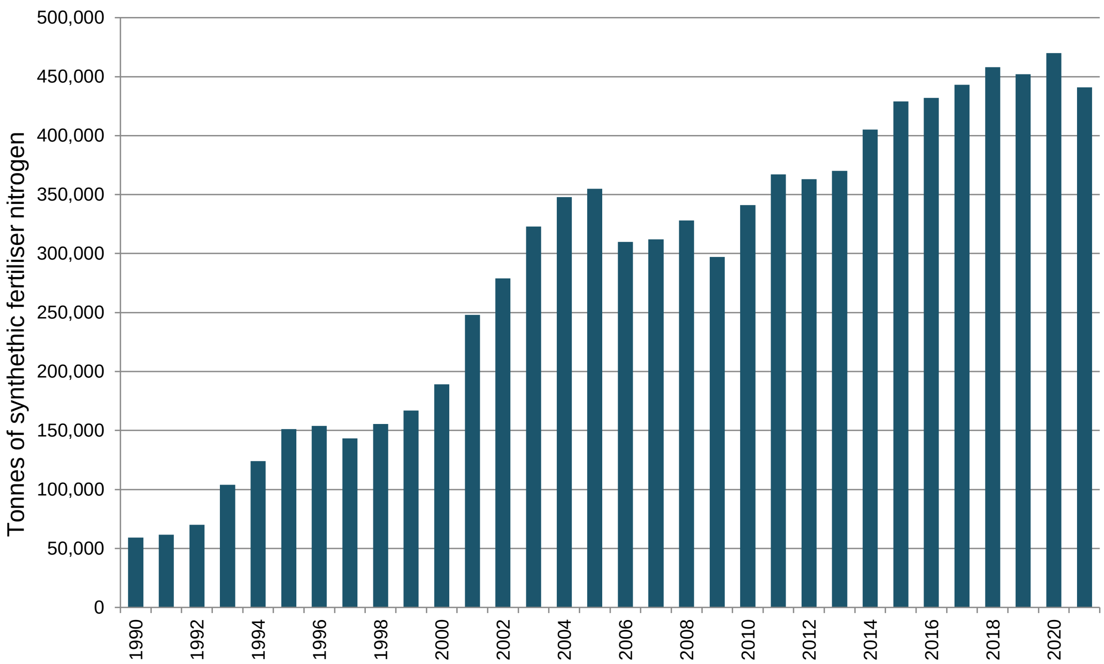
EF_1 is the proportion of direct N_2O emissions from nitrogen input to the soil (0.01; table 5.5.2).

Data on synthetic fertiliser use are provided by the Fertiliser Association of New Zealand from sales records from the two major fertiliser companies for 1990 to 2021, with estimates from smaller companies.

The $EF_{1(UREA)}$ value was changed to 0.0059 in 2017, following a recommendation from 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 around 0.5 per cent.

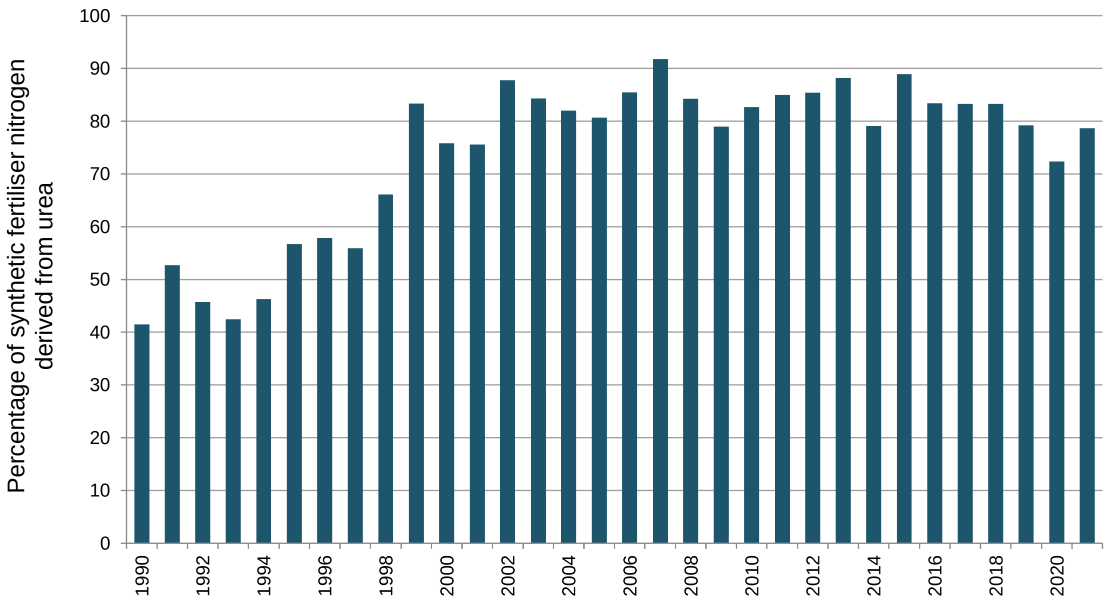
Since 1990, a large increase has occurred in nitrogen applied through synthetic fertiliser, from 59,265 tonnes in 1990 to 441,000 tonnes in 2021 (see figure 5.5.2). At the same time, the proportion of urea fertiliser applied has increased from just over 41.5 per cent to 78.7 per cent of all synthetic nitrogen fertiliser (see figure 5.5.3).

Figure 5.5.2 Synthetic nitrogen fertiliser use in New Zealand from 1990 to 2021



Source: Fertiliser Association of New Zealand

Figure 5.5.3 Percentage of synthetic nitrogen fertiliser derived from urea from 1990 to 2021



Source: 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 275.1 kt CO_2-e in 1990 (0.8 per cent of total Agriculture emissions) to 1,695.8 kt CO_2-e in 2021 (4.5 per cent of Agriculture 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. While most animal manure in New Zealand is excreted directly onto pasture, some manure from dairy farms is collected in manure management systems and applied to soils as an organic fertiliser (see table 5.3.2). A recent report by Rollo et al., (2017) found that only 8 per cent of dairy farms use land application of manure, with direct pumping from a sump. In all cases, manure that was collected was stored for least one or two days before spreading to pasture via irrigation. Therefore, it does not meet the definition of *daily spread* and the notation key 'NO' is reported in 3.B(b) of the CRF tables. The emissions calculation in this 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 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 recommendation from 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 0.0033 for flat and medium to steep sloped land respectively) and dung (0.0012) (van der Weerden et al., 2016a). Direct N_2O emissions from organic fertiliser (dairy cattle manure) in 2020 (using the EF of 0.0025) were 0.139 kt 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, N_{ex}, 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 nearly 0.025 per cent of national gross greenhouse gas emissions and, therefore, this category has been reported as 'not estimated' (NE). An updated analysis of the findings of this report is currently under way, and more information can be found in section 5.5.6.

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, or fed directly to stock.

Because most livestock manure in New Zealand is excreted directly onto pasture, emissions from the organic nitrogen fertilisers category are relatively small. In 2021, N_2O emissions from this source contributed 73.8 kt CO_2-e (1.0 per cent of emissions from *Agricultural soils*, and 0.2 per cent of total agricultural emissions). This is an increase of 38.0 kt CO_2-e (106.2 per cent) from the 1990 level of 35.8 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 beef cattle, sheep, deer and other livestock excreta deposited on pasture (see table 5.3.2). In New Zealand, dairy cattle are kept close to the milking shed and dairy farming tends to be on flatland. Sheep, beef and deer farming predominantly occur on hill country and rarely on flatland.

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:

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

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

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

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 is the population as calculated in section 5.1.3

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

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

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

$Nex_{URINE,STEEP}$ is the annual urinary N excretion per head deposited on steep slopes[60] (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).

For cattle, sheep and deer, the estimated N_{ex} values are separated into urine and dung components using the methodology outlined by Pacheco et al. (2018).

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

Urinary nitrogen 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 ($Nex_{URINE,FLAT}$), which is generally used for grazing dairy cattle.

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57 Flatland is classified as flat pastoral land or plains with a gradient lower than 12 degrees (i.e., equivalent to low slopes).

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

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

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

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

New EF_3 emission factors were incorporated in the 2020 inventory and are detailed in table 5.5.2 ($EF_{3(PRP\text{-}DUNG)}$) and table 5.5.3. These 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, 2020) 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 (see table 5.5.6):

- a statistically significant difference in urine emission factors between cattle and sheep
- that emissions from sheep, non-dairy (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 EF_3 emission factors for excreta deposited on sloped land

The meta-analysis (van der Weerden et al., 2020), built on a previous study by Kelliher et al. (2014), calculated new emission factors based on animal type, season, and slope. This was based on an expanded data set of 1,217 replicate-level emission factors from 236 field experiments conducted over the past decade, largely measured using the same standardised experimental methods for N_2O (see table 5.5.7).

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 land 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 by the van der Weerden et al. (2019, 2020) 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)
Beef cattle urine	8 (1)	40 (8)	60 (12)	20 (4)	128 (25)
Beef 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 by the van der Weerden et al. (2019, 2020) 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°)					
Beef 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
Beef 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 (0–12°)	20	8	8		36
	Medium slope (12–24°)	10	10			20
	Steep slope (>24°)	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, some of the arithmetic means were 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 (0.005)
- 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, nitrogen status 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 farmland 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 factors. When using these emission factors, the IEF for direct N_2O from dung and urine was 0.0054 in 2020. This value is comparable with that calculated for the United Kingdom (0.0037) and Australia (0.0040) in their respective inventory submissions in 2021.

Nitrous oxide emissions have not been measured 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, 2020).

To apply these emission factors, estimates of 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 farmland for each slope type, and accounts for animal behaviour where livestock spend relatively more time on lower slopes, and so deposit more excreta on these lower slopes. For more information on this model, please refer to annex 3, section 3.1.3.

The use of these revised EF_3 emission factors and the nutrient transfer model was recommended by the Agriculture Inventory Advisory Panel in late 2019.

Direct nitrous oxide emission factors for minor livestock types

Minor livestock types, including *Swine, Goats, Horses, Llamas and alpacas, Mules and asses,* 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 0.01, 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 2021, direct N_2O emissions from *Urine and dung deposited by grazing animals* (pasture, range and paddock manure from all livestock categories) contributed 48.0 per cent (3,510.0 kt CO_2-e) of emissions from *Agricultural soils*, or 9.3 per cent of total agricultural emissions. Emissions from this category have increased by 18.6 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 2021

	Emissions (kt CO_2-e)		Change from 1990–2021		Share of Agricultural soils category (%)		Share of total Agriculture sector (%)	
Livestock category	1990	2021	kt CO_2-e	%	1990	2021	1990	2021
Dairy cattle	1,123.5	2,101.1	977.5	87.0	21.5	28.7	3.4	5.6
Non-dairy *(beef)* cattle	745.9	780.7	34.9	4.7	14.3	10.7	2.2	2.1
Sheep	962.8	559.1	–403.6	–41.9	18.5	7.6	2.9	1.5
Deer	46.6	47.3	0.7	1.5	0.9	0.6	0.1	0.1
Minor livestock	80.8	21.8	–59.0	–73.0	1.5	0.3	0.2	0.1

Note: Percentages presented are calculated from unrounded values.

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

This emissions category includes emissions from nitrogen added to soils by above-ground 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 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 to increase farm productivity. The direct emissions from agricultural residue burning are reported in section 5.7.

New Zealand does not include an adjustment for crop residue removed for feed and bedding, which is assumed to be minor by Thomas et al. (2008) until such a time that appropriate activity data become available.

Nitrogen from crop residue: The non-nitrogen-fixing crops grown in New Zealand are barley, wheat, oats, potatoes, maize for seed, and other seed crops. From 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 Stats NZ 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 Stats NZ 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 Stats NZ 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 Stats NZ Agricultural Production Census and Survey, which include the area of grassland and annual crops from 1990 to 2021. 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 currently available.

The contribution of crop residues and pasture renewal to overall agricultural emissions is small, with 186.9 kt CO_2-e (0.6 per cent of total agricultural emissions) in 1990 and 272.3 kt CO_2-e (0.7 per cent of total agricultural emissions) in 2021.

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 (see chapter 6, 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 0.11 kt CO_2-e in 2021.

Cultivation (management) 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 managed 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 and cultivated organic soils in New Zealand in 2021 was 178,159 hectares, with 94.1 per cent of this area on grassland and 5.9 per cent on cropland. It is assumed that all of this area meets the definition of ‘managed’ for the purpose of estimating emissions. The estimate of managed organic soils on cropland and grassland is consistent with data and methodology used for the LULUCF sector. The total area of managed organic soils has increased slightly by 1.3 per cent (2,330 hectares) since 1990.

Emissions from organic soils are calculated using the Tier 1 methodology for all years of the time series by multiplying the area of managed organic soils by the default value of emission factor EF_2 of 8 kg N_2O-N/ha (IPCC, 2006).

In 2021, direct N_2O emissions from the management of organic soils contributed 9.1 per cent (667.6 kt CO_2-e) of emissions from *Agricultural soils*, or 1.8 per cent of total agricultural emissions). This is an increase of 1.3 per cent since 1990. Emissions from *Cultivation of organic soils* were identified as a key category (level and trend assessment).

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 (before application to land) is reported in 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 2021, N_2O emissions from volatilisation contributed 2.3 per cent (854.7 kt CO_2-e) to total Agriculture emissions, an increase of 19.4 per cent from the 1990 value of 715.7 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. The general equation is:

$$N_2O_L\ emissions = \frac{44}{28}(N_2O_L - N)$$

The following are specific equations used to calculate indirect N_2O emissions from nitrogen leaching for cropping systems, grassland and synthetic nitrogen fertilisers:

$$N_2O_L\ emissions\,(cropping\,systems) = \frac{44}{28} \cdot (F_{CR} + F_{SOM}) \cdot Frac_{LEACH-H(CROPPING)} \cdot EF_5$$

$$N_2O_L\ emissions\ (grassland) = \frac{44}{28} \cdot (F_{CR} + F_{ON} + F_{PRP}) \cdot Frac_{LEACH-H(GRASSLAND)} \cdot EF_5$$

$$N_2O_L\ emissions\ (synthetic\ N\ fertiliser) = \frac{44}{28} \cdot (F_{SN}) \cdot Frac_{LEACH-H(FERTILISER)} \cdot EF_5$$

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)

$Frac_{LEACH-H(CROPPING)}$ is the fraction of nitrogen added to, or mineralised from, cropping systems that is lost from soil through leaching and runoff (see table 5.5.4)

$Frac_{LEACH-H(GRASSLAND)}$ is the fraction of nitrogen added to, or mineralised from, grassland that is lost from soil through leaching and runoff (see table 5.5.4)

$Frac_{LEACH-H(FERTILISER)}$ is the fraction of nitrogen added to, or mineralised from, synthetic nitrogen fertiliser that is lost from soil through leaching and runoff, and

EF_5 is the IPCC (2006) default factor for N_2O emissions from leaching and runoff.

New Zealand uses differing $Frac_{LEACH}$ parameters that are dependent on the type of agricultural system the nitrogen has been applied to. These values were derived using measured values, as well as modelled values from OVERSEER®, a New Zealand-specific nutrient budgeting model. The $Frac_{LEACH}$ is 0.10 for nitrogen applied to cropland and 0.08 for grassland (Welten et al., 2021). The $Frac_{LEACH}$ for synthetic nitrogen fertiliser applied to grassland and cropland is 0.082. This is a weighted average based on recent data from Stats NZ (2022) indicating that this is applied at a 90:10 ratio to grassland and cropland. Data back to 1990 show minimal fluctuations in this ratio, however, it has been assumed that this remains static for the current inventory submission. Future inventory submissions may modify this $Frac_{LEACH}$ value if there is evidence the 90:10 ratio has changed.

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 farm dairy effluent or directly excreted by grazing animals). Dung and urine output from animals is calculated from the difference between nitrogen intake by grazing animals and nitrogen retained in animal products, such as milk, meat, wool and 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 empirical field measurements. In cropping systems, two years (previous and reporting) of monthly crop and management data are required for modelling NO_3 leaching in OVERSEER®, including nitrogen applied as fertiliser and effluent, as well as factors influencing or indicating the water content of soil, such as temperature, irrigation, rainfall, drainage and field capacity.

In 2021, N_2O emissions from leaching and runoff made up 1.5 per cent (554.5 kt CO_2-e) of total agricultural emissions, an increase of 25.7 per cent from the 1990 value of 441.2 kt CO_2-e.

Incorporation of nitrous oxide mitigation technologies into the Agriculture inventory

Urease inhibitors

The N_2O emissions reported in 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 for urease-treated urea fertiliser. This finding was based on field and laboratory studies conducted both in New Zealand and worldwide.

Indirect N_2O emissions from volatilisation from all synthetic nitrogen fertilisers (including urea and other nitrogen fertilisers, with and without urease inhibitors applied to the urea component) are calculated as shown below:

$$N_2O_{ATD-FSN}\ emissions = \frac{44}{28}(N_2O_{ATD-FSN} - N) = \frac{44}{28}\sum_{S}[F_{SN} \cdot Frac_{GASF}] \cdot EF_4$$

Where: $N_2O_{ATD\text{-}FSN}$–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 New Zealand in 2001. Activity data on urease inhibitor usage are provided by the Fertiliser Association of New Zealand from sales records.[61] These activity data record 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 2021 are shown in table 5.5.9. In 2014, 2016 and 2019, large increases occurred in the use of urease inhibitors. The percentage of urea fertiliser applied with urease inhibitor has for the first time passed 50 per cent in 2021.

Table 5.5.9 Mitigation impact of urease inhibitors on nitrous oxide emissions from volatilisation, from 2001 to 2021

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
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

61 Activity data on urease inhibitor usage before 2016 were 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)
2016	26.5	20.1
2017	27.8	21.6
2018	29.9	24.0
2019	35.5	26.8
2020	41.8	29.9
2021	50.1	36.7

Source: Fertiliser Association of New Zealand and Ballance Agri-Nutrients Limited

Nitrification inhibitor dicyandiamide

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 sales were suspended that year 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).

Limited research has been done into the effect of DCD on dung ($EF_{3(PRP\text{-}DUNG)}$); however, this research was inconclusive and further work needs to be carried out before incorporating the impact of dung emissions 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 0.0097 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 the Stats NZ Agricultural Production Survey that 2.9 per cent of the effective dairying area in New Zealand received DCD in 2012. The inhibitor is applied to pastures based on recommended 'good management practice' (either a slurry or DCD-coated granule) to maximise N_2O emission reductions. 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 dicyandiamide 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 for dairy cattle, $EF_{3(PRP)}$ (kg N_2O-N/kg N)	0.00971	0.00968	0.00972	0.00974	0.00972	0.00972
Final modified emission factor or parameter for dairy cattle, $Frac_{LEACH}$ (kg N_2O-N/kg N)	0.0695	0.0693	0.0695	0.0697	0.0696	0.0696
Mitigation (kt CO_2-e)	17.4	23.1	16.6	12.4	17.3	17.2

Note: $EF_{3(PRP)}$ = 0.0098 and $FRAC_{LEACH}$ = 0.10 for cropland and 0.08 for grassland 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 a nitrous oxide mitigation technology.

5.5.3 Uncertainties and time-series consistency

To ensure consistency in the calculations involving animal manure, a single enhanced 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 2021.

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) (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 2021 estimated using Monte Carlo simulation (1990, 2002), the 95 per cent confidence interval (2012) and the analytical method (2021)

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
2021	24.5	17.6	31.5

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. 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).

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 the Stats NZ 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 differences were evident 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. Nearly 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 (around 2 per cent). In contrast, the Agricultural Production Survey data are collected from a sampling frame of around 49,300 individual farms. Some farmers use contract fertiliser spreading companies (including aerial spreading) and may not have an accurate estimate of the tonnes of fertiliser applied or are unsure on how to fill in the questionnaire accurately, given the amount of different fertilisers used and their varying names. 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 due to the use of a country-specific emission factor for urea fertiliser and the incorporation of effect of urease inhibitors. For EF_3, the New Zealand value is also 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 2020 value	0.0034	0.0040
New Zealand-specific IEF 2021 value	0.0064	0.0053

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 2006 IPCC default and almost identical to that of Australia (0.11). Research showed that the 0.1 value was appropriate for New Zealand conditions (Sherlock et al., 2008).

This research also showed that the previously used 2006 IPCC 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 based on systems where a much higher percentage of manure management and storage is normal. Manure management and storage results 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 much lower values of $Frac_{LEACH-H}$. Research suggests that New Zealand applies a much lower rate of nitrogen fertiliser at each application than was assumed when the IPCC default value was developed (Thomas et al., 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, 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 2020 value	0.11	0.21	0.24
New Zealand-specific IEF 2021 value	0.1	0.1	0.10 (Cropland) 0.08 (Grassland) 0.082 (N Fert)

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

5.5.5 Source-specific recalculations

Emissions estimates in the *Agricultural soils* category reported in the 2023 submission have been affected by a methodological improvement to the $Frac_{LEACH}$ parameter used to calculate indirect N_2O emissions from nitrogen applied to agricultural soils.

Update to the $Frac_{LEACH}$ parameter

Previously, a uniform $Frac_{LEACH}$ value of 0.07 was used for all nitrogen applied to agricultural soils throughout New Zealand. In the 2022 inventory submission, research by Welten et al. (2021) was used to successfully disaggregate the $Frac_{LEACH}$ values into new values for nitrogen applied to cropping and grassland systems. This led to the current $Frac_{LEACH}$ value of 0.10 for cropping systems, while the value of 0.07 was retained for grassland systems. While an updated $Frac_{LEACH}$ value of 0.08 was recommended in the research for grassland systems, the Agriculture Inventory Advisory Panel, which scrutinises the suitability and robustness of inventory improvements, required further justification that the pasture quality values used in the modelling were consistent with those used in the Agriculture inventory.

Since the 2022 inventory submission, it was verified by Welten et al. (2021) that, while there were minor inconsistencies in pasture quality values between those used in OVERSEER® and the Agriculture inventory model, they had no impact on the research findings and the recommendation still stands. As such, the recommended $Frac_{LEACH}$ value of 0.08 for nitrogen applied to grassland has now been implemented.

While other sources of nitrogen could be defined as being applied exclusively to cropping or grassland systems, synthetic nitrogen fertiliser is applied to both. National data from Stats NZ (2022) indicated that around 90 per cent of all synthetic nitrogen fertiliser was applied to grassland systems, with the remaining 10 per cent applied to cropland. As the Agriculture inventory model does not currently distinguish the type of agricultural land that synthetic nitrogen fertiliser is applied to, a weighted average was used. Subsequently, based on the 90:10 split, a $Frac_{LEACH}$ value of 0.082 has been implemented for nitrogen applied via synthetic nitrogen fertilisers.

The implementation of this improvement caused estimated emissions from *Agricultural soils* to increase by 1.1 per cent (55.0 kt CO_2-e) in 1990 and 0.98 per cent (73.1 kt CO_2-e) in 2020 (see table 5.5.14).

Table 5.5.14 Comparison of the previous $Frac_{LEACH}$ values and the new $Frac_{LEACH}$ values on emissions from *Agricultural soils*

Emissions (kt CO_2-e)		1990	2020	Change in emission outputs between 1990 and 2020 (kt CO_2-e)	Percentage change in emission outputs between 1990 and 2020
Total emissions from *Agricultural soils* (kt CO_2-e)	2023 (1990–2021) emissions estimate using previous $Frac_{LEACH}$ values	5,161.8	7,469.9	2,308.1	44.7
	2023 (1990–2021) emissions estimate using new $Frac_{LEACH}$ values	5,216.8	7,543.0	2,326.2	44.6
	Absolute difference in emission estimates compared with current inventory	55.0	73.1	18.1	
	Percentage difference in emission estimates (%)	1.1	0.98		

Improved estimates of within-year Dairy cattle population change and use of non-pasture feed

Emissions estimates in the *Agricultural soils* category reported in the 2023 submission have been affected by a methodological improvement to estimates of within-year *Dairy cattle* population change and a methodological improvement to feed quality values to account for the use of non-pasture feed. For more detail on these changes, see section 5.2.5.

The implementation of the 2023 changes to estimates of within-year *Dairy cattle* population caused estimated emissions from the *Agricultural soils* to decrease by 0.85 per cent (44.8 kt CO_2-e) in 1990 and 1.1 per cent (83.6 kt CO_2-e) in 2020 (see table 5.5.15).

The inclusion of non-pasture feed in 2023 caused estimated emissions from *Agricultural soils* to decrease by 2.1 per cent (111.5 kt CO_2-e) in 1990 and 4.4 per cent (346.6 kt CO_2-e) in 2020 (see table 5.5.16).

Table 5.5.15 Comparison of the previous and improved dairy population model on emissions from *Agricultural soils*

Emissions (kt CO_2-e)		1990	2020	Change in emission outputs between 1990 and 2020 (kt CO_2-e)	Percentage change in emission outputs between 1990 and 2020 (%)
Total emissions from *Agricultural soils* (kt CO_2-e)	2023 (1990–2021) emissions estimate using previous population model	5,261.6	7,626.6	2,365.0	44.9
	2023 (1990–2021) emissions estimate using new population model	5,216.8	7,543.0	2,326.2	44.6
	Difference in emissions estimates compared with current inventory	–44.8	–83.6	–38.8	
	Percentage difference in emissions estimates (%)	–0.85	–1.1		

Table 5.5.16 Comparison of the pasture quality values and adjusted feed quality values on emissions from *Agricultural soils*

Emissions (kt CO_2-e)		1990	2020	Change in emission outputs between 1990 and 2020 (kt CO_2-e)	Percentage change in emission outputs between 1990 and 2020 (%)
Total emissions from *Agricultural soils* (kt CO_2-e)	2023 (1990–2021) emissions estimate using previous pasture quality values	5,328.3	7,889.6	2,561.3	48.1
	2023 (1990–2021) emissions estimate using adjusted feed quality values	5,216.8	7,543.0	2,326.2	44.6
	Difference in emissions estimates compared with current inventory	–111.5	–346.6	–235.1	
	Percentage difference in emissions estimates (%)	–2.1	–4.4		

5.5.6 Source-specific planned improvements

New Zealand is carrying out ongoing research to improve estimates of N_2O emissions from the *Agricultural soils* category. The projects described below outline research focused specifically on the *Agricultural soils* component of the Agriculture inventory, although several cross-cutting, broader projects will improve the accuracy of emissions in multiple categories (including *Enteric fermentation*, *Manure management* and *Agricultural soils*) that are described in section 5.1.7.

Nitrous oxide emissions from nitrogen fertilisers

This project will investigate whether more disaggregated emission factors for different types of nitrogen fertilisers are needed. The Agriculture inventory estimates direct N_2O emissions from the application of synthetic nitrogen fertiliser, and currently has separate emission factor (EF_1) values for urea and non-urea fertiliser. Field trials are under way to determine the difference in EF_1 values for different types of non-urea nitrogen fertilisers.

Measurements of nitrous oxide in spring and summer to develop EF_3 values that vary by season

The database used to produce country-specific N_2O EF_3 values is currently unbalanced, with 'summer' data representing only 11 per cent of the dataset and 'spring' data also being under-represented albeit to a lesser extent. A series of summer and spring-based N_2O EF_3 field studies across New Zealand will be conducted, with key soil and climate data also being reported on. This research will expand on the collection of the traditional set of soil and climate data to provide for future development of Tier 3 emission factors via process-based modelling of the dataset.

Improving organic soil activity data

This project will build on recently completed work assessing what is required so that New Zealand can implement the 2013 IPCC Wetland Supplement into the inventory (IPCC, 2014). The 2006 IPCC Guidelines (IPCC, 2006) are still used to estimate greenhouse gas emissions from managed organic soils, however, improved activity data and national emission factors are required to improve the accuracy of emissions accounting and reduce associated uncertainties.

Quantifying nitrous oxide emissions from eutrophic lakes

Eutrophic lakes are linked to nitrogen and/or phosphorous pollution from agriculture runoffs and wastewater discharge, with recent research showing much higher N_2O emissions from eutrophic lakes than was previously calculated based on N_2O production by bacteria. It is predicted that microalgae are responsible for this unexpected result. This project will aim to quantify N_2O emissions from a eutrophic lake due to microalgal activity to determine whether this is a significant source of emissions on a national scale. If this research demonstrates that there are significant N_2O emissions from eutrophic lakes, further research will be explored.

Inventory methodology for enhanced rock weathering

Enhanced rock weathering in an emerging negative emission technology and greenhouse gas mitigation tool. This has a large scope of application in New Zealand, considering the large deposits of silicate rock nationally and suitable agricultural land. This work aims to conduct an assessment of the availability and suitability of silicate rock deposits in New Zealand, while also complementing this with a gap analysis of other factors that require addressing before wider scale rollout as an effective greenhouse gas mitigation tool. It will also include a first draft of a New Zealand specific inventory methodology so that it could be recognised in future inventory submissions.

Review of nitrous oxide emissions from non-manure components of organic fertilisers

This research will provide a review and update of recommendations for N_2O emissions from non-manure components of organic fertilisers (van der Weerden et al., 2014). This includes identifying non-manure components of organic fertilisers applied to soil, estimating annual amounts of these components across the time series, and determining the suitability of the

IPCC default emission factor (EF_1) for estimating emissions from this source. It will also include a recommendation on whether non-manure organic fertiliser should be included in the national inventory or if continued use of 'NE' is justified.

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

Field burning of agricultural residues contributed an estimated 22.6 kt CO_2-e in 2021, which accounted for 0.06 per cent of Agriculture sector emissions. Emissions from *Field burning of agricultural residues* decreased 17.5 per cent (4.8 kt CO_2-e) between 1990 and 2021.

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).

Burning of agricultural residues was not identified as a key category in 2021.

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 considers differences in the available crop activity data between 1990 and 2004 and 2005 and 2016.

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 2019, to account for changes in the availability of activity data over these periods. Stats NZ did not collect data on crop residue burning before 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 Stats NZ 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) (Stats NZ 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 2021, calculation of the amount of biomass residue burned was based on information about the area of crop residue burning from the Stats NZ Agricultural Production Census and Surveys.

Biomass burned from 2005, 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 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 Stats NZ data for 2005 to 2007 (2005 being the first year Stats NZ gathered these data) and are, therefore, applied to the years 1990 to 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 and very wet 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 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 2020 were 40.6 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 2015 of 29.3 per cent, reflecting variations in annual weather patterns.

The country-specific values for these parameters are those from the OVERSEER® nutrient budget model for New Zealand (Wheeler et al., 2003) and are the same as those used for estimates of emissions from crop residues. This provides consistency between the two emissions estimates for crop residue and crop burning.

The proportion of residue 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. The Agriculture inventory also assumes that 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 (Thomas et al., 2008, 2011).

5.7.5 Source-specific recalculations

All activity data were updated with the latest available Stats NZ data.

5.7.6 Source-specific planned improvements

No improvements are currently planned.

5.8 Liming (CRF 3.G)

5.8.1 Description

Emissions from *Liming* (the application of limestone and dolomite) contributed an estimated 355.6 kt CO_2, representing 0.5 per cent of New Zealand’s gross emissions and 0.9 per cent of Agriculture emissions in 2021.

In New Zealand, lime and dolomite fertilisers are mainly applied to acidic grassland and cropland soils to reduce soil acidity and maintain or increase production of pasture and crops. Before the 2015 submission, emissions from lime and dolomite fertilisers were reported under chapter 6, LULUCF.

Liming was identified as a key category for the Agriculture sector in 2021 (level assessment).

Emissions from *Liming* increased 20.0 per cent (59.2 kt CO_2) between 1990 and 2021.

5.8.2 Methodological issues

Data on agricultural lime (limestone and dolomite) application are collected by Stats NZ, as a part of its five-yearly Agricultural Production Census and annual Survey 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.

New Zealand has not yet developed a country-specific methodology for calculating CO_2 emissions from the application of limestone and dolomite. Emissions from *Liming* are currently 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 and is extracted widely in New Zealand whereas dolomite is only available from a smaller, localised source. Activity data sourced from the Stats NZ Agricultural Production Census show 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). A correction factor of 0.82 is applied to the gross weight (tonnes) of lime use reported by Stats NZ. This correction factor is specified using research from Thomson et al. (2021) and accounts for impurities in the agricultural lime applied, as well the moisture content, so that emissions are based on the dry weight of calcium carbonate actually applied (see section 5.8.6).

Figure 5.8.1 Limestone usage on agricultural land in New Zealand from 1990 to 2021

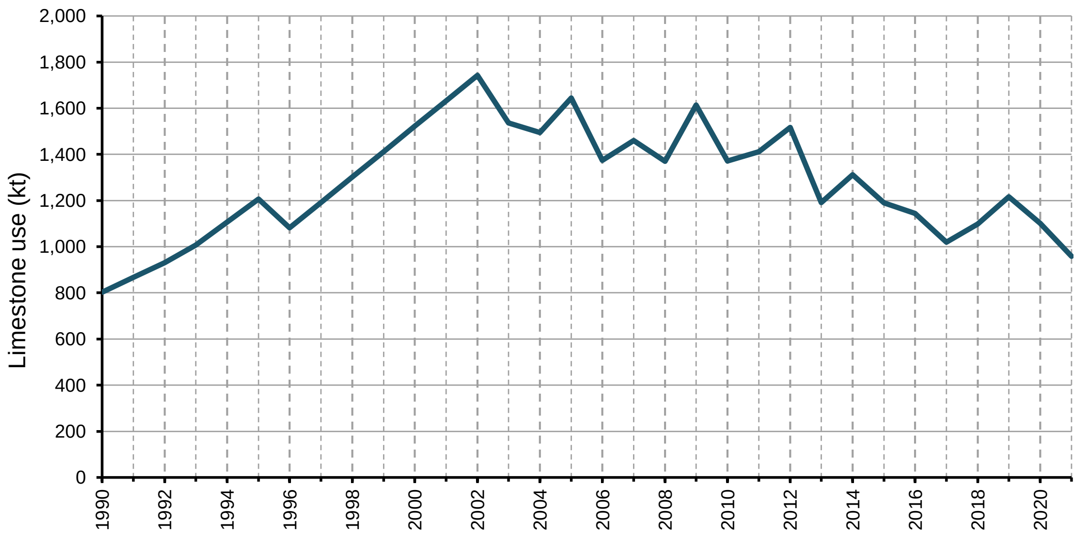
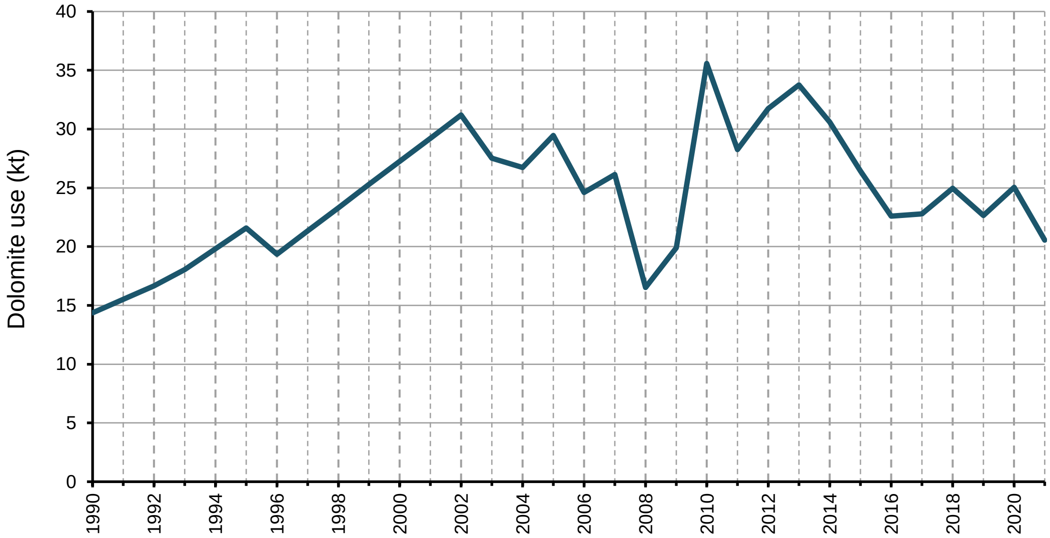


Figure 5.8.2 Dolomite usage on agricultural land in New Zealand from 1990 to 2021



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 carbon is not necessarily lost and that the emissions could be up to 50 per cent lower than estimated (IPCC, 2006).

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. Stats NZ, 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 recalculations have been performed for CO_2 emissions from *Liming* in the 2023 (1990 to 2021) submission.

5.8.7 Source-specific planned improvements

No 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 pastureland to boost pasture growth during the autumn and spring months.

Urea application was identified as a key category for the Agriculture sector in 2021 (level and trend assessment).

Urea application contributed an estimated 553.2 kt CO_2, representing 0.7 per cent of New Zealand's gross emissions and 1.5 per cent of Agriculture emissions in 2021.

Emissions from *Urea application* increased 1,311.4 per cent between 1990 and 2021. Since 1990, the proportion of urea fertiliser applied (relative to total synthetic nitrogen fertiliser use) increased from 41.5 per cent to 78.7 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 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 urease inhibitors do not reduce the release of CO_2 (S Saggar, pers. comm., 2014).

5.9.3 Activity data

Data on the volume of synthetic nitrogen fertiliser used are provided by the Fertiliser Association of New Zealand from fertiliser company sales records from 1990 to 2021. 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 were 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.

A large increase has occurred in nitrogen applied to agricultural land as urea fertiliser, from 24,586 tonnes in 1990 to 347,000 tonnes in 2021. This is consistent with the increase in the total amount of synthetic nitrogen fertiliser applied, which is 644.1 per cent greater than that used in 1990 (see reporting on the *Agricultural soils* category and figure 5.5.2).

5.9.4 Uncertainties and time-series consistency

Under the IPCC (2006) Tier 1 methodology, 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 carbon 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.

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 and provides this data to the International Fertilizer Industry Association.

5.9.6 Source-specific recalculations

No recalculations have been performed for CO_2 emissions from urea in the 2023 (1990 to 2021) submission.

5.9.7 Source-specific planned improvements

New Zealand will continue to update activity data 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

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

2021

In 2021, net emissions from the Land Use, Land-Use Change and Forestry (LULUCF) sector were –21,078.2 kilotonnes carbon dioxide equivalent (kt CO_2-e) or –27.4 per cent of New Zealand's gross greenhouse gas emissions. This comprises net removals of –21,358.2 kt CO_2, emissions of 32.6 kt CO_2-e of methane (CH_4) and 247.4 kt CO_2-e of nitrous oxide (N_2O). The category contributing the most to both removals and emissions is *Forest land remaining forest land*. This is because large removals result from the growth of all forests on this land and there are also large emissions from the sustainable harvest of New Zealand's plantation forests.

1990–2021

Net emissions in 2021 have decreased by 906.9 kt CO_2-e (4.5 per cent) from the 1990 level of –20,171.2 kt CO_2-e (see table 6.1.1 and figure 6.1.1). This is largely due to removals from forest growth and an increase in the production of harvested wood products, which have compensated for some of the emissions from the increase in forest harvesting.

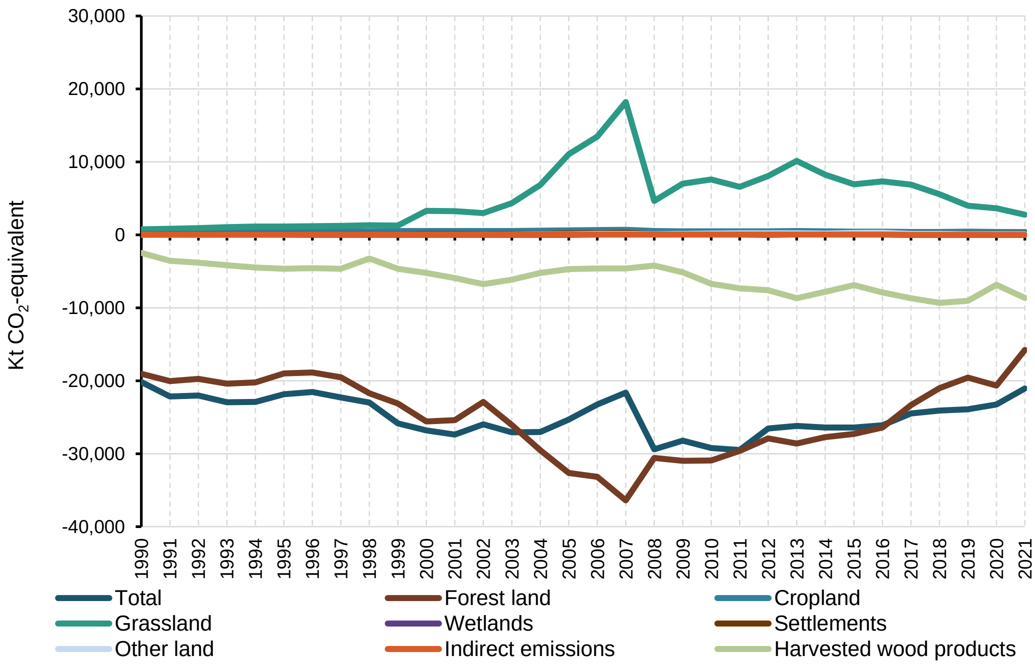
Table 6.1.1 New Zealand's greenhouse gas net emissions for the LULUCF sector by land use category in 1990 and 2021

	Net emissions (kt CO_2-e)		Difference (kt CO_2-e)	% change
Land use category	**1990**	**2021**	**1990–2021**	**1990–2021**
Forest land	–19,045.2	–15,779.7	3,265.5	17.1
Cropland	476.5	378.3	–98.2	–20.6
Grassland	756.8	2,744.3	1,987.5	262.6
Wetlands	–8.4	11.4	19.9	235.7
Settlements	75.7	122.2	46.5	61.4
Other land	13.8	85.7	71.9	522.5
Indirect emissions*	40.8	18.5	–22.3	–54.7
Harvested wood products	–2,481.2	–8,658.8	–6,177.6	–249.0
Total LULUCF	**–20,171.2**	**–21,078.2**	**–906.9**	**–4.5**

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.

* Indirect emissions as a result of N_2O emissions from leaching and runoff are not disaggregated by land use category in the common reporting format (CRF) tables and are reported separately under non-CO_2 emissions in section 6.10.4.

Figure 6.1.1 New Zealand's annual emissions from the LULUCF sector from 1990 to 2021



Emissions in the LULUCF sector are primarily driven 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 increase 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).

2020–2021

Net emissions from the LULUCF sector increased between 2020 and 2021 by 2,163.9 kt CO_2-e (9.3 per cent) (see table 6.1.2).

The largest change occurred in the *Forest land* category, with an increase in emissions of 4,882.0 kt CO_2-e. The reason for this change was an increase in harvesting of planted forests. The *Harvested wood products* category had the second-largest change, with a decrease in emissions of 1,824.3 kt CO_2-e, which was also driven by higher rates of harvesting.

Table 6.1.2 New Zealand's greenhouse gas net emissions for the LULUCF sector by land use category in 2020 and 2021

	Emissions (kt CO_2-e)		Difference (kt CO_2-e)	% change
Land use category	**2020**	**2021**	**2020–21**	**2020–21**
Forest land	–20,661.7	–15,779.7	4,882.0	23.6
Cropland	382.8	378.3	–4.5	–1.2
Grassland	3,628.1	2,744.3	–883.8	–24.4
Wetlands	11.2	11.4	0.2	1.8
Settlements	121.7	122.2	0.4	0.3
Other land	92.7	85.7	–7.0	–7.6
Indirect emissions*	17.7	18.5	0.8	4.6
Harvested wood products	–6,834.6	–8,658.8	–1,824.3	–26.7
Total LULUCF	**–23,242.0**	**–21,078.2**	**2,163.9**	**9.3**

Note: * Indirect emissions as a result of N_2O emissions from leaching and runoff are not disaggregated by land use category in the CRF and are reported separately under non-CO_2 emissions in section 6.10.4.

6.1.1 National circumstance

New Zealand has a land area of nearly 270,000 square kilometres with extensive coastlines (approximately 19,800 kilometres). This land mass is made up of two main islands, the North Island and South Island, as well as smaller outlying islands. New Zealand has a temperate climate, highly influenced by the surrounding ocean. Around 60 per cent of the land is hilly or mountainous, with 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).

Since 1990, approximately 9.6 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). 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 before European settlement remain across New Zealand (McGlone, 2009). For a summary of land use area in 2021 in New Zealand, see table 6.1.3.

New Zealand forests are either held on privately owned land or held in the publicly owned conservation estate (an area of approximately 8.5 million hectares; Ministry for the Environment and Stats NZ, 2018). Consequently, all forests in New Zealand meet the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines definition of managed land, which is "land where human interventions and practices have been applied to perform production, ecological or social functions" (IPCC, 2006a). Therefore, both forests planted for timber production and natural forests managed for conservation purposes are considered managed forests.

No timber is legally harvested from natural forests in the publicly owned conservation estate other than in exceptional circumstances where legislation allows. Most other harvesting of natural forests is required by law to be undertaken on a sustainable basis (Forests Act 1949).

Plantation forestry and agricultural 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.

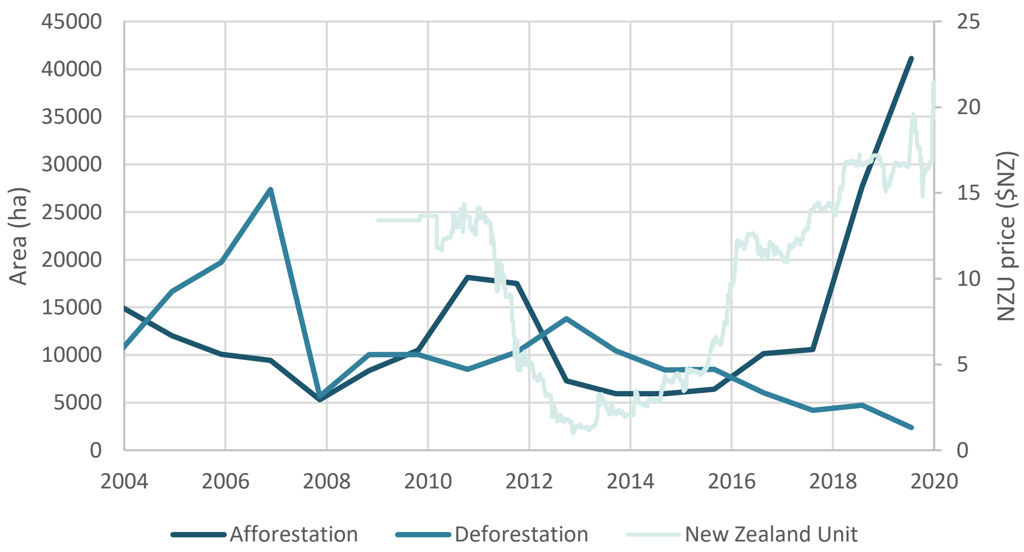
New Zealand's exotic forest plantation estate is intensively managed for production forestry, with rapid-growing genotypes selected and enhanced for optimum growth. Rates of afforestation, reforestation, harvesting and deforestation are strongly influenced by market conditions for harvested timber, competition for land use and introduced government policies. One such policy has been the introduction of the New Zealand Emissions Trading Scheme (NZ ETS) in 2008 and the inclusion of forestry within the scheme (Ministry for Primary Industries, 2015). The forestry component of the NZ ETS was included to encourage new forest planting and disincentivise deforestation. An unintended consequence of this policy was that large-scale deforestation occurred in 2007 (27,364 hectares) before the policy's introduction as land owners deforested to avoid potential future liabilities (see figures 6.1.1 and 6.1.2). Changes in afforestation and deforestation rates show they correlate strongly with fluctuations in the NZ ETS carbon price (figure 6.1.2). However, afforestation and deforestation rates are also impacted by other market conditions and other government initiatives, which are summarised in chapter 11, section 11.3.2.

Table 6.1.3 Land use in New Zealand in 2021

Category	Land use	Area (kha)	Proportion of total area (%)
Forest land	Pre-1990 natural forest	7,750.513	28.8
	Pre-1990 planted forest	1,437.783	5.3
	Post-1989 planted forest	733.805	2.7
	Post-1989 natural forest	95.163	0.4
	Subtotal	*10,017.264*	*37.2*
Cropland	Annual	371.235	1.4
	Perennial	105.493	0.4
	Subtotal	*476.728*	*1.8*
Grassland	High producing	6,903.017	25.6
	Low producing	6,273.573	23.3
	With woody biomass	1,361.332	5.1
	Subtotal	*14,537.922*	*54.0*
Wetlands	Open water	534.734	2.0
	Vegetated	223.511	0.8
	Subtotal	*758.245*	*2.8*
Settlements		238.242	0.9
Other land		896.683	3.3
Total		**26,925.085**	**100.0**

Note: Areas as at 31 December 2021. Columns may not total due to rounding. Percentages presented are calculated from unrounded values.

Figure 6.1.2 Comparison of afforestation and deforestation rates with the changing NZ ETS unit price from 2004 to 2020



6.1.2 Methodological tiers and coverage of pools applied in the LULUCF sector

New Zealand uses a combination of Tier 1, Tier 2 and Tier 3 methods, as described in the 2006 IPCC General Guidance and Reporting (IPCC, 2006b), 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 (SOC) changes from mineral soils. This model is described in more detail in annex A3.2.4 'Mineral soils'.

New Zealand's forests are disaggregated into four reporting categories to represent the different growth characteristics of the forest types more accurately: pre-1990 planted forest, pre-1990 natural forest, post-1989 planted forest and post-1989 natural forest. The terms 'post-1989' and 'pre-1990' distinguish between forests growing on land that was forested at 31 December 1989 and those growing on land that was not forested at that date. The terms 'natural' and 'planted' forest are used to identify whether the trees were established from natural regeneration or from managed planting. The term 'harvesting' refers to temporary forest loss as part of ongoing forestry land use, whereas 'deforestation' refers to permanent destocking of forest as a result of land-use change.

Similarly, the species compositions reported in the *Grassland* category are diverse, ranging from different grass types to woody trees that do not meet New Zealand's forest definition. To allow for this, the *Grassland* category is divided into four types for modelling the net emissions from land-use change.

Calculation of national emission estimates

The methods used to estimate carbon (C) by pool for each land use are summarised in table 6.1.4. Biomass carbon stocks in each land use before conversion, emission factors to estimate carbon stock changes and annual growth in biomass carbon stocks after land use conversion are summarised in the relevant category sections in this chapter. Activity data are estimated using wall-to-wall mapping from satellite imagery and other ancillary data sets and are described in more detail in section 6.2 and annex A3.2.1.

Table 6.1.4 Relationships between land use, carbon pool and method of calculation used by New Zealand

Reporting category	Living biomass		Dead organic matter		Soils	
					Soil organic matter	
Land use	Above-ground biomass	Below-ground biomass	Dead wood	Litter	Mineral soils	Organic soils
Pre-1990 natural forest	Plot measurements; allometric equations	Estimated as the ratio of below-ground biomass to above-ground biomass	Modelled from plot measurements; allometric equations	Plot samples; laboratory analysis of samples collected at plots	Tier 2, country-specific data and model	Not applicable
Pre-1990 planted forest	Modelled through allometric equations, then included in national yield tables	Estimated as the ratio of below-ground biomass to above-ground biomass	Allometric model using plot measurements, included in national yield tables. Harvest residues added to dead wood pool through CRA	Allometric model and percentage of above-ground biomass	Tier 2, country-specific data and model	IPCC Tier 1 default parameters
Post-1989 natural forest	Allometric model	Estimated as the ratio of below-ground biomass to above-ground biomass	Modelled from plot measurements; allometric model	Allometric model and percentage of above-ground biomass	Tier 2, country-specific data and model	IPCC Tier 1 default parameters
Post-1989 planted forest	Modelled through allometric equations, then included in	Estimated as the ratio of below-ground biomass to above-ground biomass	Allometric model using plot measurements, included in national yield tables. Harvest	Allometric model and percentage of above-ground biomass	Tier 2, country-specific data and model	IPCC Tier 1 default parameters

Reporting category	Living biomass		Dead organic matter		Soils	
					Soil organic matter	
Land use	**Above-ground biomass**	**Below-ground biomass**	**Dead wood**	**Litter**	**Mineral soils**	**Organic soils**
	national yield tables		residues added to dead wood pool through CRA			
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	Country-specific emission factor				Tier 2, country-specific data and model	IPCC Tier 1 default parameters
Grassland with woody biomass – permanent	Country-specific emission factor				Tier 2, country-specific data and model	IPCC Tier 1 default parameters
Wetlands – open water	IPCC Tier 1 default parameters (NE)				Tier 2, country-specific data and model	IPCC Tier 1 default parameters
Wetlands – vegetated	Country-specific emission factor		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	NE
Other land	IPCC Tier 1 default parameter (NE)				Tier 2, country-specific data and model	NE

Note: CRA = Calculation and Reporting Application; NE = not estimated. See the methodology sections for an explanation of soil carbon calculations (annex A3.2.4) and forest models, C_Change and Forest Carbon Predictor (annex A3.2.5).

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 (see annex A3.2.1)
- annual land use and land-use change area data from 1990 to 2021 (see section 6.2 and annex A3.2.2)
- biomass carbon stocks per hectare before land use conversion, and annual growth in biomass carbon stocks per hectare following conversion (described in more detail under each land use category)
- estimates of planted forest harvest area and harvest age class distribution (see section 6.3 and annex A3.2.5)
- a forest age profile for pre-1990 planted forests and post-1989 planted forests
- age-based biomass carbon yield tables for pre-1990 planted forests and post-1989 planted and natural forests (see section 6.3.2)
- growth increment for pre-1990 natural forest (see section 6.3.2)

- emission factors and country-level activity data on biomass burning (see section 6.10.8)
- 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

These calculations have been performed to produce estimates of annual carbon stock and carbon stock changes since 1990.

Note: New Zealand applies the 2006 IPCC Guidelines (IPCC, 2006a) default transition period of 20 years. The area of all land use categories is reported in the conversion status for 20 years, after which it is reported in the land remaining land categories.

New Zealand Land Use and Carbon Analysis System

New Zealand's LULUCF estimates are calculated using a program of data collection and modelling called the Land Use and Carbon Analysis System (LUCAS). This data management system stores, manages and retrieves data for international greenhouse gas reporting for the LULUCF sector. Further details on LUCAS, as well as the databases and applications it draws on, are provided in annex 3.2.9.

6.1.3 Uncertainties in LULUCF

Uncertainty for the LULUCF sector has been calculated as 67.6 per cent using the Approach 1 – propagation of error method as specified in volume 1, chapter 3 of the 2006 IPCC General Guidance and Reporting (IPCC, 2006b). Given this uncertainty, net emissions from the LULUCF sector could range from –6,832.8 kt CO_2-e to –35,359.6 kt CO_2-e. Table 6.1.5 shows the three 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 6.1.5 Land use categories making the greatest contribution to uncertainty in the LULUCF sector

Land use category	Uncertainty introduced into emissions for LULUCF (%)
Pre-1990 planted forest	± 55.5
Harvested wood products	± 28.0
Post-1989 planted forest	± 19.5

The greatest contribution of uncertainty to the LULUCF sector arises from 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. The uncertainty is calculated by combining the uncertainty of both the emissions from harvest and those from forest growth. This results in a high uncertainty relative to the net emissions estimate from both the carbon gains and losses.

Harvested wood products provide 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 (±68.2 per cent).

The third-greatest contribution of uncertainty to the LULUCF sector comes from the post-1989 planted forest in the *Forest land* category. The age structure of the post-1989 planted forest estate also results in large removals from growth and large emissions from harvesting. Because of the uncertainty in these two factors combined with the large scale of emissions and removals in this category, post-1989 planted forest makes a high contribution of uncertainty to the LULUCF sector.

Further information on uncertainties and the reasons for their relative contributions to the LULUCF sector, as well as details on emission factor and activity data uncertainties for specific land uses and non-CO_2 emissions are given within the relevant category sections of this chapter.

6.1.4 Recalculations in LULUCF

For the 2023 submission, New Zealand has recalculated its emissions estimates for the LULUCF sector from 1990 to 2020. The recalculations incorporate new activity data from deforestation mapping 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 5.0 per cent, and net emissions in 2020 have increased by 0.3 per cent (see table 6.1.6). The impact of these recalculations on net CO_2-e emissions in each land use category is provided in table 6.1.7.

Table 6.1.6 Recalculations to New Zealand's total net LULUCF emissions for 1990 and 2020

	Reported net emissions		Change in estimate	
Year	2022 submission (kt CO_2-e)	2023 submission (kt CO_2-e)	(kt CO_2-e)	(%)
1990	–21,229.2	–20,171.2	1,058.0	5.0
2020	–23,313.3	–23,242.0	71.2	0.3

Table 6.1.7 Recalculations to New Zealand's net LULUCF emissions for 1990 and 2020 by category

Land use category	Net emissions (kt CO_2-e) 2022 submission: 1990 estimate	2023 submission: 1990 estimate	2022 submission: 2020 estimate	2023 submission: 2020 estimate	Change in 1990 estimate (%)	Change in 2020 estimate (%)
Forest land	–20,068.3	–19,045.2	–19,704.7	–20,661.7	5.1	–4.9
Cropland	476.2	476.5	382.3	382.8	0.1	0.1
Grassland	724.7	756.8	2,570.2	3,628.1	4.4	41.2
Wetlands	–10.5	–8.4	13.4	11.2	19.4	–15.9
Settlements	75.4	75.7	124.1	121.7	0.3	–1.9
Other land	13.6	13.8	118.4	92.7	1.2	–21.7
Indirect emissions	40.8	40.8	17.7	17.7	0.0	–0.4
Harvested wood products	–2,481.2	–2,481.2	–6,834.6	–6,834.6	0.0	0.0
Total	**–21,229.2**	**–20,171.2**	**–23,313.3**	**–23,242.0**	**5.0**	**0.3**

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. Indirect emissions as a result of N_2O emissions from leaching and runoff are not disaggregated by land use category in the common reporting format (CRF) and are reported separately under non-CO_2 emissions in section 6.10.4.

The main differences between this submission and previous estimates of New Zealand's LULUCF emissions reported in the 2022 submission are the result of the changes made to the *Forest land* category. Note that *Forest land* contributes the greatest net emissions to the LULUCF sector and contributes the greatest uncertainty; therefore, inventory improvements to *Forest land* are generally prioritised.

The following three improvements are the main differences between this submission and the 2022 submission.

1. Improvements to the method used to estimate deforestation for unmapped years have led to an increase in the estimated deforestation area for 2020. The overall net impact of this change to the LULUCF sector is an increase of 209 kt CO_2-e in 2020. This improvement is also largely responsible for the 41.2 per cent increase in emissions reported in the *Grassland* category for 2020 (given most deforested land is converted to grassland) (for further detail, see section 6.3.5).
2. A range of modelling procedures has been improved to ensure consistency of treatment of harvesting and deforestation activities between pre-1990 and post-1989 planted forests. The overall net impact of this change to the LULUCF sector is a decrease of 106 kt CO_2-e in 2020 emissions and a decrease of 987 kt CO_2-e in 1990 emissions (for further detail, see section 6.3.6).
3. This submission uses country-specific above- and below-ground biomass carbon stocks for vegetated wetlands (Easdale et al., unpublished). Above-ground biomass carbon stocks were estimated as 20.22 tonnes of carbon per hectare (C ha^{-1}) (11.07–29.38, 95% confidence interval) and below-ground as 7.40 tonnes C ha^{-1} (1.85–12.9, nominal error range). Previous submissions used a value of 0 for the carbon stock and carbon stock change of vegetated wetlands, which meant any emissions and removals for land transitioning in to and out of this class were not estimated (for further detail, see section 6.6.5). The overall net impact of this change to the LULUCF sector is a decrease of 16 kt CO_2-e in 2020 and a decrease of 39 kt CO_2-e in 1990.

Detailed information on the recalculations is provided in the relevant source-specific recalculations sections below and in chapter 10.

6.1.5 LULUCF planned improvements

The LULUCF sector has a plan of continuous improvement and has introduced several improvements in this submission. Once a year, potential category-specific improvements are ranked in order of priority according to expert review team (ERT) recommendations, key category analysis and contribution to uncertainty in the sector. The improvement priority list is then compared with available resources and capability before a final improvements plan, for the current National Inventory Report and – in the case of the long-term improvements – for future national inventory reports, is agreed on.

Category-specific planned improvements for the 2024 and future submissions are reported separately under each of the relevant category sections of this chapter. The major themes are to:

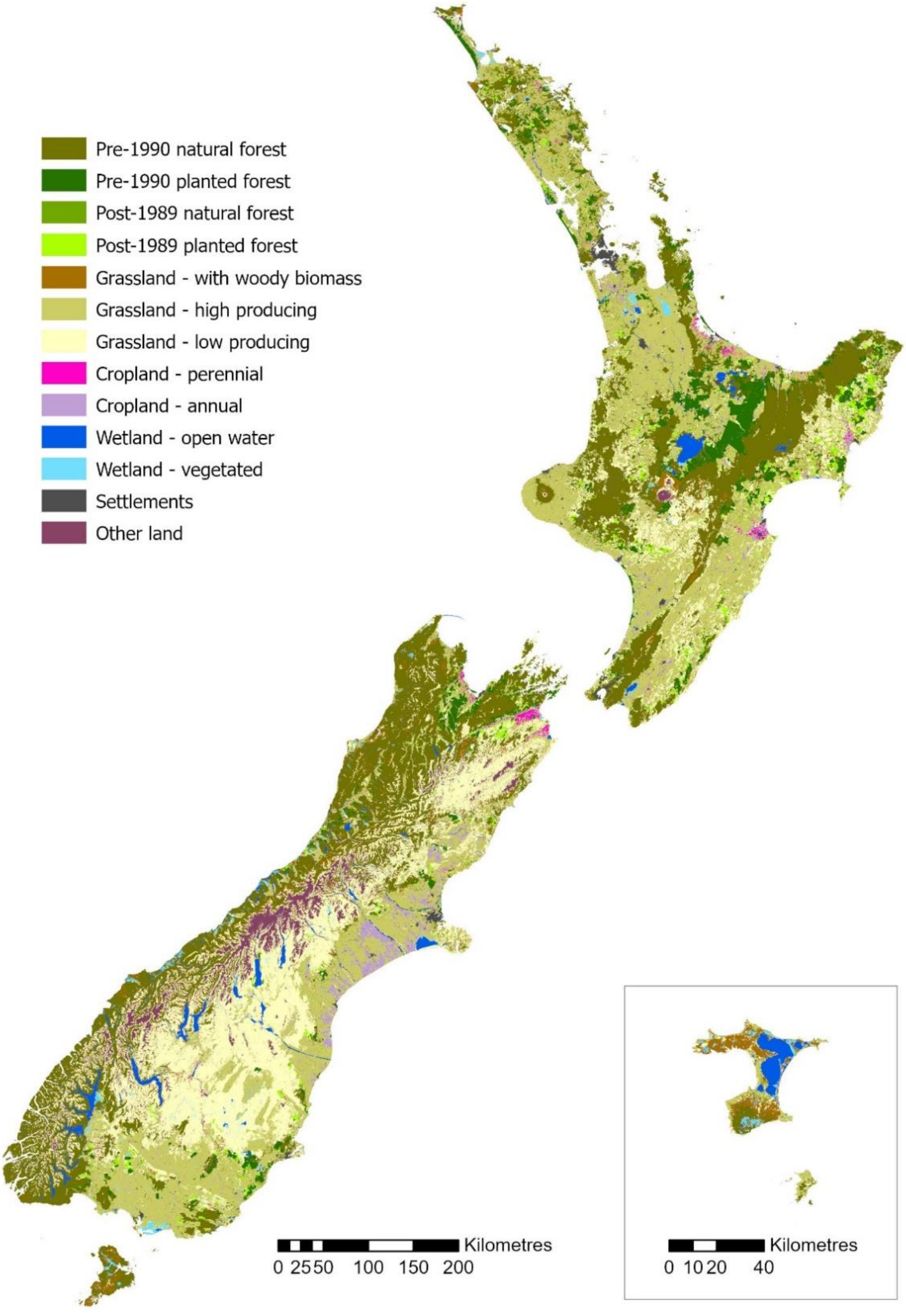
- continue with method development to implement the 2006 IPCC Guidelines (IPCC, 2006a)
- continue to re-measure the pre-1990 natural forest ground plot inventory on a continuous basis (on a 10-year cycle). The data collected to date from the third measurement cycle will be analysed and integrated into the 2024 submission
- continue to re-measure the complete planted forest plot network (pre-1990 and post-1989) on a continuous basis (on a five-year cycle). The data will be incorporated into the National Inventory Report as they become available
- produce a 2020 Land Use Map (due for completion by June 2023), which will be based on Sentintel-2 imagery acquired over the summer of 2020–21
- continue to improve land use mapping by using information collected through the 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
- incorporate research that refines the extent and identifies nutrient status and drainage depth of drained organic soils, as well as develops suitable emission factors for them, to enable the application of the 2013 *Wetlands* supplement
- improve the soil organic carbon (SOC) reference stock values for *Cropland* and *Grassland* through data being collected as part of a 12-year longitudinal study to measure the impact of management practices on agricultural soils
- use recently published New Zealand-specific half-lives and their associated uncertainty values for exported harvested wood products and those used domestically.

6.2 Representation of land areas

6.2.1 Description

New Zealand uses reporting Methods 1 and 2 and Approaches 2 and 3 to determine land-use changes occurring between 1 January 1990 and 31 December 2021 (section 2.2.4, IPCC, 2014). Areas of land use and land-use change between 1990 and 2016 are based on four wall-to-wall land use maps derived from satellite imagery at nominal mapping dates of 31 December 1989, 31 December 2007, 31 December 2012 and 31 December 2016 (see figure 6.2.1). Area information from these maps is interpolated and extrapolated to obtain a complete time series of land-use change occurring between 1990 and 2021 (see annex A3.2.2). Ancillary data – including aerial photography, additional satellite imagery, data from the NZ ETS and other national survey data – are used to support data interpolation and map production. Further information on the mapping methodology and imagery used, as well as the interpolation and extrapolation process to obtain a complete time series of land-use change occurring between 1990 and 2021 can be found in annex A3.2.2. Gross land use transitions before 1990 are estimated using a variety of different sources and following the methodology described in Watts (unpublished) and reviewed in Hunter and McNeill (unpublished), which is further described in annex A3.2.2. Applying this methodology allows for the land use transition matrix for the period 1962 to 1989 to be obtained (see table 6.2.1).

Figure 6.2.1 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.

Table 6.2.1 New Zealand's land-use change matrix from 1962 to 1989

		Forest land				Cropland		Grassland			Wetland		Settlements	Other land	Net area 31 Dec 1989 (kha)
1989	1962	Pre-1990 natural	Pre-1990 planted	Post-1989 planted	Post-1989 natural	Annual	Perennial	High producing	Low producing	With woody biomass	Open water	Vegetated	Settlements	Other land	
Forest land	Pre-1990 natural	7,777.1								42.6					**7,819.7**
	Pre-1990 planted	298.7	456.7						389.4	402.4					**1,547.2**
	Post-1989 planted														**0.0**
	Post-1989 natural														**0.0**
Cropland	Annual					325.0		21.0	8.9						**354.9**
	Perennial					0.9	58.7	5.0	4.5						**69.0**
Grassland	High producing	82.9				22.0	19.5	4,809.1	469.5	349.2		88.8			**5,840.8**
	Low producing	430.0							7,447.5	35.9					**7,913.4**
	With woody biomass	74.0							482.6	958.6					**1,515.2**
Wetland	Open water	14.4									512.7				**527.0**
	Vegetated											234.6			**234.6**
Settlements	Settlements	5.3				7.1	0.1	6.6	3.9	0.3			184.6		**207.9**
Other land	Other land													895.3	**895.3**
Area as at 1 Jan 1962 (kha)		**8,682.5**	**8,682.4**	**456.7**	**0.0**	**0.0**	**354.9**	**78.2**	**4,841.7**	**8,806.2**	**1,789.0**	**512.7**	**323.4**	**184.6**	**895.3**
Net change 1 Jan 1962–31 Dec 1989		**−859.7**	**−862.7**	**1,090.5**	**0.0**	**0.0**	**0.0**	**−9.2**	**999.1**	**−892.8**	**−273.8**	**14.4**	**−88.8**	**23.3**	**0.0**
Net change 1962–1989 (%)		**−9.9**	**−9.9**	**238.8**	**NA**	**NA**	**0.0**	**−11.7**	**20.6**	**−10.1**	**−15.3**	**2.8**	**−27.4**	**12.6**	**0.0**

6.2.2 Land use category definitions

The land use categories and matching land uses New Zealand reports for are shown in table 6.2.2.

Table 6.2.2 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 natural forest(1)
	Post-1989 planted forest(1)
Cropland	Annual cropland
	Perennial cropland
Grassland	High producing grassland
	Low producing grassland
	Grassland with woody biomass
Wetlands	Open water
	Vegetated wetland
Settlements	Settlements
Other land	Other land

Note: (1) Mapped as a single land use but stratified into 'post-1989 natural forest' and 'post-1989 planted forest' for calculating carbon stock and stock change 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* 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)
- a minimum forest width of 30 metres from canopy edge to canopy edge.

The definitions of New Zealand's land uses, as they have been mapped, are provided in table 6.2.3. 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 6.2.3 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, kānuka–mānuka (*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.

Land use	Definition
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 (assuming these will be replanted, unless deforestation is later detected) • roads, tracks, skid sites and other temporarily unstocked areas less than 30 metres in width associated with a forest land use • areas of bare ground of any size that were previously forested at 31 December 1989 but, due to natural disturbances (e.g., erosion, storms, fire), have lost vegetation cover.
Post-1989 forest	Includes post-1989 planted forest, which consists of: • exotic forest (with the potential to reach ≥5 metre height at maturity *in situ*) planted or established on land that was non-forest land as at 31 December 1989 (e.g., radiata pine, Douglas fir, eucalypts or other planted species) • riparian or erosion control plantings that meet the forest definition and that were planted after 31 December 1989 • harvested areas within post-1989 forest land (assuming these will be replanted, unless deforestation is later detected). Includes post-1989 natural forest, which consists of: • forests arising from natural regeneration of indigenous tree species as a result of management change after 31 December 1989 • self-sown exotic trees, such as wilding conifers or grey willows, established after 31 December 1989 (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.), kānuka–mānuka (*Leptospermum scoparium–Kunzea* spp.) 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

Land use	Definition
	• 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.
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 as described in volume 4, section 3.2 of the 2006 IPCC Guidelines (IPCC, 2006a).

6.2.3 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:

- updates to the extent of forest areas based on information from the NZ ETS and other forestry schemes, remapping of forest extent using deep learning techniques, and deforestation mapping
- review and correction of the mapping of *Other land* – in particular, implausible land-use changes involving *Other land*, such as *Other land* changing to *Perennial cropland*
- a small reduction in the total area of New Zealand (83 hectares) through the removal of some very small offshore islands that are well below the minimum mapping unit of 1 hectare.

6.2.4 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. Further information on QA/QC procedures specific to mapping can be found in annex A3.2.1.

6.2.5 Planned improvements

The 2020 land use map is due to be completed by June 2023. This map will be based on Sentinel-2 imagery acquired over the summer of 2020–21. It will provide another mapped data point in the time series and will include:

- annual mapped deforestation up to and including 2020
- sub-classification of pre-1990 natural forest into tall forest and regenerating shrubland areas
- all new land-use change occurring between 2016 and 2020 and identified in satellite imagery using change detection and deep learning methods
- improved mapping of wetland extent based on regional wetland mapping.

Following the production of this map, the plan is to complete an accuracy assessment of the map series with a focus on the accuracy of land-use change mapping.

6.3 Forest land (CRF 4A)

6.3.1 Description

In 2021, *Forest land* contributed –15,779.7 kt CO_2-e of net emissions. Net emissions from *Forest land* have increased by 3,265.5 kt CO_2-e (17.1 per cent) from the 1990 level of –19,045.2 kt CO_2-e (see table 6.3.1). Between 1990 and 2021, *Forest land* is the most significant contributor to carbon stock changes in the LULUCF sector. In 2021, forests covered 37.2 per cent (10.0 million hectares) of New Zealand's total land area. Note that emissions for the *Harvested wood products* category are reported separately within the CRF Reporter and are described further in section 6.9.

In 2021, *Forest land remaining forest land* and *Land converted to forest land* were key categories (based on a trend and level assessment).

Table 6.3.1 New Zealand's land-use change for the *Forest land* category, and associated CO_2-e emissions, in 1990 and 2021

Land use category	Net area as at 1990 (ha)	Net area as at 2021 (ha)	Net emissions (kt CO_2-e) 1990	2021	Change from 1990 (%)
Forest land remaining forest land	8,545,974	9,696,609	–677.9	–12,017.7	–1,672.7
Land converted to forest land	820,970	320,655	–18,367.2	–3,762.0	+79.5
Total	**9,366,944**	**10,017,264**	**–19,045.2**	**–15,779.7**	**+17.1**

Note: Net area in 1990 is as at 1 January 1990; net area in 2021 is as at 31 December. The area of *Land converted to forest land* includes land converted up to 20 years earlier, and net area values include land in a state of conversion (due to land-use change before 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.

New Zealand has applied the following parameters for land to be classified as *Forest land*:

- minimum area of 1 hectare
- potential to reach a minimum height of 5 metres
- potential to reach a minimum crown cover of 30 per cent
- a minimum forest width of 30 metres from canopy edge to canopy edge.

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. Note that New Zealand does not report linear shelterbelts under the *Forest land* category because they are not on land managed as forest. They form part of non-forest land uses, namely *Cropland* and *Grassland* (as shelter to crops and/or animals).

New Zealand uses four *Forest land* types: pre-1990 natural forest (predominantly native forest), pre-1990 planted forest (predominantly *Pinus radiata*), post-1989 planted forest and post-1989 natural forest (where post-1989 forests are those established after 31 December 1989). The definitions used for mapping these land uses are given in table 6.2.3.

Table 6.3.2 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).

Table 6.3.2 Change in land area and associated CO_2 emissions from carbon stock change between 1990 and 2021 for New Zealand's *Forest land*

Land use	Net area (ha) 1990	Net area (ha) 2021	Change from 1990 (%)	Net emissions (kt CO_2 only) 1990	2021	Change from 1990 (%)
Pre-1990 natural forest	7,819,749	7,750,513	–0.9	–1,373.5	–1,369.9	+0.3
Pre-1990 planted forest	1,547,195	1,437,783	–7.1	–18,059.9	–7,822.5	+56.7
Post-1989 planted forest	0	733,805		153.8	–6,083.9	–4,056.9
Post-1989 natural forest	0	95,163		3.8	–718.5	–19,200.1
Total	**9,366,944**	**10,017,264**	**+6.9**	**–19,275.9**	**–15,994.8**	**+17.0**

Note: NA = not applicable. Net area in 1990 is as at 1 January 1990; net area in 2021 is as at 31 December. Net area values include land in a state of conversion to forest (due to land-use change before 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 6.3.3 shows New Zealand's carbon stock change by carbon pool within the *Forest land* category from 1990 to 2021. Over this period, the total carbon stock stored in *Forest land* has increased by 214,548.4 kt C, equivalent to emissions of –786,677.5 tonnes CO_2 since 1990.

Table 6.3.3 New Zealand's net carbon stock change by carbon pool for the *Forest land* category from 1990 to 2021

	Net carbon stock change 1990–2021 (kt C)				Emissions 1990–2021
Land use	Living biomass	Dead organic matter	Soils	Total	(kt CO_2)
Pre-1990 natural forest	10,687.9	1,047.8	–135.3	11,600.3	–42,534.4
Pre-1990 planted forest	105,716.8	13,927.8	–4,239.4	115,405.2	–423,152.4
Post-1989 planted forest	83,462.3	13,523.1	–7,637.9	89,347.5	–327,607.5
Post-1989 natural forest	3,152.7	34.8	–666.8	2,520.7	–9,242.4
Total	**203,019.7**	**28,533.4**	**–12,679.5**	**218,873.6**	**–802,536.7**

Note: Emissions associated with the conversion of forest are reported in the land use category the land is converted to. Columns may not total due to rounding.

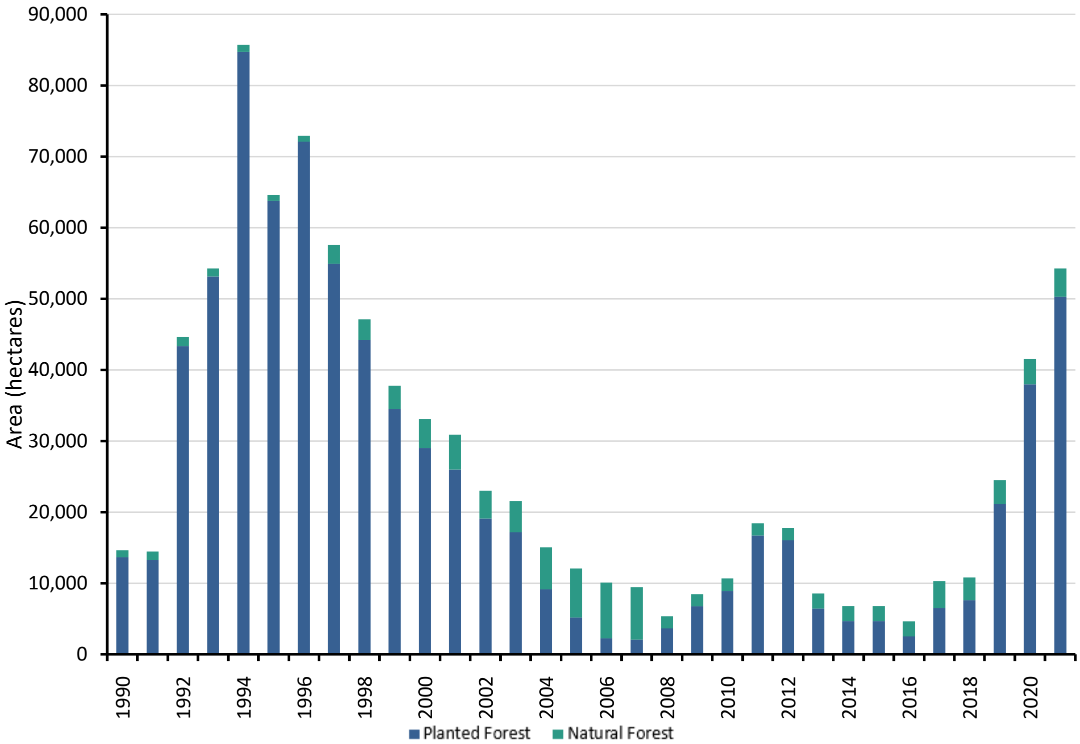
New Zealand's emissions profile in the LULUCF sector is predominantly influenced by plantation forestry. The rapid growth rates of plantation forest relative to natural forest, and the timing of afforestation and harvesting cycles drive the emissions profile and will continue to do so in the future.

6.3.2 Methodological issues

Afforestation/reforestation

Afforestation and reforestation areas of planted and natural forests are derived from a combination of land use mapping, national statistics and forestry scheme data. Annual rates of afforestation/reforestation are shown in figure 6.3.1 and are influenced greatly by market and policy conditions at the time, as described in section 6.1.1 and chapter 11, section 11.3.2. Further details on how the area of afforestation is calculated are provided in annex A3.2.2.

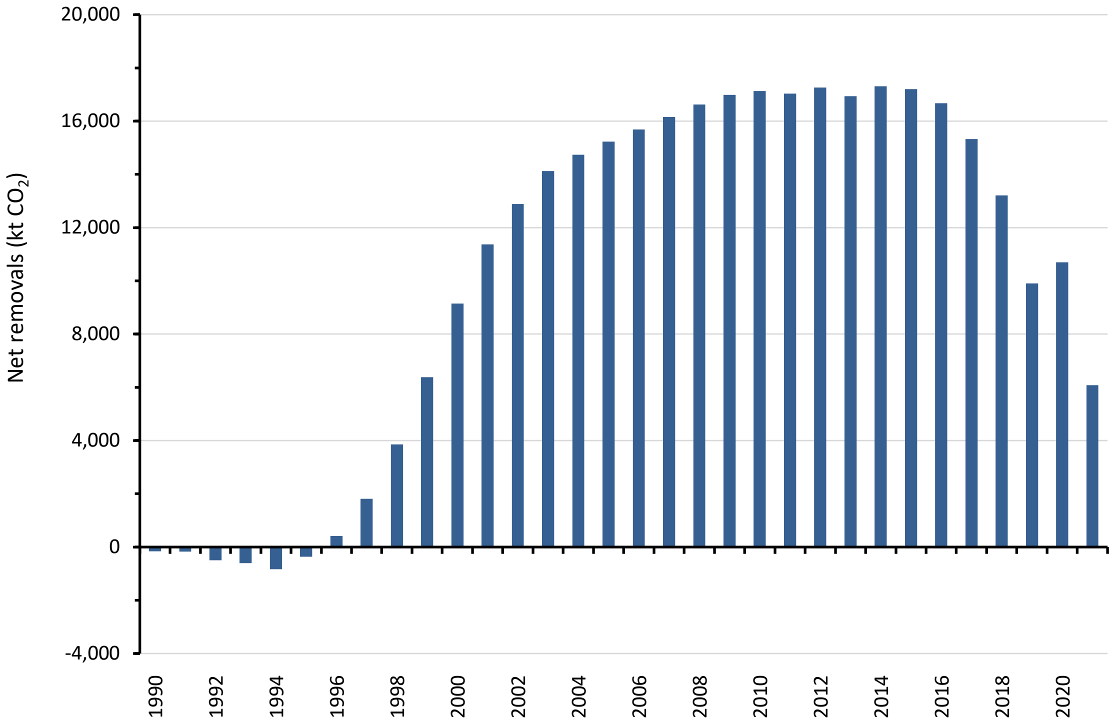
Figure 6.3.1 Annual areas of afforestation/reforestation in New Zealand from 1990 to 2021



Note: Details on how afforestation area is calculated are provided in A3.2.2.

Post-1989 planted forests did not become a net sink until 1996 (see figure 6.3.2), when net removals from forest growth surpassed net emissions. These emissions were due to the loss of biomass in carbon stocks associated with the previous land use before conversion, in addition to the loss of soil carbon associated with a land-use change to forestry.

Figure 6.3.2 New Zealand's net carbon dioxide removals by post-1989 planted forests from 1990 to 2021

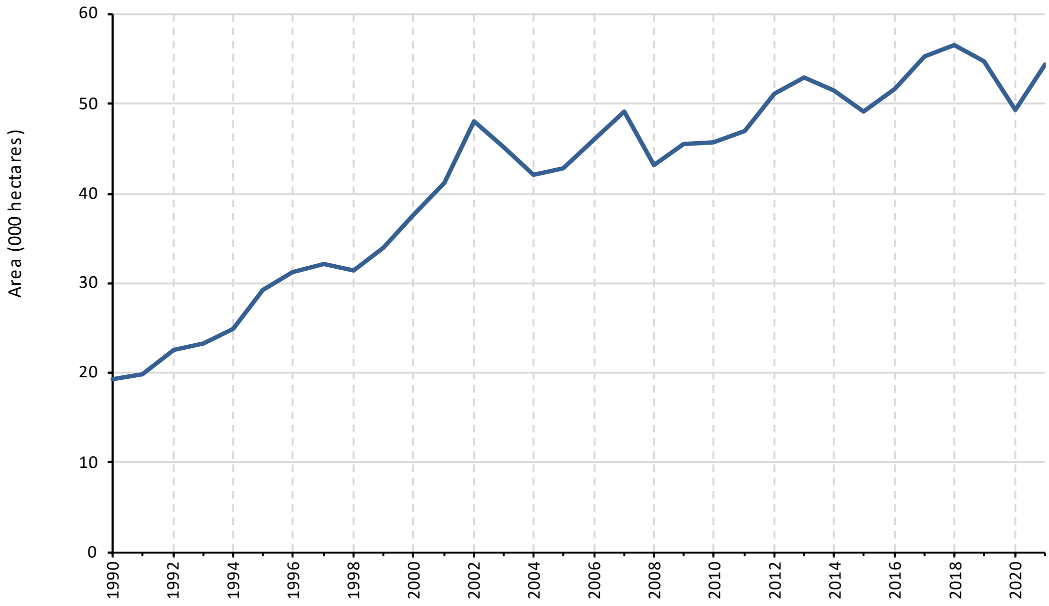


Harvesting

The annual planted forest harvest area (both pre-1990 and post-1989 planted forest combined) from 1990 to 2021 is shown in figure 6.3.3. The method used to calculate the harvest area is outlined in annex A3.2.5 'Calculation of harvest area'. Emissions from harvesting are dependent on the age of the forest being harvested. To accurately reflect the actual harvest ages that occur, and therefore the associated emissions, a harvest age profile is applied to the harvest area to determine the harvest area by age. Detailed methodology on how the harvest age profile is calculated for post-1989 planted forest and pre-1990 planted forest can be found in annex A3.2.5 'Calculation of harvest area by age and forest age profile', and addresses ERT recommendation L.17/FCCC/ARR/2019/NZL.

Only a minimal proportion of timber harvested is from the natural forest estate. In 2021, an estimated 0.03 per cent of New Zealand's total forest timber production was from the harvesting of natural forests (calculated from Ministry for Primary Industries, 2022a).

Figure 6.3.3 New Zealand's area of planted forest harvest (inclusive of deforestation) from 1990 to 2021



Deforestation

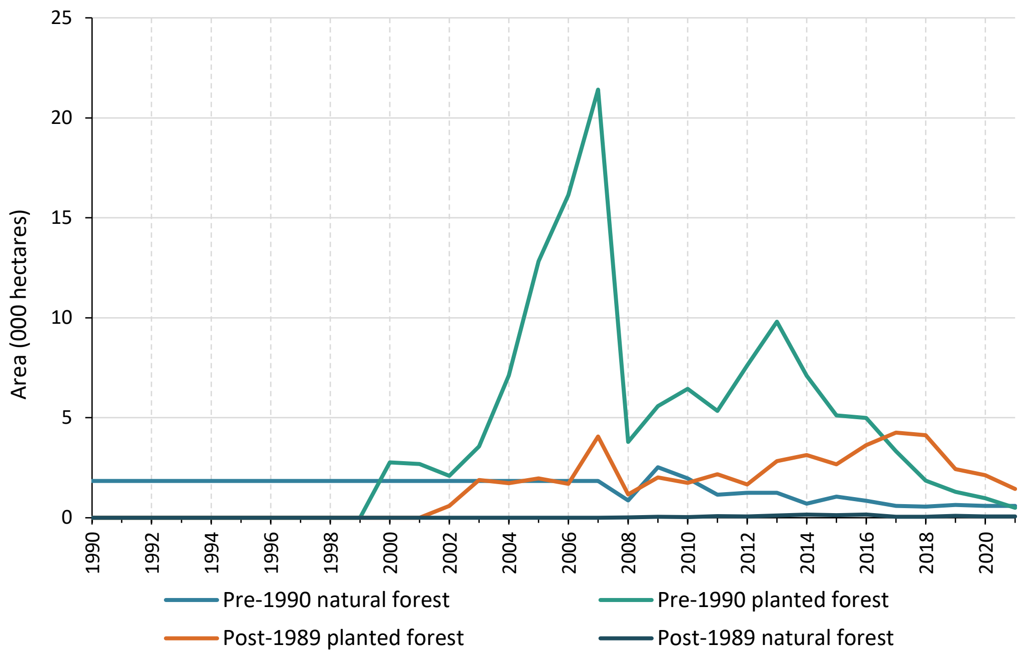
In 2021, an estimated 2,610 hectares of *Forest land* were converted to other land uses, primarily *Grassland*. Table 6.3.4 and figure 6.3.4 show the areas of *Forest land* subject to deforestation since 1990 and in 2021. Figure 6.3.4 also illustrates how planted forest deforestation increased leading up to 2008, and then decreased after the introduction of the NZ ETS in 2008.

Table 6.3.4 New Zealand's *Forest land* subject to deforestation, 1990 and 2021

		Deforestation since 1990		Deforestation in 2021	
Land use	Area of forest in 1990 (ha)	Deforestation since 1990 Area (ha)	Proportion of 1990 area (%)	Area (ha)	Proportion of 1990 area (%)
Pre-1990 natural forest	7,819,749	47,761	0.61	596	0.01
Pre-1990 planted forest	1,547,195	132,352	8.55	502	0.03
Post-1989 planted forest	0	47,347	NA	1,447	NA
Post-1989 natural forest	0	1,127	NA	65	NA
Total	**9,366,944**	**228,586**	**2.44**	**2,610**	**0.03**

Note: NA = not applicable. The 2021 areas are as at 31 December 2021; 1990 areas are as at 1 January 1990 and, therefore, differ from 1990 area values in the common reporting format (CRF) tables, which are as at 31 December 1990. Columns may not total due to rounding.

Figure 6.3.4 New Zealand's area of deforestation since 1990, by *Forest land* category



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 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 LCDBv5 using the 2008 map year, and these subcategories are defined in table 6.3.5. 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 in the calculations to be an instantaneous emission at the time of deforestation, as no information on the time lag of emissions from dead organic matter or below-ground biomass is currently available. Table 6.3.6 shows the areas of these two forest sub-classifications and table 6.3.7 shows the areas of pre-1990 natural forest deforestation split by these two forest types.

Table 6.3.5 Pre-1990 natural forest subcategories and description

Pre-1990 forest subcategories	Description
Tall	Made up of two LCDB classes: 1. Indigenous forest; tall forest dominated by indigenous conifer, broadleaved or beech species. 2. Broadleaved indigenous hardwoods; lowland scrub communities dominated by indigenous mixed broadleaved shrubs.
Regenerating	All other areas mapped as pre-1990 natural forest that fall outside the two LCDB classes above. Represents areas recovering from previous disturbances.

Table 6.3.6 Areas of tall and regenerating pre-1990 natural forest in 1990 and 2021

Pre-1990 forest sub-classification	Area of forest in 1990 (ha)	Area of forest in 2021 (ha)
Tall forest	6,688,054.7	6,666,490.4
Regenerating forest	1,131,694.0	1,084,022.2
Total	**7,819,748.6**	**7,750,512.6**

Table 6.3.7 New Zealand's areas of pre-1990 natural forest deforestation estimated by type from 1990 to 2021

Natural forest type	Area of natural forest deforestation (ha)									
	1990–2007	2008–13	2014	2015	2016	2017	2018	2019	2020[P]	2021[P]
Tall forest	8,674	3619	451	721	532	443	396	370	376	376
Regenerating	24,489	5390	249	339	318	148	162	269	220	220
Total	**33,163**	**9,009**	**700**	**1,060**	**850**	**591**	**557**	**639**	**596**	**596**

Note: P = provisional figure (figures for 2020–21 are provisional). Columns may not total due to rounding.

Estimates of biomass burning emissions associated with deforestation are provided in section 6.10.8.

Deforestation emissions are reported in the relevant *Land converted to* category, as are all emissions from land-use change.

National Forest Inventory

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 6.3.5 and 6.3.6 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. A further description of the plot network can be found in annex A3.2.5 'National forest inventory'.

Figure 6.3.5 Location of New Zealand's pre-1990 forest carbon monitoring plots

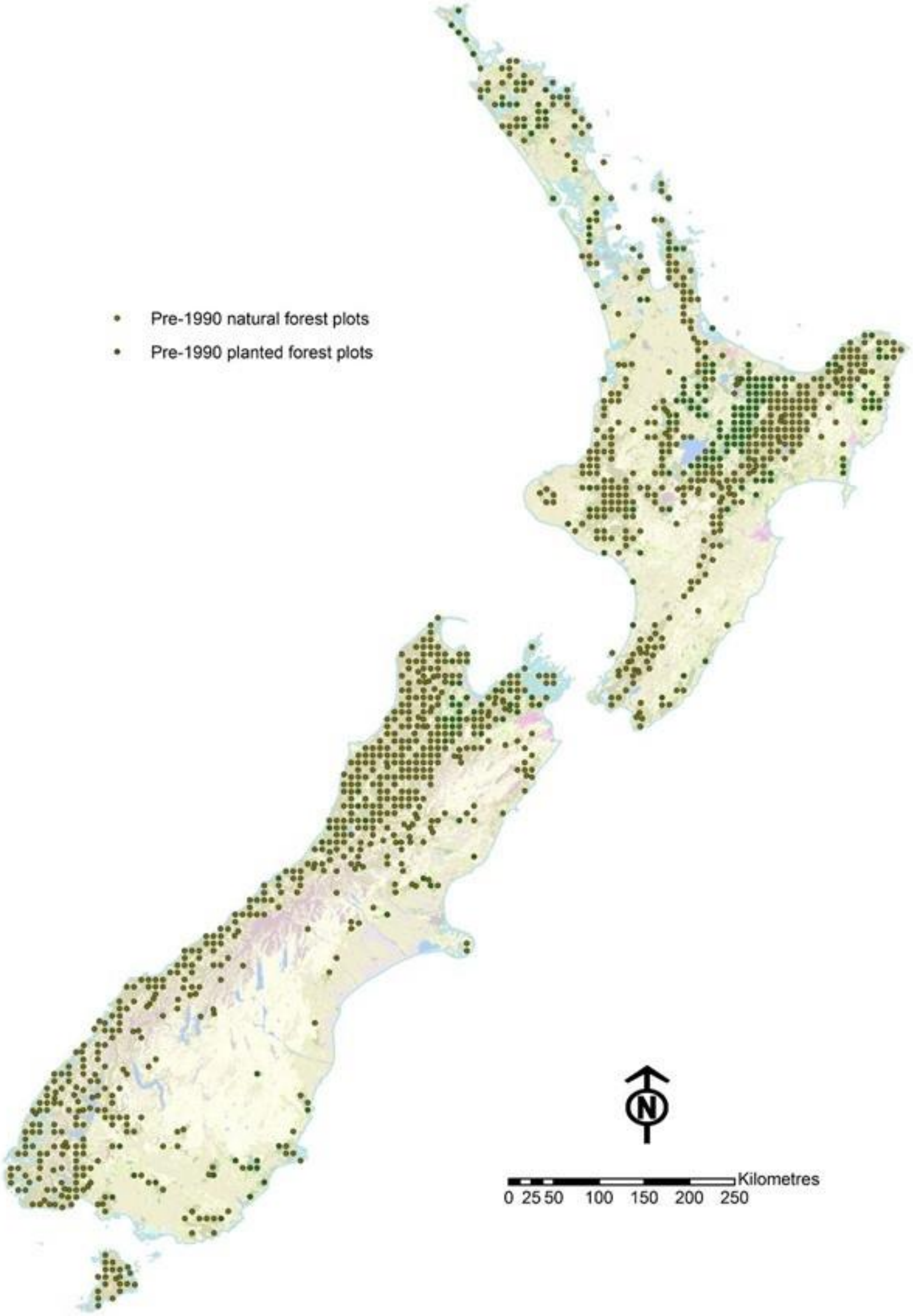
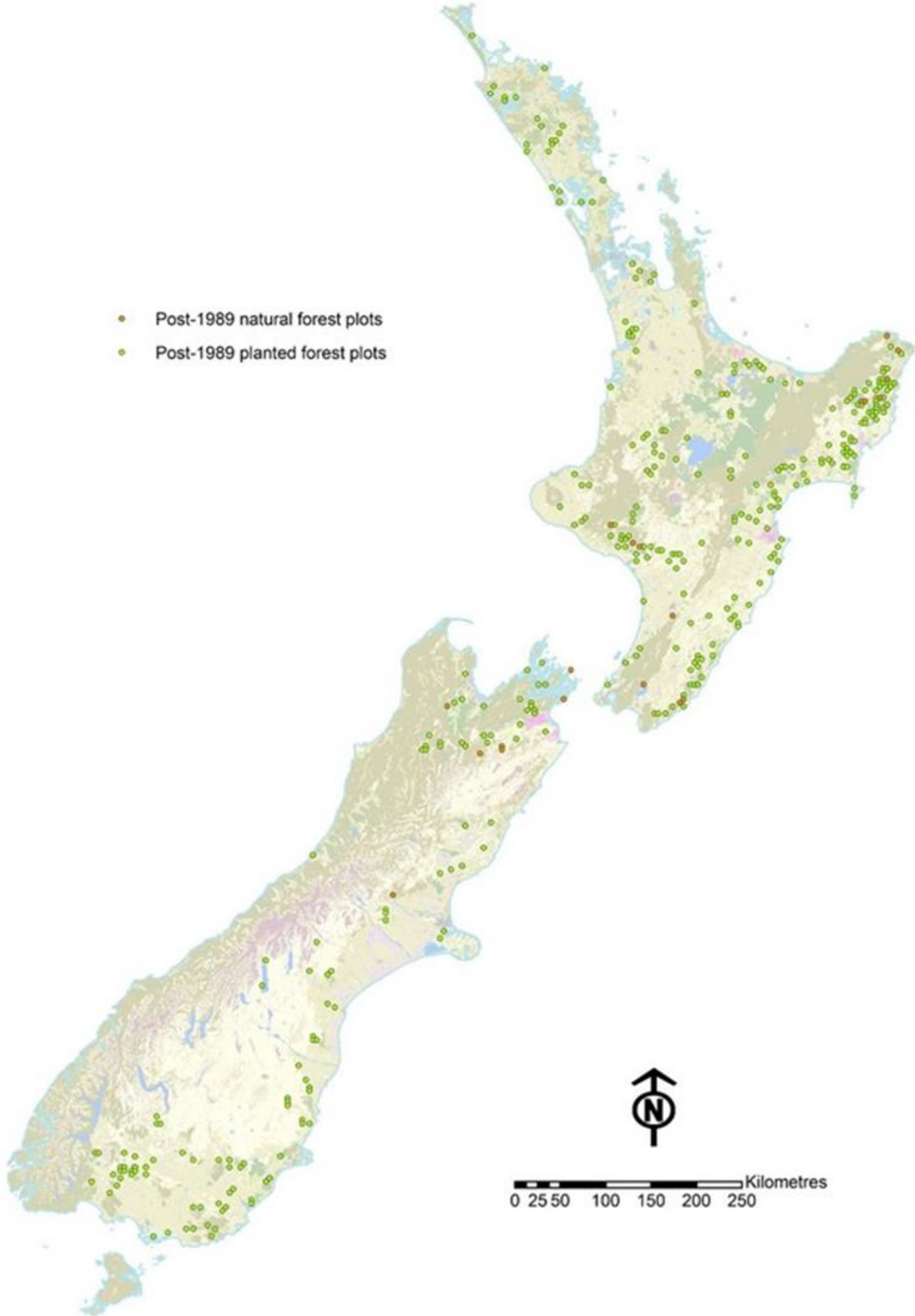


Figure 6.3.6 Location of New Zealand's post-1989 forest plots



Forest land remaining forest land (CRF 4.A.1)

Living biomass and dead organic matter

Emissions and removals for the living biomass and dead organic matter pools have been calculated using Tier 2 and 3 methods. At each forest 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).

The method used to calculate the carbon stock in each biomass pool from the information collected at each plot, for each forest classification, is summarised in table 6.3.8.

Carbon stocks in natural forest are estimated directly from the inventory plots. Further detail on methods can be found in annex A3.2.5 'National forest inventory'.

The carbon stocks for pre-1990 and post-1989 planted forest are calculated from yield tables derived from the inventory plots, which are then applied to an estimated age class distribution. The yield tables are based on plots measured in 2020 combined with all other plots measured since 2007 which are created using interpolation for multiple measurements.

A single yield table is applied to the post-1989 forest estate and two period-specific yield tables are applied to the pre-1990 forest estate based on plant date: pre-1990 forest planted before 1990 and pre-1990 forest planted from 1990 onwards.

The use of period-specific yield tables allows for a more accurate estimate of carbon stock gains and losses from planted forests through time. As increased yields are detected in more recently established plots due to improved management or genetic improvements, these will be reflected in the more recent yield table. In contrast, when using a single-period yield table for all years, the 1990 base year estimate can keep shifting due to the influence of more recently established plots.

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 20 years.

Where pre-1990 forest has undergone a deforestation event, changed to a different land use, such as *Grasslands*, and then subsequently undergone another land-use change back to *Forest land*, the land use will be classified as pre-1990 forest. This is in line with the category definitions outlined in table 6.2.3.

Detailed methodology on the plot network, sampling methods and yield table derivation, as well as validation of the yield tables with the measured plot data, can be found in annexes A3.2.5 'National forest inventory' and A3.2.5 'Forest land model validations'.

Table 6.3.8 Summary of methods used to calculate New Zealand's forest biomass carbon stock from plot data

	Pool		Method	Source
Pre-1990 natural forest	**Living biomass**	Above-ground biomass	Plot measurements; allometric equations	Paul et al. (2021)
		Below-ground biomass	Estimated as the ratio of below-ground biomass to above-ground biomass	Paul et al. (2021); Easdale et al. (2019)
	Dead organic matter	Dead wood	Modelled from plot measurements; allometric equations	Garrett et al. (2019); Paul et al. (2021); Kimberley et al. (2019)
		Litter	Plot samples; laboratory analysis of samples collected at plots	Paul et al. (2021); Garrett (unpublished)
Post-1989 natural forest	**Living biomass**	Above-ground biomass	Plot measurements; allometric equations	Paul et al. (2021)
		Below-ground biomass	Estimated as the ratio of below-ground biomass to above-ground biomass	Paul et al. (unpublished(a)); Easdale et al. (2019)

	Pool		Method	Source
	Dead organic matter	Dead wood	Modelled from plot measurements; allometric model	Garrett et al. (2019); Paul et al. (unpublished(a)); Kimberley et al. (2019)
		Litter	Allometric model and percentage of above-ground biomass	Paul et al. (unpublished(a)); Garrett (unpublished)
Pre-1990 planted forest	**Living biomass**	Above-ground biomass	Modelled through allometric equations, then included in national yield tables	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))
	Dead organic matter	Dead wood	Allometric model using plot measurements, included in national yield tables. Harvest residues added to dead wood pool through CRA	Paul et al. (unpublished(b))
		Litter	Allometric model and percentage of above-ground biomass	Paul et al. (unpublished(b))
Post-1989 planted forest	**Living biomass**	Above-ground biomass	Modelled through allometric equations, then included in national yield tables	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))
	Dead organic matter	Dead wood	Allometric model using plot measurements, included in national yield tables. Harvest residues added to dead wood pool through CRA	Paul et al. (unpublished(b))
		Litter	Allometric model and percentage of above-ground biomass	Paul et al. (unpublished(b))

Soil organic carbon

Soil organic carbon stocks in *Forest land remaining forest land* are estimated using a Tier 2 method for mineral soils, as described in annex A3.2.4 'Mineral soils'.

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. A Tier 1 approach for pre-1990 planted, post-1989 planted and post-1989 natural *Forest land remaining forest land* is applied and is described further in annex A3.2.4 'Organic soils'.

Non-CO_2 emissions for forest land

Direct and indirect nitrous oxide emissions from fertilisation of forest land and disturbance associated with land use management conversion are described in section 6.10. Note that the calculations of indirect N_2O are not disaggregated by subcategory and are therefore not included in the emissions subtotals for *Forest land*.

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.

The area of land converted to natural and planted forests is derived from a combination of land use mapping, national statistics and forestry scheme data. Further details on how the area of new forest establishment is calculated are provided in annex A3.2.2.

When non-forest land is converted to forest land, all carbon in living biomass that was present at the time of forest establishment is assumed to be instantly emitted as a result of forest establishment preparation, with the exception of *Grassland with woody biomass*. Conversions from *Grassland with woody biomass* to post-1989 natural forest represent ecological succession and do not involve the clearance of vegetation. A special case yield table (see annex 3.2.5, table A3.2.16) is used in these instances. This yield table has the same starting carbon stock as *Grassland with woody biomass*, therefore resulting in no net emissions occurring from biomass in the first year after conversion. This does not impact net carbon dioxide removals by the time the forest reaches the age of 30 years, but impacts the year in which reported emissions and removals occur.

Between 1990 and 2021, of the non-forest land converted to post-1989 forest, approximately 61 per cent has been converted from low producing grassland, 22 per cent from *Grassland with woody biomass* and a further 16 per cent from high producing grassland. Note that the grassland type allocated to afforestation in non-mapped years is proportionally based on previously mapped years. *Grassland with woody biomass* provides the largest source of emissions associated with land-use change to planted forest due to the amount of biomass present before 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 provided in annex A3.2.5 'National forest inventory'.

6.3.3 Uncertainties and time-series consistency

The uncertainty in net carbon emissions from *Forest land* was 80.8 per cent in 2021. The uncertainty in net carbon emissions from *Forest land* accounted for 61.3 per cent of the total uncertainty in emissions from the LULUCF sector. The uncertainty associated with the emissions from each forest class is shown in table 6.3.9. The methods used to calculate the uncertainty are further described in annex A3.2.8.

Time-series consistency is ensured by applying consistent methods and full recalculations in the event of any refinement or improvement to methodology.

Table 6.3.9 Uncertainty in carbon stock change emissions in 2021 from *Forest land*

	Emissions (kt CO_2-e)	Uncertainty in emissions (%)	Contribution to LULUCF uncertainty (%)
Pre-1990 planted forest	−7,822,521	149.6	55.5
Post-1989 planted forest	−6,083,896	67.7	19.5
Pre-1990 natural forest	−1,369,874	263.4	17.1
Post-1989 natural forest	−718,511	35.4	1.2
Total	**−15,994,803**	**80.8**	**61.3**

6.3.4 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 QA and QC checks as well as Tier 2, category-specific QA and QC checks. Details of these checks are provided in annex A3.2.5 'National forest inventory'.

6.3.5 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 used improved activity data. The impact of the recalculations on net CO_2-e emission estimates for the *Forest land* category is provided in table 6.3.10. The differences shown are a result of recalculations for all carbon pools used in reporting under the United Nations Framework Convention on Climate Change (UNFCCC) for the whole time series for the LULUCF sector.

Table 6.3.10 Recalculations of New Zealand's estimates for the *Forest land* category in 1990 and 2021

	2022 submission	2023 submission	Change from the 2022 submission	% change
Net emissions (kt CO_2-e)				
1990	–20,068.3	–19,045.2	1,023.2	+5.1
2020	–19,704.7	–20,661.7	–956.9	–4.9
Area (hectares)				
1990	9,381,843	9,379,712	–2,131	–0.0
2020	9,971,670	9,965,606	–6,064	–0.1

Note: Areas are as at the end of the year indicated.

For *Forest land*, a number of improvements made to both the planted and natural forest activity data led to a recalculation across the time series. These are described in more detail below. The change in the 1990 emissions estimate is caused by a change in the estimated harvest area in 1988 to 1989, driving an increase in dead wood decay in 1990. For more information, refer to the description of planned improvements in section 6.3.6.

Activity data

The area estimates of afforestation and deforestation have been updated from the previous submission due to updates in forestry scheme data and new deforestation mapping .

The area of deforestation occurring in 2017, 2018 and 2019 is now based on mapping.

The area of planted forest deforestation for 2020 and 2021 has been estimated by extrapolating the trend in mapped data as described in annex 3.2.2. The direct impact of these changes to deforestation emissions is a reduction of 378 kt CO_2 in 2019 and an increase of 1,015 kt CO_2 in 2020. However, these changes are balanced by changes to the emissions of harvesting reported in these years. This is because there has been no change to the total estimated area of destocking (harvesting + deforestation).[62] Deforestation area is deducted from this total and the remainder is assumed to be harvested. Therefore, increases in emissions associated with deforestation are nearly balanced by decreases in emissions from harvesting. For 2020, this means that the overall net impact on LULUCF emissions is an increase of 209 kt CO_2. This difference comes from the fact that deforestation results in higher

62 Total destocking is derived from Ministry for Primary Industries roundwood volumes. The estimate for 2020 remains unchanged from the estimate used in the 2022 submission.

emissions than harvesting (all biomass carbon is assumed to be an instantaneous emission at the time of deforestation, whereas emissions from harvesting are offset by removals in the harvested wood products pool).

This improvement is also largely responsible for the 41.2 per cent increase in emissions reported in the *Grassland* category for 2020 (given most deforested land is converted to grassland).

The area of deforestation of pre-1990 (tall), pre-1990 (regenerating) and post-1989 natural forest for 2020 and 2021 has been estimated as occurring at the same annual rate as the annual average of the most recently mapped three-year period (2017 to 2019).

Planted forest – yield tables, forest age, harvest age profile modelling and harvest area calculations

In this submission, there are no recalculations associated with updated yield tables. Yield tables for the pre-1990 planted forest and post-1989 planted forest were last updated for the 2022 submission to include data from plots measured in the 2020 forest inventory (see annex 3.2.5, 'Planted forest yield tables').

A range of modelling procedures has been improved to ensure consistency of treatment of harvesting and deforestation activities between pre-1990 and post-1989 planted forests. These include:

- accounting for the change in the average harvest age through time (using a moving average from successive National Exotic Forest Description releases from 1995 to 2020)
- basing the harvest area split for pre-1990 and post-1989 planted forests on mapped area proportions for 2017 and 2018
- improving the process for creating harvesting events for pre-1990 planted forest to address a minor discrepancy in age profile that has historically existed in the models
- improving the process for deriving pre-1990 planted forest harvesting on organic soils to ensure model reliability in the future
- improving the harvest area by age calculation for post-1989 planted forests to ensure that enough is area available to harvest each year and to better incorporate mapped harvest data
- changing the estimated pre-1990 planted forest harvest area in 1988 to 1989. This has driven an increase in estimated dead wood decay in 1990, which increases the 1990 emissions estimate for the *Forest land* category.

Details on method updates applied in the 2022 submission are included in annex 3.2.

In this submission, improvements to deforestation activity data (described above) subsequently affect the calculation of post-1989 and pre-1990 harvest area, which is determined as the difference between destocking and deforestation (refer to annex 3.2.5 for detailed methods).

Natural forest – updates to yield tables and emissions calculations

In this submission, there are no recalculations associated with natural forest yield tables. Yield tables for both pre-1990 natural forest and post-1989 natural forest were last updated for the 2022 submission (see annex 3.2.5, 'Natural forest carbon stock change estimates and yield tables').

6.3.6 Category-specific planned improvements

Plot networks and yield tables

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. An updated analysis is anticipated to be ready for the 2024 submission. The post-1989 natural forest plot network will be re-measured in 2023/24. The complete planted forest plot network (pre-1990 and post-1989) is being remeasured on a continuous basis (at five-year intervals). These data will be incorporated into the National Inventory Report as they become available. New Zealand will update the pre-1990 and post-1989 planted forest yield tables in the 2024 submission.

An additional yield table is planned for post-1989 natural forest, to be produced by disaggregating data from plots dominated by exotic vegetation (typically *Pinus spp.*, or 'wilding pines') from those dominated by native vegetation communities. The current method of including both vegetation types in the one yield table limits its applicability in reporting carbon stock change and other areas of conservation and environmental management. At present these results should always be used and reported as the combination of both native and exotic communities. Analyses up until now have aggregated these data due to a low sample size (a total of 25 plots). It is planned, however, to increase the number of post-1989 plots surveyed in future to provide an overall sample that is large enough to separate into native and exotic communities and two respective yield tables.

Mapping and activity data

Mapping of forest areas will be improved through changes to the 2016 land use map and the addition of a 2020 land use map. Planned forest-specific mapping improvements include:

- mapping of newly planted forests through data supplied from Government-funded forestry scheme mapping, including the NZ ETS, and identified in Sentinel-2 satellite imagery
- review of the consistency of image classification and mapping of all *Forest land remaining forest land* that has not been subject to earlier land-use change, using deep learning techniques to identify mapping errors and areas of uncertainty
- mapped sub-classification of pre-1990 natural forest into tall and regenerating forest.

Planted forest model

A number of improvements will be made to the planted forest model including:

- refining harvest and deforestation age profile calculations
- reviewing organic soil harvesting assumptions with the aim of ensuring model reliability
- reviewing harvesting model methodology for forests existing prior to 1990.

QA/QC processes for checking and improving consistency between different data sets are planned for a future submission. Currently a number of inconsistencies require further investigation and remediation. These inconsistencies include:

- the estimated annual volume removed from planted forests, based on the CRA model, is not entirely consistent with estimated annual roundwood volume statistics produced by the Ministry for Primary Industries (MPI) (Ministry for Primary Industries, 2022a) for part of the time series (1990 to 2012). Note that a comparison between the two data sources across the time series was carried out and is further described in annex A3.2.5 'Forest land model validations'

- the pre-1990 average carbon stock per hectare estimated from the CRA model is greater than the average carbon stock per hectare estimated from plots in the forest inventory (further described in annex A3.2.5 'Forest land model validations')
- the pre-1990 planted forest yield tables have higher carbon stock per hectare estimates on average than plots measured in the planted forest inventory (further described in annex A3.2.5 'Forest land model validations').

6.4 Cropland (CRF 4B)

6.4.1 Description

In 2021, the net emissions from *Cropland* were 378.3 kt CO_2-e, comprising 372.2 kt CO_2 from carbon stock change and 0.02 kt N_2O (6.1 kt CO_2-e) from the nitrogen mineralisation on *Land converted to cropland*. Net emissions from *Cropland* have decreased by 98.2 kt CO_2-e (20.6 per cent) from the 1990 level when net emissions were 476.5 kt CO_2-e (see table 6.4.1).

Table 6.4.1 New Zealand's land-use change by *Cropland* category, and associated CO_2-e emissions, 1990 and 2021

Cropland land use category	Net area as at 1990 (ha)	Net area as at 2021 (ha)	Net emissions (kt CO_2-e) 1990	2021	Change from 1990 (%)
Cropland remaining cropland	395,792	451,633	351.2	320.7	–8.7
Land converted to cropland	28,121	25,096	125.4	57.5	–54.1
Total	**423,912**	**476,728**	**476.5**	**378.3**	**–20.6**

Note: Net area in 1990 is as at 1 January 1990; net area in 2021 is as at 31 December. *Land converted to cropland* includes land converted up to 20 years earlier. 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 94.7 per cent of all *Cropland* area in 2021.

Most emissions due to carbon stock change that have occurred in the *Cropland* category since 1990 are in the SOC pool (4,381.4 kt C) (see table 6.4.2). Within the SOC pool, the majority of changes in carbon stocks result from drained organic soils (3,255.1 kt C). This is because organic soils continue to lose carbon even after the 20-year transition period (IPCC, 2006a).

Table 6.4.2 New Zealand's carbon stock change by carbon pool for the *Cropland* category from 1990 to 2021

Land use	Net carbon stock change 1990–2021 (kt C) Living biomass	Dead organic matter	Soils	Total	Emissions 1990–2020 (kt CO_2)
Annual cropland	–189.2	–12.3	–2,945.8	–3,147.3	11,540.1
Perennial cropland	376.6	–8.6	–1,435.6	–1,067.6	3,914.5
Total	**187.4**	**–20.9**	**–4,381.4**	**–4,214.9**	**15,454.6**

Note: This table includes CO_2 emissions from carbon stock change only (so it does not include emissions from N_2O disturbance). 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 6.4.3 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 2021, 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 *Cropland* depends on crop type, management practices, soil properties and climate variables. Annual crops are harvested each year, with little long-term storage of carbon in biomass. Woody vegetation in orchards stores more carbon in biomass, with the amount largely determined by the crop species and presence of shelterbelts.

Table 6.4.3 New Zealand's land-use change by *Cropland* land use, and associated CO_2 emissions from carbon stock change, from 1990 to 2021

Land use	Net area in 1990 (ha)	Net area in 2021 (ha)	Change from 1990 (%)	Net emissions (kt CO_2 only) 1990	2021	Change from 1990 (%)
Annual cropland	354,898	371,235	+4.6	342.9	306.8	–10.6
Perennial cropland	69,014	105,493	+52.9	126.1	65.4	–48.1
Total	**423,912**	**476,728**	**+12.5**	**469.0**	**372.2**	**–20.6**

Note: Net area in 1990 is as at 1 January 1990; net area in 2021 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 6.4.4. 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 6.4.4 New Zealand's land-use change for the *Cropland* category from 1990 to 2021

Cropland category		Net area in 1990 (ha)	Net area in 2021 (ha)	Change from 1990 (%)
Cropland remaining cropland	Annual remaining annual	333,534	361,006	8.2
	Perennial remaining perennial	61,614	86,658	40.6
	Annual to perennial	643	2,579	301.0
	Perennial to annual	0	1,389	NA
	Subtotal	*395,792*	*451,633*	14.1
Land converted to cropland	Annual cropland	21,364	8839.0	–58.6
	Perennial cropland	6,757	16,257	140.6
	Subtotal	28,121	25,096	–10.8
Total		**423,912**	**476,728**	**+12.5**

Note: NA = not applicable. This table shows the change between 1 January 1990 and 31 December 2021. Columns may not total due to rounding.

In 2021, *Cropland remaining cropland* (level and trend assessment) was a key category.

6.4.2 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 as described in annex A3.2.4.

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 6.4.5.

Table 6.4.5 Summary of New Zealand's carbon stock change emission factors for the *Cropland* category

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 or –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 or –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 annex A3.2.4 'Mineral soils'. ** The emission factor for organic soils is –5.0 t C ha^{-1} yr^{-1} for cold temperate regions and –10.0 t C ha^{-1} yr^{-1} for warm temperate regions.

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 land-use change has occurred between the *Cropland* land use categories, carbon stock changes are reported in *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 (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. It is assumed any biomass gains after this 28-year 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.

The assumption of net zero change in biomass stock after 28 years may be overly simplistic, as outlined by the ERT recommendation L.21, 2019 (FCCC/ARR/2019/NZL, UNFCCC, 2020). However, activity data for biomass stock change beyond 28 years, or temporary destocking, are not available annually. Collection of these data is unlikely in the short to medium term because the funding required for research and method development is being prioritised for the *Forest land* category.

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. Consequently, no gains in these areas are reported either when they are restocked.

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 common reporting format (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

Soil organic carbon stocks in mineral soil for *Cropland remaining cropland* are estimated using a Tier 2 method (see annex A3.2.4 'Mineral soils'). For organic soils, loss of soil carbon is estimated using the Tier 1 method as described in annex A3.2.4 'Organic soils'.

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 2.25, IPCC, 2006a).

Non-CO_2 emissions

All direct and indirect N_2O emissions occurring from management activities in *Cropland remaining cropland* are reported under the Agriculture sector.

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 dependent on the land use category undergoing the conversion and is described further under each category-specific section in this chapter.

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 $ha^{-1} yr^{-1}$ until 18.76 tonnes C ha^{-1} is reached, as described in the *Cropland remaining cropland* section above. The final eight years of biomass gain are reported in *Cropland remaining cropland* because the 2006 IPCC Guidelines (IPCC, 2006a) default transition period of 20 years has been applied across the entire LULUCF sector.

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 before conversion to *Cropland*. It is assumed that, immediately after conversion, dead organic matter is zero (all carbon in dead organic matter before 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 NA (not applicable) is used in the CRF tables in accordance with Decision 24/CP.19 (UNFCCC, 2014) as a given source/sink category does not result in emissions or removals of a specific gas.

Soil organic carbon

Soil organic carbon stocks in *Land converted to cropland* are estimated using a Tier 2 method for mineral soils and a Tier 1 method for organic soils (see annex A3.2.4 for further information).

Non-CO_2 emissions

Nitrous oxide emissions from disturbance associated with land use conversion to *Cropland* and land-use management are described in section 6.10.

6.4.3 Uncertainties and time-series consistency

The uncertainty in net carbon emissions from *Cropland* was 71.3 per cent in 2021. The uncertainty in net carbon emissions from *Cropland* accounted for 1.3 per cent of the total uncertainty in emissions from the LULUCF sector. The uncertainty associated with the emissions from each *Cropland* class is shown in table 6.4.6. The methods used to calculate the uncertainty are further described in annex A3.2.8.

Time-series consistency is ensured by applying consistent methods and full recalculations in the event of any refinement or improvement to methodology.

Table 6.4.6 Uncertainty in net carbon stock change emissions in 2021 for the *Cropland* category

Land use	Emissions (kt CO_2-e)	Uncertainty in emissions (%)	Contribution to LULUCF uncertainty (%)
Annual cropland	306.7	81.0	1.2
Perennial cropland	65.4	141.9	0.4
Total	**372.2**	**71.3**	**1.3**

6.4.4 Category-specific QA/QC and verification

In the preparation of this inventory, the data for CO_2 emissions from the *Land converted to cropland* category underwent Tier 1 quality checks. *Cropland remaining cropland* (level and trend assessment) was a key category in 2021.

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. The country-specific emission factor used is based on a New Zealand study, taking 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 significant proportion of New Zealand's main perennial crops are vine fruit, such as kiwifruit and grapes (Davis and Wakelin, unpublished). This means the country-specific value has lower carbon stocks per hectare in living biomass at maturity than the *Cropland* types included in the study on which the IPCC default value is based.

6.4.5 Category-specific recalculations

Recalculations of the entire time series were carried out for this category as a result of updated activity data. Updates to activity data included improvements made to *Forest land* to *Cropland* area estimates, for each forest type. Updates to emission factors applied on conversion from *Forest land* to *Cropland* also occur due to changes to the planted forest yield tables and average deforestation age, and changes to the pre-1990 natural forest carbon stock estimates. The impact of recalculations on net CO_2-e emission estimates for the *Cropland* category is shown in table 6.4.7.

Table 6.4.7 Recalculations of New Zealand's net emissions from the *Cropland* category in 1990 and 2020

	Net emissions (kt CO_2-e)		Change from the 2022 submission	
Year	2022 submission	2023 submission	(kt CO_2-e)	(%)
1990	476.2	476.5	0.3	0.1
2020	382.3	382.8	0.4	0.1

Note: Columns may not total due to rounding.

6.4.6 Category-specific planned improvements

A longitudinal study on the impact of management practices on *Grasslands* and *Croplands* soils is under way (Manaaki Whenua Landcare Research, 2020). This study will collect time-series data on a network of 500 soil sample plots over 12 years. This is likely to improve the SOC reference values for *Cropland*. These data are not expected to be available for several years.

While the above-mentioned study may help improve SOC reference values, it will not address review recommendation L.18, 2020 raised in the ERT review report of the 2020 submission (FCCC/ARR/2019/NZL, UNFCCC, 2020). The report questioned whether the estimated SOC reference values were systematically overestimated or underestimated given that land-use change is most likely to occur on a subset of each land use category. The current soils model also assumes land use management practices are static and cannot be updated to include activity data on improvements in soil management practices. To create and validate a new model requires significant resourcing. Funding to investigate updating the soils model is currently being sought. However, even if this funding is received, updating or replacing the Soil Carbon Monitoring System (Soil CMS) model itself is likely to take a number of years.

6.5 Grassland (CRF 4C)

6.5.1 Description

In 2021, the net emissions from *Grassland* were 2,744.3 kt CO_2-e (see table 6.5.1). These emissions comprise 2,708.1 kt CO_2 emissions from carbon stock change, 0.07 kt N_2O (20.6 kt CO_2-e) and 0.6 kt CH_4 (15.6 kt CO_2-e) emissions from *Biomass burning* and nitrogen mineralisation on *Land converted to grassland*.

Net emissions from *Grassland* have increased by 1,987.5 kt CO_2-e (262.6 per cent) from the 1990 level of 756.8 kt CO_2-e (see table 6.5.1). 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.

The *Grassland remaining grassland* and *Land converted to grassland* categories were identified as key categories for the level and trend assessment in 2021.

Table 6.5.1 New Zealand's land-use change for the *Grassland* category, and associated CO_2-e emissions, from 1990 to 2021

Grassland land use category	Area as at 1990 (ha)	Area as at 2021 (ha)	Net emissions (kt CO_2-e)		Change from 1990 (%)
			1990	2021	
Grassland remaining grassland	14,924,506	14,336,128	302.7	1,247.3	312.0
Land converted to grassland	344,864	201,794	454.1	1,497.0	229.7
Total	**15,269,371**	**14,537,922**	**756.8**	**2,744.3**	**262.6**

Note: Net area in 1990 is as at 1 January 1990; net area in 2021 is as at 31 December. *Land converted to grassland* includes land converted up to 20 years earlier. Net emission estimates are for the whole year indicated. Columns may not total due to rounding.

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. Detailed descriptions of each *Grassland* type can be found in table 6.2.3 and are briefly summarised below:

- *High producing grassland* – intensively managed pasture land
- *Low producing grassland* – 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* – 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), or due to characteristics of the vegetation or environmental constraints (e.g., alpine shrubland).

Grassland with woody biomass is a diverse land use and has therefore been disaggregated into two types: permanent and transitional, described in table 6.5.2. 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.

Table 6.5.2 Grassland with woody biomass sub-classification and description

Grassland with woody biomass sub-classification	Description	Expected occurrence
Transitional	Areas of woody shrublands within farmland that do not become forest over a 30- to 40-year timeframe (Trotter and MacKay, unpublished)	Where livestock grazes areas of woody shrubland or where woody shrubland is managed in other ways (e.g., spraying) to prevent it from becoming forest.
Permanent	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.	Where 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.

In 2021, there were 6,903,017 hectares of high producing grassland (25.6 per cent of total land area), 6,273,573 hectares of low producing grassland (23.3 per cent of total land area) and 1,361,332 hectares of *Grassland with woody biomass* (5.1 per cent of total land area). The area *of Grassland with woody biomass* is comprised of 487,646 hectares of permanent and 873,685 hectares of transitional *Grassland with woody biomass*.

From 1990 to 2021, the net carbon stock change attributed to *Grassland* was a loss of 43,690.2 kt C, equivalent to 160,197.4 kt CO_2 emissions (see table 6.5.3). The majority of these emissions are due to the loss of living biomass carbon stock associated with *Forest land* conversion to *Grassland* (deforestation).

Table 6.5.3 New Zealand's carbon stock change by carbon pool for the *Grassland* category from 1990 to 2021

	Net carbon stock change 1990–2021 (kt C)				Emissions 1990–2021
Grassland category	Living biomass	Dead organic matter	Soils	Total	(kt CO_2)
Grassland – high producing	–16,936.9	–2,145.6	–9,402.5	–28,485.0	104,445.0
Grassland – low producing	–9,789.5	–1,357.2	653.4	–10,493.3	38,475.4
Grassland – with woody biomass	–3,135.4	–622.0	–954.4	–4,711.9	17,277.0
Total	**–29,861.9**	**–4,124.8**	**–9,703.5**	**–43,690.2**	**160,197.4**

Note: Columns may not total due to rounding.

Grassland remaining grassland

There were 14,336,128 hectares of *Grassland remaining grassland* as at 2020, equivalent to 53.0 per cent of New Zealand's total land area.

Land converted to grassland

Between 2020 and 2021, an estimated 2,883 hectares of land was converted to *Grassland*, while 55,570 hectares of *Grassland* was converted to other land use categories.

The majority (91.6 per cent) of *Land converted to grassland* since 1 January 1990 is land that was previously *Forest land*. The 222,328 hectares of *Forest land* converted to *Grassland* since 1 January 1990 is comprised of an estimated 129,088 hectares of pre-1990 planted forest, 45,758 hectares of pre-1990 natural forest, 46,373 hectares of post-1989 planted forest and 1,110 hectares of post-1989 natural forest. For more information on deforestation, see annex A3.2.2. Land-use change of *Forest land* to *Grassland* resulted in net emissions of 1,461.4 kt CO_2 in 2021.

6.5.2 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 6.5.4). Emissions and removals from mineral soils are estimated using a Tier 2 method, whereas organic soils are estimated using a Tier 1 method (see annex A3.2.4).

Table 6.5.4 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**	**0.48**	**20**	Wakelin and Beets (unpublished)
	Living biomass				
	AGB	9.35	0.36	20	
	BGB	3.05	0.08	20	
	Dead organic matter				
	Dead wood	0.10	0.004	20	
	Litter	0.55	0.02	20	
With woody biomass – permanent	**Total biomass**	**60.57**	**NO**	**NO**	Wakelin and Beets (unpublished)
	Living biomass				
	AGB	45.18	NO	**NO**	
	BGB	11.71	NO	**NO**	
	Dead organic matter			**NO**	
	Dead wood	3.68	NO	**NO**	
	Litter	0.00	NO	**NO**	

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 the annual accumulation rates for *Grassland with woody biomass* – transitional do not equal the total biomass steady state carbon stock value over 20 years because the starting stock value at year 1 is 3.54 t C ha^{-1}.

Grassland remaining grassland (CRF 4.C.1)

For *Grassland remaining grassland*, the Tier 1 assumption is there is no change in carbon stocks for *Grassland* remaining in the same subcategory (section 6.2.1.1 of 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 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 (570,311 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 6.5.4, representing the annual growth in biomass for land converted to another land use.

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 (IPCC, 2006a). 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 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 organic carbon

Soil organic carbon stocks in *Grassland remaining grassland* are estimated using a Tier 2 method for mineral soils and a Tier 1 method for organic soils (see annex A3.2.4).

Non-CO_2 emissions

Direct and indirect N_2O emissions occurring as a result of nitrogen inputs, as well as drainage of managed soils, in *Grassland remaining grassland* are reported under the Agriculture sector.

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 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 before 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 before 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 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 6.5.4) over 20 years (the IPCC default period for land to reach steady state (IPCC, 2006a).

Soil organic carbon

Soil organic 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 annex A3.2.4).

Non-CO_2 emissions

Nitrous oxide emissions from disturbance associated with land use conversion to *Grassland* and land use management are described in section 6.10.

6.5.3 Uncertainties and time-series consistency

The uncertainty in net carbon emissions from *Grassland* was 42.5 per cent in 2021. The uncertainty in net carbon emissions from *Grassland* accounted for 4.9 per cent of the total uncertainty in emissions from the LULUCF sector. The uncertainty associated with the emissions from each *Grassland* class is shown in table 6.5.5. The methods used to calculate the uncertainty are further described in annex A3.2.8.

Time-series consistency is ensured by applying consistent methods and full recalculations in the event of any refinement or improvement to methodology.

Table 6.5.5 Uncertainty in carbon stock change emissions in 2021 for *Grassland*

	Emissions (kt CO_2-e)	Uncertainty in emissions (%)	Contribution to LULUCF uncertainty (%)
Grassland – low producing	1,784.3	63.1	5.3
Grassland – high producing	583.6	21.9	0.6
Grassland – with woody biomass	340.2	57.7	0.9
Total	**2,708.1**	**42.5**	**5.5**

6.5.4 Category-specific QA/QC and verification

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.

6.5.5 Category-specific recalculations

The impact of recalculations on net CO_2-e emission estimates for the *Grassland* category is shown in table 6.5.6.

Table 6.5.6 Recalculations of New Zealand's net emissions from the *Grassland* category in 1990 and 2020

Year	Net emissions (kt CO_2-e) 2022 submission	Net emissions (kt CO_2-e) 2023 submission	Change from the 2022 submission (kt CO_2-e)	Change from the 2022 submission (%)
1990	724.7	756.8	32.1	+4.4
2020	2,570.2	3,628.1	1,057.9	+41.2

Recalculations of the entire time series were carried out for this category as a result of the following updates to activity data.

- Additional deforestation to grassland in recent years was identified due to the application of the four-year rule – that is, land that lost forest cover but showed no evidence of land-use change is considered deforested after four years. Applying this rule led primarily to an increase in emissions in the *Grassland with woody biomass* category.
- The estimated area of deforestation that occurred in 2020 increased relative to the previous submission, leading to increased emissions in the *Grassland* categories for that year (see also section 6.1.4).

6.5.6 Category-specific planned improvements

A longitudinal study on the impact of management practices on carbon stocks in *Grassland* and *Cropland* soils is under way. This is further described in section 6.4.6.

6.6 Wetlands (CRF 4D)

6.6.1 Description

In 2021, there were 11.4 kt CO_2-e emissions from *Wetlands*, compared with emissions of –8.4 kt CO_2-e from *Wetlands* in 1990 (see table 6.6.1). This changing trend, from net remover in 1990 to net emitter in 2020, 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 of 2021, there were 5,638 hectares in a state of conversion to *Wetlands* (see table 6.6.1). These lands have been converted to *Wetlands* during the previous 20 years but have not yet reached steady state.

Removals from wetlands are driven by increases to mineral soil carbon stocks following conversion to wetland (2.4 kt CO_2-e of removals in 2021 from mineral soils), while emissions are driven by the extraction of peat each year.

Table 6.6.1 New Zealand's land-use change for the *Wetlands* category, and associated CO_2-e emissions, in 1990 and 2021

Wetlands land use category	Net area (ha) as at 1990	Net area (ha) as at 2021	Net emissions (kt CO_2-e) 1990	Net emissions (kt CO_2-e) 2021	Change from 1990 (%)
Wetlands remaining wetlands	751,390	752,607	11.5	19.1	66.0
Land converted to wetlands	10,276	5,638	–20.0	–7.7	61.5
Total	**761,665**	**758,245**	**–8.4**	**11.4**	**+235.7**

Note: Net area in 1990 is as at 1 January 1990; net area in 2021 is as at 31 December. *Land converted to wetlands* includes land converted up to 20 years earlier. *Land converted to wetlands* consists of land converted to hydro lakes before 1990. Net emission values are for the whole year indicated. Columns may not total due to rounding.

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. 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.[63]

In 2021, there were 534,734 hectares of open water and 223,511 hectares of vegetated wetlands. Together these two land use types make up 2.8 per cent of the total New Zealand land area.

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 study showed that in 2020, there were 273 hectares under peat extraction. The results of this study have been incorporated into New Zealand's 2016 land use map.

From 1990 to 2021, the net carbon stocks in *Wetlands* decreased by 8.8 kt C, equivalent to emissions of 32.1 kt CO_2 in total since 1990 (see table 6.6.2).

Table 6.6.2 New Zealand's carbon stock change by carbon pool for the *Wetlands* category from 1990 to 2021

	Net carbon stock change 1990–2021 (kt C)				
Land use	**Living biomass**	**Dead organic matter**	**Soils**	**Total**	**Emissions 1990–2021 (kt CO_2)**
Wetlands – vegetated	–20.2	–2.4	12.3	–10.3	37.8
Wetlands – open water	–92.6	–6.1	100.3	1.5	–5.7
Total	**–112.8**	**–8.6**	**112.7**	**–8.8**	**32.1**

Note: Columns may not total due to rounding.

6.6.2 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)).[64] 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.

63 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.

64 New Zealand has elected not to apply the 2013 *Wetlands* supplement. This decision will be revised at a later date.

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 in the CRF table for this category. However, carbon stock changes associated with changes between the two wetland sub-categories are reported under *Wetlands remaining wetlands.*

Soil organic carbon

Soil organic carbon stocks in *Wetlands remaining wetlands* are estimated using a Tier 2 method for mineral soils and Tier 1 methods for organic soils (see annex A3.2.4). For open water, the SOC stock at equilibrium is assumed to be the same value as that of low producing grassland.

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 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 CH4 emissions occur from this activity. As such, the ERT recommendation L.7, 2017 (FCCC/ARR/2017/NZL) cannot be addressed. During the review of the 2021 submission, the ERT considered that this issue had been resolved given there is no method for estimating these emissions in the 2006 IPCC Guidelines (IPCC, 2006a). 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

The vegetated wetland subcategory includes areas of forest that are part of the wetland ecosystem. Where the forest area has been judged to be part of the wetland ecosystem, it has been classed as vegetated wetland.

Land converted to wetlands (CRF 4.D.2)

Between 1990 and 2021, 9,060 hectares of land were converted to *Wetlands*, while 12,012 hectares of *Wetlands* were converted to other land uses (mainly *Grassland*, at 10,066 hectares). This resulted in a net decrease in total area reported under *Wetlands* of 3,420 hectares. The wetland losses were mainly related to the conversion of vegetated wetland to grassland (9,540 hectares). Increases in area of wetland open water (8,386 hectares) are 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 NE 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. All emissions from land-use change to *Wetlands* from the removal of the previous vegetation are instantly emitted.

For open water wetlands, the carbon stocks in living biomass and dead organic matter following conversions are equal to zero. For *Wetlands – vegetated*, a Tier 2 method is used that includes changes in carbon stocks from the year of conversion into this category, as outlined in equation 2.9 of the 2006 IPCC Guidelines (IPCC, 2006a). When land is converted to *Wetlands – vegetated*, living biomass accumulates to 1.4 tonnes C ha^{-1} (see table 6.6.3) over 20 years (the IPCC default period for land to reach steady state (IPCC, 2006a)). This rate of accumulation is based on a literature review of carbon stocks in New Zealand wetland vegetation (Easdale et al., unpublished). Due to the methods used in the review, the above-ground component of the estimated accumulation rate is based on biomass estimates of living and dead plant material as well as coarse dead wood for the woody vegetation types that are included in the *Wetlands – vegetated* category (Easdale et al., unpublished).

Table 6.6.3 Summary of New Zealand's biomass emission factors for *Wetlands*

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
Open water	**Total biomass**	**NE**	**NE**	**NE**	No IPCC guidelines
	Living biomass				
	AGB	NE	NE	NE	
	BGB	NE	NE	NE	
	Dead organic matter	NE	NE	NE	
Vegetated	**Total biomass**	**27.6**	**1.4**	**20**	Easdale (unpublished)
	Living biomass				
	AGB	20.2	1	20	
	BGB	7.4	0.4	20	
	Dead organic matter				
	Dead wood	NE	NE	NE	
	Litter	NE	NE	NE	

Note: AGB = above-ground biomass; BGB = below-ground biomass; NE = not estimated . Columns may not total due to rounding.

Soil organic carbon

Soil organic carbon stocks in *Land converted to wetlands* are estimated using a Tier 2 method, as described in annex A3.2.4.

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 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 this notation key is in accordance with Decision 24/CP.19 (UNFCCC, 2014).

6.6.3 Uncertainties and time-series consistency

The uncertainty in net carbon emissions from *Wetlands* was 77.7 per cent in 2021. The uncertainty in net carbon emissions from *Wetlands* accounted for 0.0 per cent of the total uncertainty in emissions from the LULUCF sector. The uncertainty associated with the emissions from each *Wetland* class is shown in table 6.6.4. The methods used to calculate the uncertainty are further described in annex A3.2.8.

Time-series consistency is ensured by applying consistent methods and full recalculations in the event of any refinement or improvement to methodology.

Table 6.6.4 Uncertainty in carbon stock change emissions in 2021 for *Wetlands*

	Emissions (kt CO_2-e)	Uncertainty in emissions (%)	Contribution to LULUCF uncertainty (%)
Wetlands – open water	–2.2	211.2	0.0
Wetlands – vegetative	–4.4	53.6	0.0
Peat extraction	18.0	18.9	0.0
Total	**11.4**	**77.7**	**0.0**

6.6.4 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.

6.6.5 Category-specific recalculations

The impact of recalculations on net CO_2-e emission estimates for *Wetlands* is shown in table 6.6.5. Recalculations were carried out for this category as a result of updating biomass carbon stock estimates for the *Wetlands – vegetated* category.

Table 6.6.5 Recalculations for New Zealand's net emissions from the *Wetlands* category in 1990 and 2020

	Net emissions (kt CO_2-e)		Change from the 2022 submission	
Year	2022 submission	2023 submission	(kt CO_2-e)	(%)
1990	–10.5	–8.4	2.0	19.4
2020	13.4	11.2	–2.1	–15.9

The overall net impact of these recalculations for the LULUCF sector (rather than the *Wetlands* category specifically) is a decrease of 15.8 kt CO_2-e in 2020 and a decrease of 38.8 kt CO_2-e in 1990.

6.6.6 Category-specific planned improvements

The following improvements are planned for the *Wetlands* category.

- Research is under way to identify activity data, nutrient status, drainage depth and suitable emission factors for drained organic soils to enable the application of the 2013 *Wetlands* supplement in future submissions. It is unlikely this work will be complete before the 2023 submission.
- Wetland mapping will be improved throughout the time series as part of the production of the 2020 land use map.

6.7 Settlements (CRF 4E)

6.7.1 Description

In 2021, the net emissions from *Settlements* were 122.2 kt CO_2-e, an increase of 61.4 per cent from net emissions in 1990 (see table 6.7.1). 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 2021.

Table 6.7.1 New Zealand's land-use change for the *Settlements* category, and associated CO_2-e emissions, from 1990 to 2021

Settlements land use category	Net area (ha) as at 1990	2021	Net emissions (kt CO_2-e) 1990	2021	Change from 1990 (%)
Settlements remaining settlements	191,271	219,151	67.2	77.4	15.2
Land converted to settlements	16,624	19,092	8.5	44.8	425.3
Total	**207,895**	**238,242**	**75.7**	**122.2**	**61.4**

Note: Net area at 1990 is as of 1 January 1990; net area at 2021 is as of 31 December 2021. *Land converted to settlements* includes land converted up to 20 years earlier. Net emission values are for the whole year indicated. Columns may not total due to rounding.

From 1990 to 2021, the net carbon stock change for *Settlements* decreased by 1,054.7 kt C, equivalent to emissions of 3,867.2 kt CO_2 in total since 1990 (see table 6.7.2). 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 6.7.2 New Zealand's carbon stock change by carbon pool for the *Settlements* category from 1990 to 2021

Land use category	Net carbon stock change 1990–2021 (kt C) Living biomass	Dead organic matter	Soils	Total	Emissions 1990–2021 (kt CO_2)
Settlements	–425.0	–32.2	–597.4	–1,054.7	3,867.2

The *Settlements* land use category, as described in chapter 3.2 of the 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 2021, there were 238,242 hectares of *Settlements* in New Zealand, an increase of 30,347 hectares since 1990. This category comprised 0.9 per cent of New Zealand's total land area in 2021. The largest area of change to *Settlements* between 1990 and 2021 came from high producing grassland, with 24,038 hectares between 1990 and 2021.

The emissions in the *Settlements remaining settlements* category are all from anthropogenic 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 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.

6.7.2 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. See annex A3.2.4 'Organic soils' for further information on the methods applied to organic soils.

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 took 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 organic carbon

Soil organic carbon stocks in mineral soil for *Land converted to settlements* are estimated using a Tier 2 method (see annex A3.2.4 'Mineral soils'). For organic soils, loss of soil carbon is estimated using the Tier 1 method applied to *Settlements remaining settlements*.

6.7.3 Uncertainties and time-series consistency

The uncertainty in net carbon emissions from *Settlements* was 63.4 per cent in 2021. The uncertainty in net carbon emissions from *Settlements* accounted for 0.4 per cent of the total uncertainty in emissions from the LULUCF sector. The methods used to calculate the uncertainty are further described in annex A3.2.8.

Time-series consistency is ensured by applying consistent methods and full recalculations in the event of any refinement or improvement to methodology.

6.7.4 Category-specific QA/QC and verification

In the preparation of this inventory, the activity data for these emissions underwent Tier 1 quality checks.

6.7.5 Category-specific recalculations

Recalculations were carried out for this category (see table 6.7.3). Recalculations in the *Settlements* category are largely due to emissions associated with small mapping changes to the areas of deforestation that have been converted to *Settlements*.

Table 6.7.3 Recalculations for New Zealand's net emissions from the *Settlements* category in 1990 and 2020

	Net emissions (kt CO_2-e)		Change from the 2022 submission	
Year	2022 submission	2023 submission	(kt CO_2-e)	(%)
1990	75.4	75.7	0.3	0.35
2020	124.1	121.7	–2.3	–1.9

6.7.6 Category-specific planned improvements

During the review of the 2021 submission, the ERT recommended that New Zealand calculate N_2O emissions associated with the drainage of organic soils in settlements. Although there is no default method in the IPCC 2006 Guidelines (IPCC, 2006a) for N_2O emissions associated with drainage for this land use category, New Zealand considers that most of its *Settlements* area can be assimilated to *Grassland* when it comes to soil carbon. Therefore, the default methods applied to *Grassland* should also be applied to *Settlements*. Given there is no reporting category for these emissions in the CRF, assistance was sought on how these emissions could be reported. Unfortunately, the response to this request was not received in time to incorporate into this submission. Therefore, the 23.2 kt CO_2-e of emissions resulting from drained organic soils in *Settlements* has not been included in the total emissions for LULUCF. It is planned that this will be included in the 2024 submission.

6.8 Other land (CRF 4F)

6.8.1 Description

In 2021, the net emissions from *Other land* were 85.7 kt CO_2-e (see table 6.8.1). This is 71.9 kt CO_2-e (522.5 per cent) higher than the 1990 level of 13.8 kt CO_2e. 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.

Other land is defined in section 3.2 of the 2006 IPCC Guidelines (IPCC, 2006a) as including bare soil, rock, ice and all land areas that do not fall into any of the other five land use categories. This means that this category includes any land which has not been actively classified into one of the other 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.

An analysis of change in area between 1990 and 2021 shows that, of the 7,140 hectares converted from *Other land* to different land use categories, 2,974 hectares were converted to post-1989 planted forest, 714 hectares of post-1989 natural forest and 1,462 hectares were converted to *Grassland with woody biomass*. *Land converted to other land* is dominated by quarries, with the largest individual site in the region of Otago measuring approximately 1,400 hectares. Also included in this change are coastal areas where sand dunes have advanced into previously vegetated areas, some areas of new rural roading not associated with settlements, and areas that have been cleared of vegetation but where the future land use is uncertain. In some cases these uncertain areas undergo a subsequent land-use change to *Settlements*.

Between 1 January 1990 and 31 December 2021, there were 8,525 hectares of *Land converted to other land*; most (5,279 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 2021, *Land converted to other land* was not a key category.

Table 6.8.1 New Zealand's land-use change for the land use category *Other land* from 1990 to 2021

Land use category – Other land	Net area as at 1990 (ha)	Net area as at 2021 (ha)	Net emissions (kt CO_2-e) 1990	2021	Change from 1990 (%)
Other land remaining other land	895,297	890,384	0.1	4.1	3,816.6
Land converted to other land	0	6,299	13.7	81.6	497.5
Total	**895,297**	**896,683**	**13.8**	**85.7**	**522.5**

Note: Net area at 1990 is as of 1 January 1990; net area at 2021 is as of 31 December. *Land converted to other land* includes land converted up to 20 years earlier. The net emission values for *Other land remaining other land* are due to N_2O emissions from N mineralisation as a result of land-use change. Columns may not total due to rounding.

6.8.2 Methodological issues

Other land remaining other land (CRF 4.F.1)

A summary of the New Zealand emission factors and other parameters used to estimate greenhouse gas emissions for *Other land* is provided in table 6.8.2.

Table 6.8.2 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

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 organic carbon

Soil organic carbon stocks in *Other land remaining other land* are estimated using a Tier 2 method for mineral soils (see annex A3.2.4 'Mineral soils'). 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). The 2006 IPCC Guidelines provides a default value for soil carbon in *Other land* of 0 tonnes C ha^{-1} (section 9.3.3.2, IPCC, 2006a). However, due to the hierarchical structure of defining land use classes, *Other land* is defined as "any other remaining land that does not fall into any of the other land use categories", which can result in the SOC measured potentially being greater than zero.

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 the method 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 organic carbon

Soil organic carbon stocks in *Land converted to other land* before conversion are estimated using a Tier 2 method (see annex A3.2.4 'Mineral soils'). 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.

6.8.3 Uncertainties and time-series consistency

The uncertainty in net carbon emissions from *Other land* was 86.9 per cent in 2021. Emissions from *Other land* accounted for 0.4 per cent of the net emissions from the LULUCF sector. The methods used to calculate the uncertainty are further described in annex A3.2.8.

Time-series consistency is ensured by applying consistent methods and full recalculations in the event of any refinement or improvement to methodology.

6.8.4 Category-specific QA/QC and verification

In the preparation of this inventory, the data for these emissions underwent Tier 1 quality checks.

6.8.5 Category-specific recalculations

The impact of recalculations on net CO_2-e emission estimates for the *Other land* category is shown in table 6.8.3. Recalculations were carried out for this category as a result of mapping data as described section 6.2 and annex A3.2.2. Recalculations in the *Other land* category are largely due to emissions associated with small mapping changes to the areas of deforestation that have been converted to *Other lands*.

Table 6.8.3 Recalculations for New Zealand's net emissions from the *Other land* category in 1990 and 2020

	Net emissions (kt CO_2-e)		Change from the 2022 submission	
Year	2022 submission	2023 submission	(kt CO_2-e)	(%)
1990	13.6	13.8	0.2	+1.2
2020	118.4	92.7	–25.7	–21.7

6.8.6 Category-specific planned improvements

The reference SOC value, based on only three estimates, is high compared with the 2006 IPCC Guidelines (IPCC, 2006a) default value and has a relatively high uncertainty. Further soil sampling in land classified as *Other land* is required to improve soil carbon estimates in this land use category.

6.9 Harvested wood products (CRF 4G)

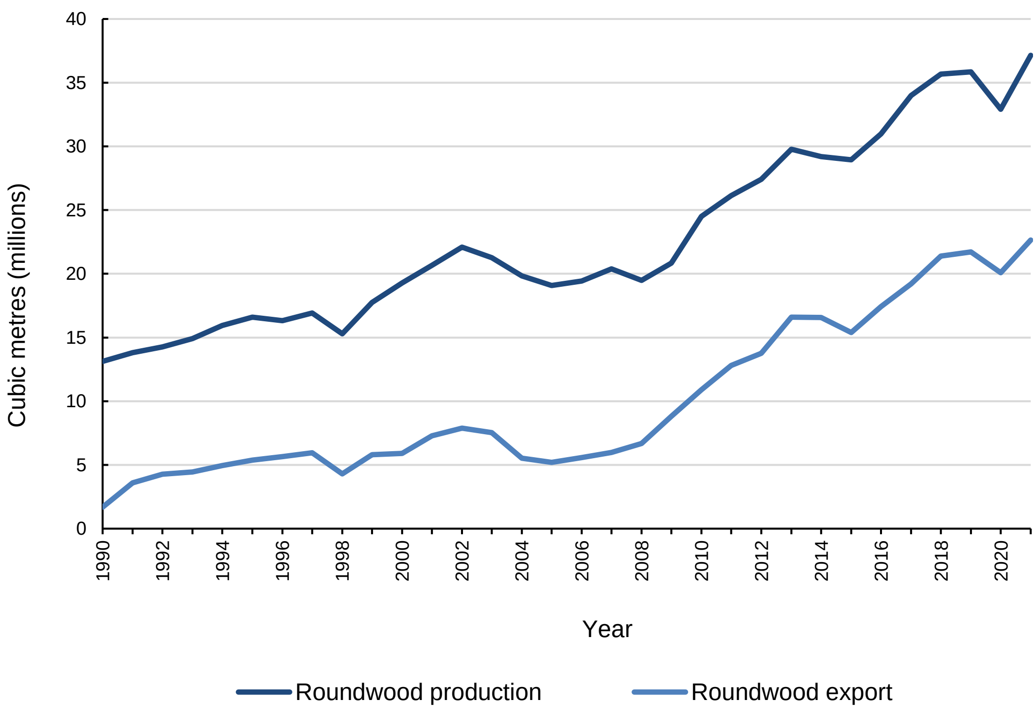
6.9.1 Description

In 2021, the net emissions from *Harvested wood products* were –8,658.8 kt CO_2-e. This is –6,177.6 kt CO_2-e (249.0 per cent) lower than the 1990 level of –2,481.2 kt CO_2-e. The decrease in emissions in the *Harvested wood products* category is driven by the increase in harvesting and production of roundwood that has occurred since 1990, as shown in figure 6.9.1.

Net emissions in the *Harvested wood products* category are driven by the harvesting of planted forests to produce roundwood, resulting in changes to the carbon stock of this pool. The *Harvested wood products* pool gains carbon as new *Harvested wood products* are created. Losses from the *Harvested wood products* pool occur due to products being discarded. To account for these losses through time, a decay profile, or half-life, is applied for each product type.

Between 2020 and 2021 removals in the *Harvested wood products* category have increased by 1,824.3 kt CO_2-e. The reason for this change was an increase in harvesting compared with 2020.

Figure 6.9.1 Volume of roundwood produced and exported from 1990 to 2021



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. New Zealand currently processes around 40 per cent of its annual harvest (Ministry for Primary Industries, 2022a). The remaining harvest is exported in raw material form. New Zealand is currently the largest exporter of industrial roundwood followed by the Russian Federation and Czechia (Food and Agriculture Organization, 2019). New Zealand's planted forests are dominated by radiata pine (*Pinus radiata*), which is used in a wide range of applications including timber-frame construction, packaging, furniture, joinery and interior fittings, decking, general external outdoor products, concrete formwork, printing and writing paper, corrugated materials, tissue products, newsprint, kitchen and bathroom cabinets, flooring, posts and poles (Ministry for Primary Industries, 2022b; Wekesa, 2022).

In 2021, *Harvested wood products* was a key category (level and trend assessment).

6.9.2 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 et al., 2020).

Activity data

Activity data on roundwood production volume, roundwood export volume and the production of New Zealand processed wood products are sourced from MPI (Ministry for Primary Industries, 2022a, 2022c). Additional data on New Zealand wood product production and export that are not available from the published MPI statistics are sourced from the Food and Agriculture Organization statistical database (the FAOSTAT database), which contains data that MPI provides to the Food and Agriculture Organization. The FAOSTAT database provides more granular breakdowns of semi-finished wood products produced in New Zealand, to which specific carbon fractions can then be applied.

Activity data for the period 1900 to 1960 are populated using the IPCC model method, which assumes that consumption is correlated with population growth. New Zealand used the default value for Oceania for the annual rate of increase for the period 1900 to 1960. This information is used to initialise *Harvested wood products* stocks 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 2021, as shown in figure 6.9.1 (Ministry for Primary Industries, 2022a). Note that the exported volume of *Harvested wood products* described in CRF table 4.Gs2 does not sum to 60 per cent of all exported products. This is because this table includes only products produced in New Zealand and does not include the volume of raw logs exported that are then processed offshore.

MPI 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).

Further research was commissioned in 2017 to update the model assumptions that are used for calculating harvested wood product volume and associated emissions to include the activity data and half-lives of the 2016 report (Wakelin and Kimberley, unpublished). Note that the model also includes export variables to Japan, which was historically a large export market but has reduced and is projected to continue to reduce over time. It also includes 'Other countries', which account for a small volume of exports that are sold to other markets. Details of product volume and half-lives for these export markets can be found in annex A3.2.6.

Activity data for exported log volumes and *Harvested wood products* to individual countries are periodically published by MPI (Ministry for Primary Industries, 2022a, 2022c). The proportion of exported roundwood to product type in these export markets is obtained by applying the ratios of product type produced (sawnwood, wood panels, or paper) as identified in the 2016 report (Ministry for Primary Industries, 2016) to the volume of timber exported to each of the export markets.

Emission factors

The default wood carbon content value of 50 per cent, from table 12.4 of the 2006 IPCC Guidelines (IPCC, 2006a), 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 cubic metre is used for sawnwood produced from coniferous species (Jones, 2005). This value is used to reflect coniferous species' contribution to New Zealand roundwood, which makes up around 98 per cent of annual harvest. A country-specific wood density value of 500 kilograms per cubic 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 6.9.1).

Exported raw logs are first converted to tonnes of carbon, based on the carbon fractions for coniferous species and for non-coniferous species as outlined above. This carbon is then apportioned into each export market and wood product combination (sawnwood, panels, and paper).

Table 6.9.1 Conversion factors for *Harvested wood products* produced from New Zealand wood in New Zealand

Category	Factor (t C/m^3 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 increase the accuracy of the estimates over the default categories (*Solid wood* and *Paper and paperboard*) (table 12.2, IPCC, 2006a).

Most of New Zealand's exported logs are converted into construction and packaging material (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*, as demonstrated in table 6.9.2. 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. Further information on the half-lives for conversions of exported logs is provided in annex A3.2.6.

Table 6.9.2 Comparison of weighted half-lives for harvested wood products produced in export markets and the defaults applied in the IPCC, 2014 guidance

	Weighted half-lives		
Country	Sawnwood	Wood panels	Paper
China	8.3	8.3	2
India	1.4	10.4	2
South Korea	15.5	23.9	2
Japan	3.1	2.8	2
Other	8.3	8.3	2
IPCC default	35	25	2

6.9.3 Uncertainties and time-series consistency

The uncertainty in net carbon emissions from *Harvested wood products* was 68.2 per cent in 2021*,* which accounted for 28.0 per cent of the total uncertainty in emissions from the LULUCF sector. Uncertainty in the *Harvested wood products* estimates is introduced by activity data, conversion factors and decay parameters and is driven by large removals in this pool and high uncertainty associated with the end-use and discard rates of New Zealand wood. The methods used to calculate the uncertainty are further described in annex A3.2.8.

Time-series consistency is ensured by applying consistent methods and full recalculations in the event of any refinement or improvement to methodology.

6.9.4 Category-specific QA/QC and verification

Activity data for roundwood are sourced from annual statistics produced by MPI. However, as section 6.3 describes, the methodology for estimating above-ground biomass losses on harvest uses the LUCAS model, which combines harvest area by age with yield table carbon values. To ensure consistency between MPI roundwood volume statistics and LUCAS harvest estimates, a comparison between the two data sources across the time series was carried out and is further described in annex A3.2.5 'Forest land model validations'.

The results show a relatively good match between the two data sources between 2013 and 2020. This is because roundwood volume is now used to determine the total destocking area over this period. However, the two data sources deviate in earlier years. LUCAS above-ground biomass losses from harvest are greater than those estimated from roundwood volume statistics from 1996 to 2012 and are slightly lower from 1990 to 1994.

The implications of these earlier differences are that New Zealand may be reporting more carbon losses from harvesting and deforestation than carbon gains from roundwood creation and inputs into the *Harvested wood products* pool across most of the time series.

Work is under way to establish how best to fix this inconsistency through the time series.

6.9.5 Category-specific recalculations

All data on total roundwood production, roundwood exports and the production of New Zealand processed wood products were previously sourced from the FAOSTAT database. During the review of the 2021 submission, and in line with review recommendation L.11/FCCC/ARR/2019/NZL, concerns were raised around the reliability and timeliness of this data set. From the 2022 submission onwards these data are now being sourced directly from MPI published statistics (Ministry for Primary Industries, 2022a, 2022c). This means that up-to-date data on roundwood production and trade, and wood production are now available for the current reporting year. Therefore, the 1990 and 2020 *Harvested wood products* removal and emission estimates have not changed as MPI data are usually final and do not fluctuate on an annual basis.

Table 6.9.3 Recalculations for New Zealand's net emissions from the *Harvested wood products* category in 1990 and 2020

Year	Net emissions (kt CO_2-e) 2021 submission	Net emissions (kt CO_2-e) 2022 submission	Change from the 2021 submission (kt CO_2-e)	Change from the 2021 submission (%)
1990	−2,481.2	−2,481.2	0.0	0.0
2020	−6,834.6	−6,834.6	0.0	0.0

6.9.6 Category-specific planned improvements

Data are now available on the country-specific end-use products and half-lives of roundwood logs processed and consumed in New Zealand (Ministry for Primary Industries, 2022b; Wekesa, 2022). Research is currently under way to update the existing *Harvested wood products* model to include this information. Moreover, the research will update decay profiles for country-specific end-use products and harvested wood products sold abroad in different export markets. The findings will be included in the 2024 inventory submission.

6.10 Non-CO_2 emissions (CRF 4(I–V))

In 2021, net N_2O emissions from soils associated with land-use change reported in the LULUCF sector were 225.2 kt CO_2-e (see table 6.10.1). This is 74.8 kt CO_2-e (24.9 per cent) lower than the 1990 level of 300.0 kt CO_2-e.

Table 6.10.1 N_2O emissions from soils associated with land-use change reported in the LULUCF sector from 1990 to 2021

Emissions source	Net emissions (kt N_2O) 1990	Net emissions (kt N_2O) 2021	Net emissions (kt CO_2-e) 1990	Net emissions (kt CO_2-e) 2021	Change from 1990 (%)
Direct emissions from nitrogen mineralisation/ immobilisation	0.6	0.3	181.4	82.1	−54.7
Direct emissions from drainage of organic and mineral soils	0.3	0.4	77.8	124.6	60.2
Indirect emissions from leaching and runoff	0.1	0.1	40.8	18.5	−54.5
Total	**1.0**	**0.8**	**300.0**	**225.2**	**−24.9**

Note: Columns may not total due to rounding.

6.10.1 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 is reported in the CRF tables for the LULUCF sector.

6.10.2 Emissions from drainage and rewetting of organic and mineral soils (CRF 4(II))

Description

New Zealand reports on N_2O emissions, as a result of oxidation of organic matter, from the drainage of organic soils. N_2O emissions on *Croplands* and *Grasslands* are reported under the Agriculture sector. Direct N_2O emissions from drained organic soils in *Forest land* are estimated to be 0.4 kt N_2O in 2020 compared with 0.3 kt N_2O in 1990.

Methodological issues

To estimate N_2O emissions associated with the drainage of organic soils on forest land, New Zealand uses the Tier 1 method outlined in the 2006 IPCC Guidelines (equation 11.1, IPCC, 2006a). The Tier 1 default value for temperate, nutrient-poor forest soils of 0.1 kg N_2O-N ha^{-1} is applied. Note that the area of pre-1990 natural forest remaining pre-1990 natural forest on organic soils is assumed to be in its natural, undisturbed state, and therefore is presumed not to be drained.

6.10.3 Direct N_2O emissions from nitrogen mineralisation/immobilisation (CRF 4(III))

Description

Direct N_2O emissions from nitrogen mineralisation/immobilisation are minor in New Zealand, estimated at 0.3 kt N_2O in 2021 compared with 0.6 kt N_2O in 1990. Note that N_2O emissions on *Cropland remaining cropland* from nitrogen mineralisation/immobilisation are reported under the Agriculture sector. Direct N_2O emissions from nitrogen mineralisation/immobilisation associated with land-use change for all other land use categories are reported under the LULUCF sector.

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).

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 annex A3.2.4, table A3.2.6). In these situations, the notation key NO (not occurring) is reported in the CRF tables.

6.10.4 Indirect N_2O emissions from leaching and runoff (CRF 4(IV))

Indirect N_2O emissions from leaching and runoff is associated with mineralisation of N from loss of soil carbon in mineral and drained/managed organic soils through land-use change or management practices. Emissions on *Cropland remaining cropland* from leaching and runoff are reported under the Agriculture sector. Indirect N_2O emissions from leaching and runoff for all other land use categories are reported under the LULUCF sector.

Indirect emissions from leaching and runoff in all land use categories excluding *Cropland remaining cropland* were estimated as 0.1 kt N_2O in 2021, which is the same as the value reported in 1990.

Methodological issues

New Zealand applies the Tier 1 method outlined in the 2006 IPCC Guidelines (equation 11.10, IPCC, 2006a) for estimating N_2O emissions from leaching and runoff. The following are the inputs to this equation.

- F_{SOM} – annual amount of N mineralised in mineral soils associated with loss of soil C from soil organic matter as a result of changes to land use or management in regions where leaching/runoff occurs, kg N yr^{-1}, is calculated using the method described in section 6.10.3 above.
- EF_5 – emission factor for N_2O emissions from N leaching and runoff, kg N2O–N (kg N leached and runoff)$^{-1}$ uses the default emission factor of 0.0075 provided in table 11.3 (IPCC, 2006a).
- $Frac_{LEACH-(H)}$ – fraction of all N added to/mineralised in managed soils in regions where leaching/runoff occurs that is lost through leaching and runoff, kg N (kg of N additions)$^{-1}$ uses the default value of 0.30 provided in table 11.3 (IPCC, 2006a).

6.10.5 Indirect N_2O emissions from atmospheric deposition of N volatilised from managed soil (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 atmospheric deposition of N volatilised from managed soil* within CRF table 3.D.b in the Agriculture sector and uses the notation key IE within CRF table 4(IV) of the LULUCF sector.

6.10.6 Uncertainties and time-series consistency for N_2O emissions in soils associated with land-use change

The uncertainty in net N_2O emissions from nitrogen in soils associated with land-use change in 2021 is outlined in table 6.10.2. The methods used to calculate the uncertainty are further described in annex A3.2.8.

Table 6.10.2 Net N_2O emissions from nitrogen in soils associated with land-use change in 2021

	Emissions (kt CO_2-e)	Uncertainty in emissions (%)	Contribution to LULUCF uncertainty (%)
Direct N_2O emissions from N mineralisation/immobilisation	82.1	86.9	0.3
Direct N_2O emissions from drainage and rewetting	124.6	86.5	0.5
Indirect emissions from leaching and runoff	18.5	127.8	0.1

Time-series consistency is ensured by applying consistent methods and full recalculations in the event of any refinement or improvement to methodology.

6.10.7 Source-specific planned improvements for N_2O emissions in soils associated with land-use change

Nitrous oxide emissions associated with the drainage of organic soils in *Settlements* will be included in the 2024 submission as New Zealand considers that most of its *Settlements* area can be assimilated to *Grassland* when it comes to soil carbon. This is covered in section 6.7.6.

6.10.8 Biomass burning (CRF 4(V))

Description

Non-CO_2 emissions from *Biomass burning* in 2021 were 1.3 kt CH_4 (32.6 kt CO_2-e) and 0.1 kt N_2O (22.2 kt CO_2-e) (see table 6.10.3).

Table 6.10.3 Non-CO_2 emissions from *Biomass burning*

Emissions	1990	2021	Change since 1990 (%)
CH_4 emissions (kt CH_4)	2.7	1.3	–52.3
N_2O emissions (kt N_2O)	0.1	0.1	–13.3

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 (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 tussock land (in ecosystems dominated by *Chionochloa* spp.) and from wildfires in exotic pasture grassland.

Methodological issues

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), (e); Payton and Pearce, 2009) is 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). These variables are summarised in tables 6.10.4 and 6.10.5 and further information on their application is provided in annex A3.2.7.

Table 6.10.4 Summary of *Biomass burning* carbon fractions and emission factors

	Biomass burning implied emission factors derived from 2006 IPCC Guidelines (IPCC, 2006a) and New Zealand-specific carbon fractions							
	Grassland/savannah		**GWB/shrubland**		**Forest land**			
	Controlled burning	Wildfire	Controlled burning	Wildfire	Controlled burning		Wildfire	
					Planted forest	Natural forest	Planted forest	Natural forest
Carbon fraction	0.44	0.44	0.44	0.44	0.51*	0.47	0.51*	0.47
C:N ratio	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
CO emission factor	0.06	0.06	0.06	0.06	0.09	0.10	0.09	0.10
CH_4 emission factor	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01
N_2O emission factor	0.03	0.03	0.03	0.03	0.03	0.04	0.03	0.04
NO_x emission factor	0.27	0.27	0.27	0.27	0.18	0.19	0.18	0.19

Note: GWB = grassland with woody biomass. Values are rounded to two decimal places. *0.51 New Zealand-specific carbon fraction for planted forests (Beets, unpublished).

Table 6.10.5 Summary of *Biomass burning* combustion factor values

<table>
<tr><th colspan="4">Combustion factor values (proportion of pre-fire biomass consumed) for fires (table 2.6, IPCC, 2006a)</th></tr>
<tr><th></th><th colspan="2">Vegetation type</th><th>Value</th></tr>
<tr><td rowspan="3">Forest</td><td rowspan="2">Other temperate forests</td><td>Post logging slash burn</td><td>0.62</td></tr>
<tr><td>Felled and burned (land clearing fire)</td><td>0.51</td></tr>
<tr><td colspan="2">All “other” temperate forests</td><td>0.45</td></tr>
<tr><td rowspan="3">GWB and shrubland</td><td colspan="2">Shrubland (general)</td><td>0.95</td></tr>
<tr><td colspan="2">All shrubland</td><td>0.72</td></tr>
<tr><td colspan="2">GWB NZ-specific</td><td>0.7*</td></tr>
<tr><td rowspan="4">Grassland</td><td colspan="2">All savannah/grasslands (early dry season burns)</td><td>0.74</td></tr>
<tr><td colspan="2">All savannah/grasslands (mid/late dry season burns)</td><td>0.77</td></tr>
<tr><td colspan="2">Average of IPCC savannah/grasslands</td><td>0.755</td></tr>
<tr><td colspan="2">Controlled grassland burn NZ specific</td><td>0.555**</td></tr>
</table>

Note: GWB = grassland with woody biomass. *Wakelin (unpublished(e)) **Payton and Pearce (2009).

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 resulting from *Biomass burning* are reported as IE, where emissions are captured in the stock change calculation within the land use category.

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. This is because emissions from the burning of crop stubble associated with controlled burning in *Cropland* are reported under the Agriculture sector and reported within CRF table 3.F.

Both CO and NO_x are also released from biomass burning and are reported in relevant aggregate land use categories. Carbon monoxide and NOx emissions from biomass burning are captured as part of the biomass burning model and reported in the CRF.

Controlled burning emissions are reported within:

- *Grassland* converted to *Forest land* (due to site preparation for conversion)
- *Forest land remaining forest land* (from the clearing of vegetation (natural forest) before the establishment of exotic planted forest and the burning of post-harvest slash before restocking)
- *Forest land* converted to *Grassland* (from controlled burning associated with deforestation)
- *Grassland remaining grassland* (due to savanna (tussock) and pastureland management practices).

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 is used.

Wildfire activity data are sourced from Fire and Emergency New Zealand (FENZ). Historically, burned areas were estimated and allocated by field staff to vegetation types: grass, tussock, gorse, scrub, wetland, plantation forest and indigenous forest. The process (since 2017) now involves mapping the burn area. This area is overlaid on the 2016 land use map in order to determine what type of land cover has been burnt.

Activity data for controlled burning for *Forest land* are estimated based on a 2011 survey of forest owners (Wakelin, unpublished(d)). 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. Earlier estimates of controlled burning in planted forest (Forest Industry Training and Education Council, 2005; Robertson, 1998) were used in addition to the 2011 survey to provide activity data throughout the time series. Further details of the survey findings and extrapolation can be found in annex A3.2.7.

Activity data are combined with emission factors derived from the national forest plot network (see table 6.3.8) to estimate non-CO_2 emissions from burning associated with the clearing of vegetation before the establishment of exotic planted forest. Below-ground biomass is assumed not to burn. Further detailed information on the methodology applied can be found in annex A3.2.7.

Biomass burning is not a key category for New Zealand.

Uncertainties and time-series consistency

The uncertainty in net emissions from CH_4 and N_2O emissions from *Biomass burning* was 51.3 per cent in 2021. Emissions from *Biomass burning* accounted for 0.1 per cent of the net emissions from the LULUCF sector.

Time-series consistency is ensured by applying consistent methods and full recalculations in the event of any refinement or improvement to methodology.

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), (c), (d), (e); 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 not been updated in this submission (see section 6.3.5 for further details).

Wildfire activity data for 2018 to 2020 have been updated for this submission to incorporate both improvements to mapping of the wildfire extent and updates to the vegetation classification from the land use map. 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, most solid waste is disposed to land. The majority of the country's household and commercial waste is placed in managed municipal landfills. Before 2010, some municipal waste was also disposed to unmanaged or uncategorised sites. Unmanaged[65] sites consist of many small landfills, such as those on farms and in industry, which are still in operation. One major exception to disposal to land is that about half of all farm waste is disposed by open burning. Figure 7.1.1 shows the sources of and disposal practices for solid waste in New Zealand.

Most wastewater treatment in New Zealand is aerobic, including domestic, commercial and industrial wastewater, which releases methane (CH_4) emissions. Methane emissions from domestic wastewater are mainly from rural septic tank usage. Wastewater emissions also occur 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 generally not incinerated in New Zealand. Incineration is used only on a very small scale, mainly for hazardous waste, clinical waste and sewage sludge, and has declined over time due to environmental regulation and the availability of other disposal options.

Emissions from composting activities are included. An anaerobic digestion plant is under development, however, it was not yet operating in 2021. No other emission sources for direct greenhouse gases are applicable to New Zealand and no other activity data are available.

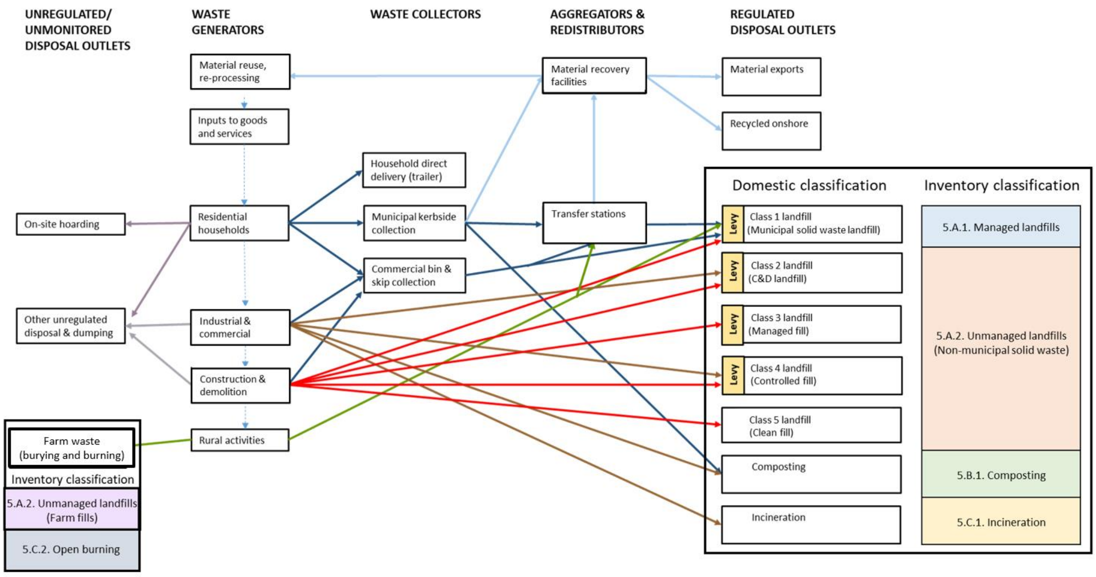
In 2022, the Ministry for the Environment published the first emissions reduction plan, which sets out actions for achieving New Zealand's emissions budget for 2022–25, and chapter 15 in the plan covers actions for waste.[66] The effects of these actions will be reported in future inventories.

The impact of COVID-19 on emissions from the Waste sector is negligible, because annual variations are within usual ranges. In addition, variations to solid waste disposal activity have a reduced effect on annual emissions. This is due to the dampening effect of the first-order decay models used to estimate emissions from landfills.

[65] This chapter uses classifications according to the United Nations Framework Convention on Climate Change (UNFCCC) and Intergovernmental Panel on Climate Change (IPCC) reporting guidelines. The sites categorised as 'unmanaged' may actually be managed by requirements such as council consent conditions; however, they do not meet the definition of a managed landfill under the greenhouse gas inventory (IPCC, 2006a).

[66] See New Zealand's first emissions reduction plan at environment.govt.nz/publications/aotearoa-new-zealands-first-emissions-reduction-plan.

Figure 7.1.1 Flows of solid waste generation and disposal in New Zealand



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 (91.9 per cent) followed by nitrous oxide (N_2O) (5.3 per cent) and carbon dioxide (CO_2) emissions (2.8 per cent). The Waste sector produces 9.0 per cent of gross CH_4 emissions in New Zealand. There are also emissions of CO_2 from the disposal of solid waste, but these are of biogenic origin and are not reported.

2021

In 2021, emissions from the Waste sector contributed 3,214.9 kt CO_2-e or 4.2 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.

1990–2021

In 2021, emissions from the Waste sector decreased by 18.5 per cent (729.7 kt CO_2-e), from 3,944.6 kt CO_2-e in 1990.

Annual emissions increased between 1990 and 2002, peaking at 4,470.0 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 in emissions is primarily 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 chapter 2, figure 2.2.11 and in figures 7.1.2 and 7.1.3.

2020–2021

Between 2020 and 2021, emissions from the Waste sector decreased by 51.6 kt CO_2-e (1.6 per cent). This decrease is largely the result of decreases in CH_4 emissions in the *Managed waste disposal sites* category mainly due to increasing landfill gas capture and changes in the composition of waste, with a reduction in the proportion of garden, food and paper waste disposed to those sites.

Table 7.1.1 New Zealand's greenhouse gas emissions for the Waste sector by source category in 1990 and 2021

	Emissions (kt CO_2-e)		Difference (kt CO_2-e)	Change (%)	Share (%)	
Source category	**1990**	**2021**	**1990–2021**	**1990–2021**	**1990**	**2021**
Solid waste disposal (5.A)	3,318.2	2,578.2	–740.0	–22.3	84.1	80.2
Biological treatment of solid waste (5.B)	4.7	72.1	67.4	1,435.0	0.1	2.2
Incineration and open burning of waste (5.C)	315.7	187.1	–128.6	–40.7	8.0	5.8
Wastewater treatment and discharge (5.D)	306.0	377.6	71.6	23.4	7.8	11.7
Waste sector total	**3,944.6**	**3,214.9**	**–729.7**	**–18.5**	**–**	**–**

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

Figure 7.1.2 Profile of emissions from New Zealand's Waste sector by source category from 1990 to 2021

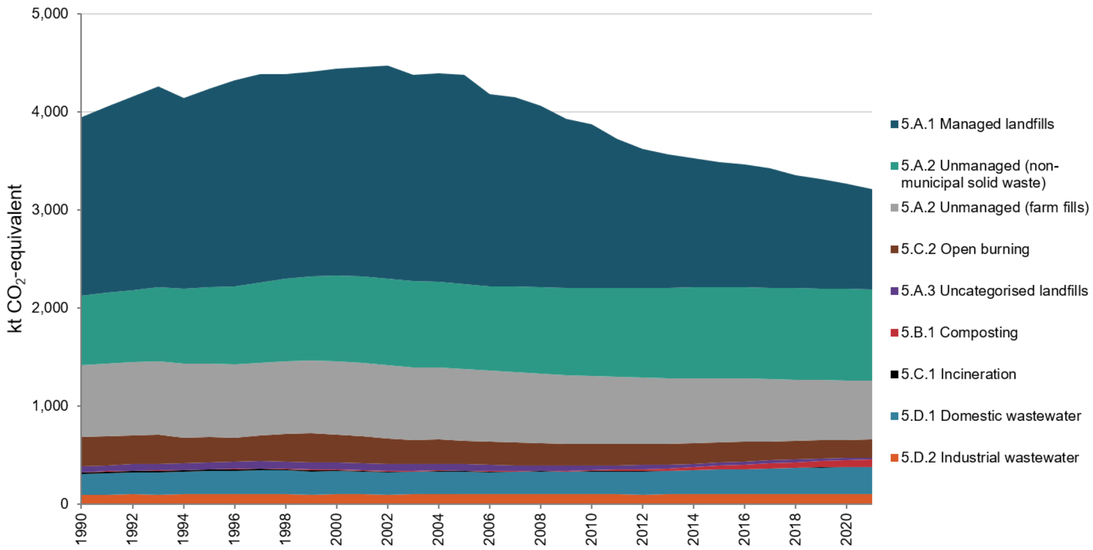
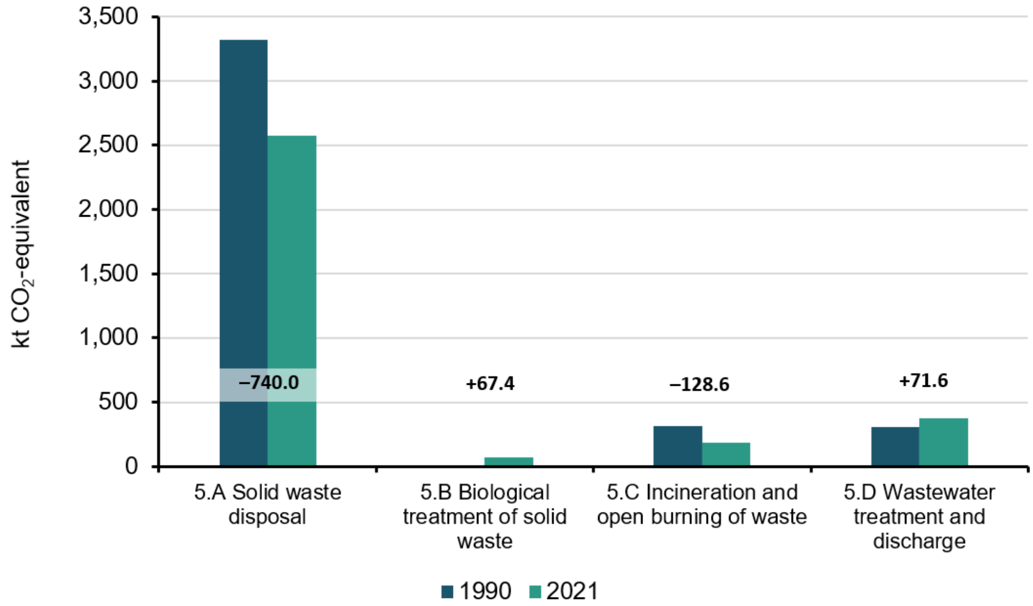


Figure 7.1.3 Change in New Zealand's emissions from the Waste sector by source category from 1990 to 2021



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 category	Gas	Criteria for identification
5.A	Solid waste disposal	CH_4	L1, T1
5.C	Incineration and open burning of waste	CO_2	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 (Eunomia, unpublished(a)) 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 seawater due to uncertainty in the emission factors.

7.1.6 Verification

Where available, data from different sources were used for verification. All of the municipal landfills report their activity data either monthly or annually under the requirements of the Waste Minimisation Act 2008. In addition, most of these landfills also report activity data and estimated emissions (by mass balance) 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

Improvements and recalculations made to estimates in the Waste sector have resulted in a 0.04 per cent (1.5 kt CO_2-e) increase in emissions in 1990 and a 0.1 per cent (2.4 kt CO_2-e) decrease in emissions in 2020.

Minor changes have been made that affect emissions as follows.

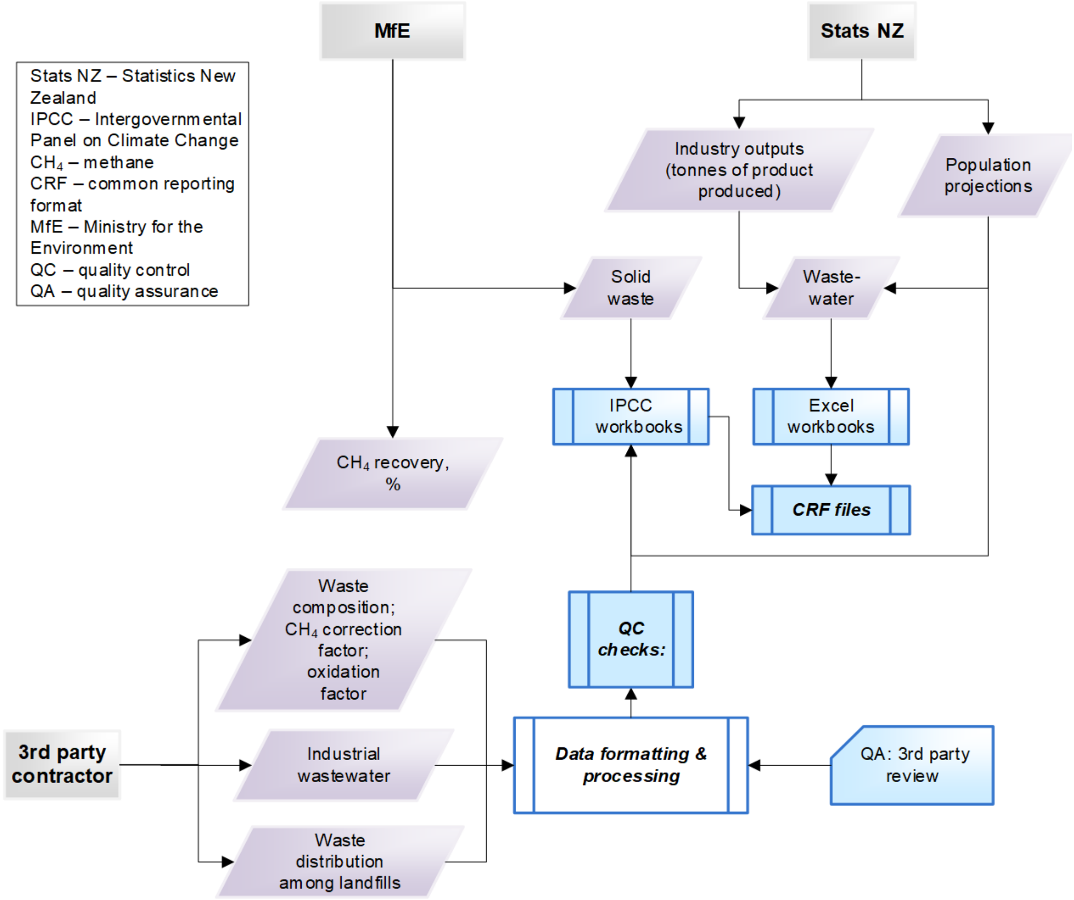
- Accuracy: activity data for *Managed waste disposal sites* were revised for 2018, 2019 and 2020, to remove small amounts of cover material that should not be included in the waste tonnage.
- Accuracy: the Coulson Road landfill within the *Managed waste disposal sites* category stopped accepting waste in 2019, and, as a result, the landfill gas capture rate was revised for the entire duration of gas capture beginning in 2018 from 68 per cent to 52 per cent, which is the value for closed sites. Further, the Victoria Flats landfill had a gas capture system installed during 2021, and the estimate for 2021 reflects this.
- Completeness: activity data for *Composting* is revised upward to account for the effects of policy actions beginning in 2020.
- Accuracy: activity data for *Industrial wastewater* is revised for the paper and paperboard and wood pulp industries due to revised statistics.

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 7.1.4 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 7.1.4 Tier 1 quality checks for the Waste sector



7.2 Solid waste disposal (5.A)

7.2.1 Description

Household, industrial and commercial[67] solid waste in New Zealand is disposed of almost exclusively to landfills, except for about half of all farm waste, which is disposed by open burning. The three broad types of landfill sites in New Zealand are:

1. municipal landfills, which are used for disposal of household waste but also accept industrial waste or other types of solid waste
2. non-municipal landfills, including 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 (in addition to open burning) 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, due to first-order decay, some emissions continue to come from uncategorised municipal landfill sites, which were in operation before 2010.

[67] The term 'industrial and commercial' is used in a general sense in this report, which is different from how these terms are used in a domestic policy setting.

Table 7.2.1 **Landfill emissions in the common reporting format table**

CRF category code	Landfill type using New Zealand terminology	Comment
5.A.1.a (Anaerobic)	Managed municipal landfills (Class 1)	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 (Classes 2–5)	Includes industrial landfills
5.A.2 (Unmanaged)	Farm fills	Disposal of about half of farm waste
5.A.3 (Uncategorised)	Other municipal landfills (now closed)	While disposal is prior to 2010 only, emissions continue to be reported due to decay over time

Since 1990, several initiatives have been undertaken to improve solid waste management practices in New Zealand. These include:

- requirements for all municipal 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 (LFG). 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). There is a new waste strategy currently in development as at the time of the 2023 submission[68]
- 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 Ministry for the Environment has commissioned an update to the 2002 Solid Waste Analysis Protocol, which is not yet finalised as of the 2023 submission
- the Waste Minimisation Act 2008, which imposes a levy on the disposal of municipal solid waste and enables regulations to establish product stewardship requirements and for information reporting. The levy started at NZ$10 per tonne and is increasing over time, to NZ$20 per tonne from 1 July 2021 for municipal landfills and up to NZ$60 per tonne from 1 July 2024. Further, the levy is expanding over time to numerous non-municipal landfills (construction and demolition fills) as of 1 July 2022.

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 closed, and most communities are now using larger, more modern regional facilities for disposal of their waste. In 2020, 39 municipal landfill sites were active, in comparison with 327 in 1995 and 563 in 1971. These changes have occurred because the policy initiatives outlined above lead to a consolidation of solid waste into fewer, better-managed landfills. The overall volume of waste disposal to these landfills has increased over time, especially to non-municipal fills (see tables 7.2.3 and 7.2.4). The increased disposal activity and reduction in the number of landfills means the operating facilities are larger.

[68] More information can be found about the new waste strategy and other developments at environment.govt.nz/what-government-is-doing/areas-of-work/waste/waste-legislation-review.

Non-municipal landfills and farm fills are required to comply with regional policies and plans made under the Resource Management Act 1991. For most of the time series, these facilities were not required to monitor and report the waste they accept, or to pay the waste levy or to participate in the NZ ETS.

In 2021, the *Solid waste disposal* source category contributed 2,578.2 kt CO_2-e (80.2 per cent) of total emissions from the Waste sector. Emissions from *Solid waste disposal* in 2021 were 740.0 kt CO_2-e (22.3 per cent) below the 1990 level of 3,318.2 kt CO_2-e. While there is year-to-year variation, this net decrease is the result of two contrary trends. First, population and economic growth have driven ongoing increases in the total and per capita amount of municipal waste generated but, secondly, changing composition over time and improved landfill management practices, particularly LFG recovery, have offset this increase, resulting in emissions peaking in 2002.

Methane emissions from *Solid waste disposal* were identified as a key category in the 2021 level assessment and trend assessment.

7.2.2 Methodological issues

Choice of activity data

Activity data for *Solid waste disposal* vary significantly in quality and quantity. Most data are based on estimates and infrequent surveys rather than annual data, except for municipal sites since 2010.

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 involves a linear interpolation. Other methods were explored, but this approach gave the most robust estimates (Eunomia and Waste Not Consulting, 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, 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 an LFG system in 2018. Both have been included in the emissions estimates. From 2010 onwards, all municipal landfills report volumes of waste placement under the Waste Minimisation Act 2008. Table 7.2.2 shows the number of managed landfills.

Table 7.2.2 Landfill categories in 2021

Landfill type	Sites with LFG recovery	Sites without LFG recovery	Total
Landfills under the NZ ETS and waste levy	18	20	38
Closed landfills (still emitting)	9	Not reported	Not reported
Total	27	Not reported	Not reported

Note: LFG = landfill gas; NZ ETS = New Zealand 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:

$$\text{disposal for } 5.A.3 = \ 10\% \times (\text{national total} - \text{disposal for LFG sites})$$

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 2021. 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 systems installed before 1985.

Table 7.2.3 Solid waste deposited to municipal and uncategorised landfills from 1950 to 2021

Year	Sites with LFG recovery (kt)	Sites without LFG recovery (kt)	Uncategorised sites (kt)	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	20.0	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	33.0	778.2
1964	447.9	369.1	41.0	858.0
1965	447.9	477.2	53.0	978.1
1966	447.9	566.8	63.0	1,077.6
1967	495.8	486.0	54.0	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	83.0	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

Year	Sites with LFG recovery (kt)	Sites without LFG recovery (kt)	Uncategorised sites (kt)	Total (kt)
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
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	1,605.0	1,067.2	92.8	2,765.0
1999	1,605.0	1,134.5	89.8	2,829.3
2000	1,605.0	1,202.6	85.9	2,893.5
2001	1,748.3	1,136.9	72.6	2,957.8
2002	1,797.0	1,159.7	65.3	3,022.0
2003	1,694.9	1,297.1	63.5	3,055.5
2004	1,746.2	1,289.1	53.7	3,089.0
2005	1,954.3	1,129.2	38.9	3,122.5
2006	2,384.2	751.2	20.6	3,156.0
2007	2,244.9	739.8	15.1	2,999.8
2008	2,189.3	645.4	8.7	2,843.5
2009	2,143.9	539.8	3.6	2,687.2
2010	2,338.7	193.8	NO	2,532.5
2011	2,330.1	182.4	NO	2,512.5
2012	2,335.8	179.1	NO	2,515.0
2013	2,524.2	161.2	NO	2,685.4
2014	2,776.8	156.2	NO	2,933.1
2015	3,053.9	168.5	NO	3,222.4
2016	3,232.9	172.1	NO	3,404.9
2017	3,349.1	145.2	NO	3,494.3
2018	3,610.1	95.1	NO	3,705.3
2019	3,405.8	93.9	NO	3,499.7
2020	3,297.2	85.8	NO	3,382.9
2021	3,424.8	113.0	NO	3,537.8

Note: 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 predominantly accept commercial and industrial waste. They are not intended to accept household waste; however, they do account for a small amount of municipal waste. Non-municipal landfills 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)). These sites are subject to mandatory reporting (with obligations beginning 1 January 2022 for construction and demolition sites and 1 January 2023 for other sites, including cleanfills and industrial monofils).

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 of each type 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 and limited in relation to the number and type of farms in New Zealand. Further, the overall volume of farm waste is based strictly on the number of farms and does not account for changing farm sizes over time, noting that the number of farms has decreased since the 1990s.

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 and across time (Tonkin and Taylor Ltd, unpublished(b)).

Data obtained from the Agriculture Production Survey has been used to estimate the number and type of farms throughout the time series. The Agriculture Production Survey also provides the livestock numbers used in the Agriculture sector, which ensures consistency between the sectors.

A change introduced in the 2021 submission is that the methods of disposal of farm waste are evenly split between disposal to land in farm fills and disposal by open burning, at 47 per cent each (noting that 6 per cent is disposed in other ways). Previous submissions assumed that open burning was only about 2 per cent of the farm waste, because Tonkin and Taylor Ltd (unpublished(b)) reported that “the majority of wastes were buried”. However, open burning is a common practice in New Zealand, in part evidenced by the dozens of complaints received by regional councils each year about potential issues with open burning. Further, GHD (2014) states “the surveys team felt that burning was the most prevalent practice, with virtually every farm having a burn pile, or some form of brazier” and GHD (2013) states “other wood waste was invariably burnt”. Wood wastes make up a large proportion of methane emissions from farm fills, so it is appropriate to account for farm waste, including wood that is burned instead of buried.

Taking a balanced approach, this submission has assumed an even split in the absence of better information. In 2022, Eunomia (unpublished(c)) investigated this further with experts from around the country and found this assumption was still appropriate. This will be revised again when quantitative data become available.

Table 7.2.4 shows waste placement for farm fills only (not including open burning or other disposal methods) and non-municipal landfills from the beginning of the model in 1950 to 2021.

Table 7.2.4 Solid waste deposited to unmanaged landfills from 1950 to 2021

Year	Farm fills (kt)	Non-municipal landfills (kt)	Total waste disposed (kt)
1950	866.3	763.8	1,630.1
1951	865.7	791.9	1,657.6
1952	866.2	820.9	1,687.2
1953	868.6	851.0	1,719.6
1954	879.7	882.2	1,761.9
1955	886.5	914.5	1,801.0
1956	812.7	948.0	1,760.7
1957	811.7	982.7	1,794.4
1958	796.6	1,018.6	1,815.2
1959	799.7	1,055.8	1,855.5
1960	738.1	1,094.4	1,832.5
1961	702.0	1,134.4	1,836.3
1962	698.0	1,175.8	1,873.8
1963	693.6	1,218.6	1,912.2
1964	687.9	1,263.1	1,950.9
1965	676.1	1,309.1	1,985.2
1966	670.6	1,356.8	2,027.3
1967	654.1	1,406.1	2,060.3
1968	641.5	1,457.3	2,098.8
1969	636.9	1,510.3	2,147.1
1970	626.8	1,565.2	2,192.0
1971	622.5	1,622.0	2,244.5
1972	602.4	1,680.9	2,283.3
1973	606.3	1,741.9	2,348.2
1974	608.8	1,805.0	2,413.8
1975	643.4	1,870.5	2,513.9
1976	650.2	1,938.2	2,588.5
1977	657.9	2,008.4	2,666.3
1978	665.8	2,081.7	2,747.6
1979	675.9	2,088.3	2,764.3
1980	686.0	2,134.1	2,820.1
1981	695.7	2,161.5	2,857.2
1982	709.3	2,262.1	2,971.4
1983	726.7	2,283.2	3,009.9
1984	735.2	2,362.9	3,098.1
1985	756.1	2,476.1	3,232.2
1986	765.8	2,516.1	3,282.0
1987	775.2	2,584.2	3,359.4
1988	787.3	2,609.3	3,396.6
1989	793.3	2,600.1	3,393.4
1990	783.7	2,604.3	3,387.9
1991	777.9	2,608.2	3,386.1

Year	Farm fills (kt)	Non-municipal landfills (kt)	Total waste disposed (kt)
1992	768.9	2,579.8	3,348.7
1993	784.4	2,608.0	3,392.4
1994	669.9	2,774.7	3,444.6
1995	663.5	2,916.8	3,580.2
1996	637.3	3,054.5	3,691.8
1997	684.9	3,164.9	3,849.8
1998	732.4	3,229.8	3,962.2
1999	779.9	3,255.6	4,035.5
2000	745.8	3,433.0	4,178.9
2001	711.7	3,532.8	4,244.5
2002	677.6	3,655.2	4,332.8
2003	636.6	3,826.0	4,462.6
2004	641.4	4,000.1	4,641.5
2005	621.4	4,161.2	4,782.6
2006	622.9	4,299.4	4,922.3
2007	611.2	4,423.3	5,034.5
2008	584.5	4,557.2	5,141.7
2009	572.4	4,506.6	5,079.0
2010	577.8	4,500.5	5,078.3
2011	559.8	4,569.1	5,128.8
2012	561.2	4,671.9	5,233.1
2013	546.9	4,776.8	5,323.7
2014	547.3	4,905.6	5,452.9
2015	533.0	5,092.8	5,625.8
2016	535.4	5,092.8	5,628.2
2017	505.5	5,092.8	5,598.3
2018	490.5	5,092.8	5,583.2
2019	478.9	5,092.8	5,571.6
2020	476.4	5,092.8	5,569.2
2021	480.8	5,092.8	5,573.6

Note: Columns may not total due to rounding. It is assumed that an equal and additional amount of farm waste that is buried in farm fills is burned (see section 7.4).

Choice of methods

Estimations of CH_4 emissions from *Solid waste disposal* to land were calculated 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)

Municipal landfills use a multi-phase FOD model consistent with the IPCC (2006a) model using country-specific parameters.

For each of the 27 landfill sites that had LFG recovery at any time, the FOD multi-phase model (IPCC, 2006a) has been applied to develop estimates of CH_4 emissions, with site-specific data on waste placement, k-values dependent on local climate, and an LFG recovery efficiency rate that reflects the landfill's operational status as either open or closed. The 19 sites that are still operational account for approximately 95 per cent of waste disposed to municipal landfills, as per the data in table 7.2.3.

Municipal waste outside of these 27 sites is disposed to smaller landfills that have never had gas recovery. In 1990, there were more than 300 of these sites and in 2021 approximately

21 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 as a whole, using the same approach as the sites with LFG recovery, except that all of these sites are assumed to have a wet climate and zero LFG recovery.

Non-municipal landfills and farm fills (5.A.2)

Non-municipal landfills include privately owned industrial landfills and a large number of landfill sites (cleanfills and construction and demolition fills) that are consented for largely inert waste. These sites in some cases are allowed to receive up to 5–10 per cent putrescible 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 from the proportion of total farm waste that is landfilled. 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 farms 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 commercial and 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, 2012 and 2018 based on individual landfill surveys (Eunomia, unpublished(a); Waste Not Consulting, unpublished(b), unpublished(c)). The waste surveys have been based on the Solid Waste Analysis Protocol (Ministry for the Environment, 2002b) to ensure consistent methodologies for sampling and analysis. The 2018 Solid Waste Analysis Protocol surveys assessed were conducted by territorial authorities from 18 disposal facilities and transfer stations, which collectively represent 66 per cent of all waste disposed of at municipal landfills in 2018.

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 and Waste Not Consulting, unpublished). Linear interpolation was used for years between the survey years, and the years since 2018 are assumed to be the same as 2018. 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 2021. 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 2021

Year	Food (%)	Garden (%)	Paper (%)	Wood (%)	Textile (%)	Nappies (%)	Sludge (%)	Inert (%)	Notes
1950–60	17.2	11.0	16.3	7.1	0.5	0.0	2.9	45.0	No nappies
1961–69	17.2	11.0	16.3	7.1	0.5	1.0	2.9	44.0	Interpolation
1970–79	17.2	11.0	16.3	7.1	0.5	2.0	2.9	43.0	Interpolation
1980–94	17.2	11.0	16.3	7.1	0.5	2.7	2.9	42.3	As for 1995
1995	17.2	11.0	16.3	7.1	0.5	2.7	2.9	42.3	National survey
1996	16.9	10.8	16.1	7.9	0.9	2.7	2.9	41.9	Interpolation
1997	16.5	10.6	16.0	8.6	1.3	2.7	2.9	41.4	Interpolation
1998	16.2	10.4	15.8	9.4	1.6	2.7	2.9	41.0	Interpolation
1999	15.9	10.1	15.7	10.1	2.0	2.7	2.9	40.6	Interpolation
2000	15.5	9.9	15.5	10.9	2.4	2.7	2.9	40.1	Interpolation
2001	15.2	9.7	15.4	11.6	2.8	2.7	2.9	39.7	Interpolation
2002	14.9	9.5	15.2	12.4	3.1	2.7	2.9	39.3	Interpolation
2003	14.5	9.3	15.1	13.1	3.5	2.7	2.9	38.8	Interpolation
2004	14.2	9.1	14.9	13.9	3.9	2.7	2.9	38.4	National survey
2005	14.9	9.2	13.4	13.4	3.9	2.9	2.9	39.4	Interpolation
2006	15.7	9.2	12.0	13.0	3.9	3.0	2.9	40.4	Interpolation
2007	16.4	9.3	10.5	12.5	3.9	3.2	2.9	41.4	Interpolation
2008	17.1	9.4	9.0	12.0	3.8	3.3	2.9	42.4	Survey
2009	17.0	9.1	9.4	12.0	4.3	3.2	3.1	41.8	Interpolation
2010	16.9	8.9	9.8	11.9	4.7	3.2	3.4	41.1	Interpolation
2011	16.9	8.6	10.3	11.9	5.2	3.1	3.6	40.5	Interpolation
2012	16.8	8.3	10.7	11.9	5.6	3.0	3.9	39.9	Survey
2013	15.5	7.9	9.9	12.0	5.5	2.9	3.6	42.8	Interpolation
2014	14.2	7.5	9.1	12.1	5.4	2.8	3.2	45.7	Interpolation
2015	12.9	7.0	8.3	12.2	5.3	2.7	2.9	48.6	Interpolation
2016	11.6	6.6	7.5	12.4	5.2	2.6	2.6	51.5	Interpolation
2017	10.3	6.2	6.7	12.5	5.1	2.6	2.3	54.4	Interpolation
2018	9.0	5.7	5.9	12.6	5.0	2.5	1.9	57.3	Survey
2019	9.0	5.7	5.9	12.6	5.0	2.5	1.9	57.3	Assumed same as 2018
2020	9.0	5.7	5.9	12.6	5.0	2.5	1.9	57.3	Assumed same as 2018
2021	9.0	5.7	5.9	12.6	5.0	2.5	1.9	57.3	Assumed same as 2018

The changes in composition over time lead to varying amounts of decomposable degradable organic carbon (DDOC) being entered into the landfill over time. Refer to table 7.2.6 for the values used for DDOC and other variables.

Methane correction factor, oxidation factor and fraction of methane in landfill gas (F)

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.

The fraction of methane in landfill gas (F) is 57 per cent for municipal landfills (Eunomia, unpublished(a)). This figure is based on research in the United Kingdom and the general similarities in landfill management practices between the United Kingdom and New Zealand. Uncategorised sites use the IPCC (2006a) default of 50 per cent.

Methane generation rates

The study by Eunomia (unpublished(a)) provides the parameters used to determine the quantity and rate of methane generation. Table 7.2.6 details the parameters used.

Table 7.2.6 Parameters by waste type that determine the quantity and rate of methane generation

Parameter	Food	Garden	Paper	Wood	Textile	Nappies	Sludge[b]
DDOC	0.11[a]	0.09	0.16	0.06	0.20 (1950s) to 0.08 (2020 onwards)	0.04	0.025
DOCf[c]	0.7	0.56	0.5	0.14	0.5	0.5	0.5
DOC (=DDOC/DOCf)	0.16	0.16	0.32	0.43	0.40 (1950s) to 0.16 (2020 onwards)	0.08	0.05
k-value wet sites (>700 mm rain/year)	0.69	0.12	0.076	0.076	0.076	0.12	0.19
k-value dry sites	0.12	0.076	0.046	0.046	0.046	0.076	0.19

Note: DDOC = decomposable degradable organic carbon; DOC = degradable organic carbon; DOCf = DOC fraction. All parameters are from Eunomia (unpublished(a)) except: (a) DDOC for food is from IPCC (2019); (b) all values for sludge are from IPCC (2006a) default wet temperate; and (c) all DOCf values are from IPCC (2019) except for garden waste.

Eunomia (unpublished(a)) recommended DOC fraction (DOCf) values consistent with the 2019 refinement to the 2006 IPCC Guidelines, except for garden waste, which is adjusted for a proportion of woody branches. DOC values are calculated based on the ratio of the DDOC to DOCf instead of being given explicitly. The DDOC values for all materials differ from IPCC (2006a) defaults, which is largely a reflection of global trends in the characteristics of materials. On balance, the most suitable DDOC for food is the IPCC default (IPCC, 2019). Paper is lower than the IPCC (2006a) default to account for the types of paper such as magazine and newsprint paper that do not degrade as easily as plain paper due to their high lignin content. The wood DDOC is specific to New Zealand, much lower than IPCC (2006a) defaults but closer to IPCC (2019) values, because it accounts for the ratio of treated and untreated wood disposed in New Zealand landfills, as well as the degradability of these types of wood wastes. DDOC for textiles varies to account for an increasing quantity of synthetic fibres over time. Nappies have a lower DDOC than the IPCC default, which is based on the Swedish anaerobic digestion model, noting that there is no source or justification for the IPCC default. The rates of decay (k-values) are differentiated by climate and composition as determined by Eunomia (unpublished(a)).

Eunomia (unpublished(a)) has carefully assessed international data, particularly from the United Kingdom, for its applicability to New Zealand landfills. It considered factors that could influence parameters at national and regional levels. For example, New Zealand is an island nation with a maritime climate, as is the United Kingdom, and some studies based in the United Kingdom take these factors into account when the IPCC default parameters (i.e., k-values) do not. Further, landfill site management practices, such as landfill cell capping, gas capture methods, daily cover, intermediate cover and leachate management in the United Kingdom and New Zealand are reasonably well aligned. Therefore, these represent the best data available for New Zealand landfills, until more New Zealand studies are available.

Gas recovery

Based on studies of similar landfills in the United Kingdom (Eunomia, unpublished(a)) gas recovery rates use one of two values, depending on whether the site is currently open or not. These values are applied to all years and are representative of average recovery rates over the lifetime of the landfill as follows.

- Sites that are open in the latest reporting year use a 68 per cent gas recovery rate.
- Sites that are closed in the latest reporting year use a 52 per cent gas recovery rate.

Using a higher recovery rate for open sites reflects that most of them are modern, large, well-managed facilities that have more efficient systems than older sites that are less well-managed. This approach is chosen due to the limited data available in New Zealand. This will be revised if and when more capture data become available to the Ministry for the Environment.

Noting that most parameters used in the landfill models are similar to those in the United Kingdom, the observed methane recovery rates in the United Kingdom can be compared with the parameters used in the New Zealand model. Recovery rates in the United Kingdom were found to be between 45 per cent and 70 per cent or more (Eunomia, unpublished(a)). The values chosen for New Zealand are within this range.

Summary of parameters used

Table 7.2.7 gives a summary of the parameter values that have been applied for estimating CH_4 emissions for solid waste disposed to municipal landfills.

Table 7.2.7 Summary of parameters for municipal landfills

Parameter	Values	Source	Reference
Managed landfills			
k-value (by waste type and rainfall)	0.046–0.694	Country specific	Eunomia (unpublished(a)), IPCC (2006a)
Methane correction factor	1	IPCC default	IPCC (2006a)
Oxidation factor	10 per cent	IPCC default	IPCC (2006a)
Recovery efficiency	52 per cent (closed) 68 per cent (open) 0 per cent (no recovery)	Site specific	Eunomia (unpublished(a))
DDOC (kt C/kt waste)	0.025–0.20	Country specific	Eunomia (unpublished(a)), IPCC (2006a)
DOCf that decomposes	0.14–0.7	Country specific	Eunomia (unpublished(a)), IPCC (2006a)
Fraction of methane in landfill gas (F)	0.57	Country specific	Eunomia (unpublished(a))
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)
DOCf that decomposes	0.5	IPCC default	IPCC (2006a)
Fraction of methane in landfill gas (F)	0.5	IPCC default	IPCC (2006a)
All landfill sites			
Starting year	1950	IPCC default	IPCC (2006a)
Delay time	6 months	IPCC default	IPCC (2006a)

Note: DDOC = decomposable degradable organic carbon; DOC =degradable organic carbon; DOCf = DOC fraction; IPCC = Intergovernmental Panel on Climate Change.

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. 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). These were mapped to the IPCC waste types (IPCC, 2006a), and the IPCC default DOC values were applied, except for wood waste, which uses a custom DDOC value. Wood waste contains a significant proportion of wood processing waste, which studies show has a higher lignin content that breaks down more slowly and less completely (Eunomia, unpublished(a)) and therefore generates less methane.

For farm fills, the DOC for bulk municipal solid waste is adopted for some farm waste based on results from the non-natural rural wastes survey (GHD, 2013). This is because it is expected to comprise a mixture of domestic refuse, inert wastes (e.g., 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

Most 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 of 0.42 for these sites
- for farm fills with deeper pits that have an average depth greater than 5 metres, 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 7.2.8 gives a summary of the parameter values that have been applied for estimating CH_4 emissions for solid waste disposed to non-municipal landfills and farm fills.

Table 7.2.8 Summary of parameters for non-municipal landfills and farm fills

Parameter	Values	Source	Reference
Non-municipal landfills			
k-value	0.030–0.185	IPCC default	IPCC (2006a)
Methane correction factor	0.42	Country specific	Tonkin and Taylor Ltd (unpublished(b))
DOC (kt C/kt waste)	0.040–0.34	Country specific	Waste Not Consulting (unpublished(b)), Eunomia (unpublished(a))
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)

Parameter	Values	Source	Reference
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)

Note: DOC = degradable organic carbon.

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 (see table 7.2.9). This is consistent with the estimates provided in the 2006 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, most of the parameters are based on international data and are not site-specific.

For non-municipal landfills and farm fills, the uncertainty in activity data is estimated to be ±140 per cent. 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 the same as the uncertainty for the underlying categories because they are consistent.

Table 7.2.9 Uncertainty in emissions from *Solid waste disposal*

Emissions category	Uncertainty in activity data (%)	Uncertainty in emission factors (%)
Managed landfills	±40	±40
Unmanaged landfills	±140	±40
Uncategorised landfills	±40	±40
Overall uncertainty in CH_4 emissions	±87	±40

Time-series consistency

As a result of substantial changes in waste disposal practices over time, the basis for calculating emissions has changed significantly. Notable changes include closure of the majority of landfill sites that were operating in 1990, the move to waste levy and NZ ETS reporting, and the ongoing improvement in the quality and completeness of activity data for *Solid waste disposal*. These changes have occurred gradually and affect CH_4 emissions over a long period of time. Therefore, there is little effect on the apparent consistency of data or the implied emission factors.

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 recalculations are included for the 2022 submission. There are minor updates to activity data for *Managed waste disposal sites*.

- Activity data for *Managed waste disposal sites* were revised for 2018, 2019 and 2020 to remove small amounts of cover material that should not be included in the waste tonnage.
- The Coulson Road landfill within the *Managed waste disposal sites* category stopped receiving waste in 2019, and, as a result, the landfill gas capture rate was revised for the entire duration of gas capture beginning in 2018 from 68 per cent to 52 per cent, which is the value for closed sites. Further, the Victoria Flats landfill had a gas capture system installed during 2021, and the estimate for 2021 reflects this.

Combined, these changes have reduced emissions in 1990 by 0.0 kt CO_2-e and reduced emissions by 1.5 kt CO_2-e in 2020. Recalculations are described in greater detail in chapter 10.

7.2.6 Source-specific planned improvements

No improvements are planned in this category, which is the largest source of emissions in the Waste sector.

Several areas in the *Solid waste disposal* category are being considered for future improvements, particularly for *Unmanaged waste disposal sites* (non-municipal landfills and farm fills), depending on the availability of budget, resourcing and data. As and when better activity data become available, they will be used to improve the estimates of waste disposal on farms.

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 were reported for the first time in the 2019 submission in 5.B.1. An anaerobic digestion plant is under development; however, its operation has not yet started. No other biological treatment of solid waste occurs in New Zealand.

In 2021, *Biological treatment of solid waste* accounted for 72.1 kt CO_2-e (2.2 per cent) of Waste sector emissions. This was an increase of 67.4 kt CO_2-e (1,435.0 per cent) above the 1990 level of 4.7 kt CO_2-e, and an increase of 2.8 kt CO_2-e (4.0 per cent) from 2020.

7.3.2 Methodological issues

Choice of activity data

Activity data have been estimated based on expert judgement, in part using evidence of large-scale commercial composting operating around New Zealand. In 1990, it is estimated that an equivalent of 1 per cent of total municipal solid waste was composted (see the total solid waste reported in table 7.2.3). Between 1991 and 2008, this amount was assumed to grow by 2 per cent per annum. Between 2009 and 2018, this amount is estimated to have grown much faster (between 10 per cent and 40 per cent per annum), to align to reported volumes for 2019 (Eunomia, unpublished(b)). This reflects the increase in commercial-scale composting estimated since 2009. Policy actions taking effect from 2020 are also included. Activity data for composting can be derived from table 7.2.3 using this description.

Note that the proportion of food and garden waste disposed to managed landfills has decreased between 2012 and 2018 (see table 7.2.5). While this has not been demonstrated to be a direct result, it is consistent with the trend towards composting.

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	IPCC (2006a)
Nitrous oxide	0.24	IPCC (2006a)

The emission factors are sourced from table 4.1 of volume 5, chapter 4 of the 2006 IPCC Guidelines (IPCC, 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, some data are 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 composting

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 *Solid waste disposal* to land and *Wastewater treatment and discharge* categories.

7.3.5 Source-specific recalculations

Emissions from *Composting* (5.B.1.a) have not changed in 1990, and increased by 0.8 kt CO_2-e (1.2 per cent) in 2020 compared with the previous submission due to accounting for the effects of policy actions starting in 2020.

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 clinical wastes, 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. In the context of New Zealand's greenhouse gas inventory, the term 'clinical wastes' refers to a combination of clinical, medical and quarantine wastes.

Waste incineration is regulated under the Resource Management Act 1991. In addition, in 2004, a national environmental standard was introduced that required consents for all existing low-temperature incinerators, such as those historically used in schools and sometimes in hospitals.

There is no open burning of waste at municipal or non-municipal landfill facilities in New Zealand. It is common for farms to practise open burning of rural waste (GHD, 2014) and, while limited information is available on the extent of the practice, emissions from open burning are reported. It is assumed that an equal amount of farm waste that is buried (see table 7.2.4) is burned, which is additional to the amount buried.

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 (P Guiney, Ministry of Education, pers. comm., 4 December 2019). Emissions from this source are not estimated for this submission and are reported as not estimated (NE). See annex 6.2 for more information.

Where data are available, the burning of waste materials, including waste oil, wood chips and tyres for fuelling boilers and/or a cement kiln, is reported under the Energy sector in the *Manufacturing industries and construction* category. In 2021, *Incineration and open burning of waste* accounted for 187.1 kt CO_2-e (5.8 per cent) of Waste sector emissions (see table 7.4.1).

This was a decrease of 128.6 kt CO_2-e below the 1990 level of 315.7 kt CO_2-e, and a decrease of 1.7 kt CO_2-e (0.9 per cent) from 2020.

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**	**2021**	**1990–2021**	**1990–2021**
Incineration (5.C.1)	14.8	2.4	–12.3	–83.5
Open burning (5.C.2)	301.0	184.7	–116.3	–38.6
Total (5.C)	**315.7**	**187.1**	**–128.6**	**–40.7**

Note: Percentages presented are calculated from unrounded values.

Carbon dioxide emissions from the *Incineration and open burning of waste* source category were identified as a key category in the 2021 trend assessment.

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 2008. 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 2008, 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 from 1990 to 2021

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

Year	Clinical wastes (kt)	Hazardous wastes (kt)	Sewage sludge (kt)	Total waste incinerated (kt)
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
2019	0.6	0.3	4.5	5.4
2020	0.6	0.3	4.5	5.4
2021	0.6	0.3	4.5	5.4

Note: Columns may not total due to rounding.

Open burning (5.C.2)

Little information is available on the quantities of farm wastes burned. A change introduced in the 2021 submission is that the methods of disposal of farm waste are evenly split between disposal to land in farm fills and disposal by open burning, at 47 per cent farm fills, 47 per cent open burning and 6 per cent other.

Refer to section 7.2.2 for a discussion on farm waste landfilling and open burning. In summary, because open burning is a significant and common practice (GHD, 2013, 2014) it is being considered to be equal in volume. The amount of waste disposed to farm fills reported in table 7.2.4 is additional and equal to the amount that is disposed by open burning.

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 the same composition of farm waste as is landfilled, for consistency. Table 7.4.3 shows the parameters that determine dry-matter content, total carbon content and fossil carbon content (IPCC defaults), which are then weighted against composition.

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	1.1	90	46	1
Textiles	19.5	80	50	20
Food waste	15.6	40	38	0
Wood	40.2	85	50	0
Garden and park waste	NA	40	49	0
Nappies	NA	40	70	10
Rubber and leather	0.3	84	67	20
Plastics	10.9	100	75	100
Metal	2.5	100	–	–
Glass	0.4	100	–	–
Other, inert	9.6	90	3	100
Weighted average	**–**	**79.6**	**44.9**	**24.4**

Source: Dry-matter content, total carbon content and fossil carbon content values are from table 2.4 (IPCC, 2006a).

Note: NA = not applicable.

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 wastes	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 (table 5.2)	IPCC (2006a)
Oxidation factor	1	1	1	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)	0.5	0.57	0.17	
Methane emission factor (kg/kt) as directly referenced	NA	NA	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)	NA	IPCC (2006b)
Methane (MJ/kg waste)	12.8	16.8	NA	Ministry of Commerce (1993)
Methane emission factor (kg/kt) calculated as a quotient of the above parameters	2.34	17.86	NA	
Nitrous oxide emission factor (kg/kt)	100	60	900	IPCC (2006b), table 5.6

Note: NA = Not applicable.

These parameters are as given in the 2006 IPCC Guidelines (IPCC, 2006a, 2006b), noting that:

- some parameters have been chosen as the closest available to the specific type of waste
- where a range is given, the mid-point is used
- methane 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.

Clinical wastes are a significant proportion of the material incinerated in New Zealand. There is no IPCC default category that specifies medical or quarantine waste. The composition of medical and quarantine wastes is closest to clinical waste, so the emission factors for clinical waste have been used and the activity data for these waste types are combined into the category for clinical wastes.

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 (%)	79.6	Calculated (see table 7.4.3)
Total carbon content (%)	44.9	Calculated (see table 7.4.3)
Fossil carbon content (%)	24.4	Calculated (see table 7.4.3)
Oxidation factor (%)	58	IPCC default
Conversion factor	44/12	
Other gases		
Methane emission factor (kg/kt wet waste)	6500	IPCC default
Nitrous oxide emission factor (kg/kt dry waste)	150	IPCC default

To calculate N_2O emissions, the activity data are 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

Consistent with 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 (see table 7.4.6).

The data collected for the composition of waste are not detailed. Therefore, following 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); for this reason, 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 of waste*

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

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 *Solid waste disposal* to land and *Wastewater treatment and discharge* categories. Activity data for open burning are derived from the landfill data.

7.4.5 Source-specific recalculations

No recalculations have been made for *Incineration and open burning of waste*.

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. Further work is needed to understand the ratio of farm waste disposed to open burning or landfills (also see section 7.2.6). Anecdotal evidence suggests that incineration may be occurring at lower volumes than is assumed. Changes will be made when evidence becomes available to confirm this, noting that emissions from incineration are under 1 per cent of the Waste sector, and that there are other incineration sources (eg, rural schools) currently not estimated.

7.5 Wastewater treatment and discharge (5.D)

7.5.1 Description

In 2021, *Wastewater treatment and discharge* contributed 377.6 kt CO_2-e (11.7 per cent) of emissions from the Waste sector. This was an increase of 71.6 kt CO_2-e (23.4 per cent) from the 1990 level of 306.0 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’ under 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 included elsewhere (IE) 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	2021	1990–2021	1990–2021
Domestic wastewater (5.D.1)	212.7	276.2	63.5	29.9
Industrial wastewater (5.D.2)	93.3	101.4	8.1	8.6
Total (5.D)	306.0	377.6	71.6	23.4

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 2021 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. This is 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 onward. Emissions from the 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, using the latest population data. This information is obtained from Stats NZ. For intermediate years, data are interpolated. Years before 1997 are driven by national population growth using the *methane correction factor* from 1997.

In 2021, the population connected to treatment plants was estimated to be about 4.1 million. The connected population excludes people connected to rural septic tanks, estimated at 497,000 people in 2021, and approximately 55,000 people using other aerobic plants. The total population of New Zealand was 5.1 million, therefore a remaining population of 448,000 people is not accounted for. This 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 emissions from the remaining population, CH_4 emissions for the *Domestic wastewater* source category were scaled up proportionately based on the population for which emissions are known. An assumption is made to apply the average emission factor for wastewater treatment 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 2021

Year	National population	Aggregate methane correction factor	Domestic wastewater total organic product (kt)
1990	3,410,400	Same as 1997	137.6
1991	3,516,000	Same as 1997	142.1
1992	3,552,200	Same as 1997	143.9
1993	3,597,800	Same as 1997	146.1
1994	3,648,300	Same as 1997	148.5
1995	3,706,700	Same as 1997	151.2
1996	3,762,300	Same as 1997	153.8
1997	3,802,700	0.0425	155.8
1998	3,829,200	Interpolated	154.8
1999	3,851,100	Interpolated	153.9
2000	3,873,100	Interpolated	152.9
2001	3,916,200	0.0378	151.9
2002	3,989,500	Interpolated	155.2
2003	4,061,600	Interpolated	158.6
2004	4,114,300	Interpolated	161.9
2005	4,161,000	Interpolated	165.4
2006	4,209,100	0.032	168.0
2007	4,245,700	Interpolated	170.6

Year	National population	Aggregate methane correction factor	Domestic wastewater total organic product (kt)
2008	4,280,300	Interpolated	172.4
2009	4,332,100	Interpolated	174.2
2010	4,373,900	Interpolated	176.0
2011	4,399,400	Interpolated	177.8
2012	4,425,900	Interpolated	179.7
2013	4,477,400	0.0316	181.7
2014	4,564,400	0.0316	185.2
2015	4,663,700	0.0318	189.2
2016	4,767,600	0.0317	193.3
2017	4,859,500	0.0318	196.8
2018	4,941,200	0.0319	200.0
2019	5,040,400	0.032	203.9
2020	5,103,700	0.0321	206.8
2021	5,122,300	0.0324	207.5

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 from 1990 to 2021

Year	Meat industries TOW (kt)	Pulp and paper industry TOW (kt)	All other industries TOW (kt)	Total industrial TOW (kt)
1990	55.6	76.7	20.2	152.5
1991	59.2	76.3	18.8	154.2
1992	64.1	72.7	17.2	154.1
1993	59.3	79.3	15.7	154.3
1994	62.1	80.0	14.4	156.5
1995	64.5	83.3	13.3	161.1
1996	65.7	79.9	11.9	157.6
1997	66.6	82.7	10.3	159.7
1998	68.7	81.1	9.2	158.9
1999	61.4	81.9	7.8	151.1
2000	65.8	89.4	6.4	161.6
2001	67.7	84.2	4.9	156.8
2002	65.0	87.1	5.5	157.6
2003	70.1	80.2	5.0	155.3
2004	73.8	90.5	6.1	170.5
2005	72.6	91.9	5.9	170.4
2006	71.3	86.5	6.4	164.3
2007	72.5	86.7	6.7	166.0
2008	72.8	85.8	7.7	166.2
2009	68.3	87.0	7.7	163.0
2010	66.6	91.2	7.5	165.3
2011	65.6	87.9	4.1	157.6
2012	65.7	84.9	3.3	153.9

Year	Meat industries TOW (kt)	Pulp and paper industry TOW (kt)	All other industries TOW (kt)	Total industrial TOW (kt)
2013	67.9	79.1	4.3	151.3
2014	68.7	77.5	5.5	151.8
2015	71.7	78.6	4.0	154.4
2016	69.2	78.4	5.4	153.0
2017	71.2	78.6	4.9	154.7
2018	72.7	77.2	5.2	155.2
2019	73.0	77.7	5.1	155.8
2020	73.8	71.8	5.7	151.2
2021	74.6	68.2	4.6	147.4

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 (N) in effluent from industrial wastewater from 1990 to 2021

Year	Meat industries (excl poultry) N in effluent (kt)	Poultry N in effluent (kt)	Dairy processing N in effluent (kt)	Leather & skins N in effluent (kt)	Total industrial N in effluent (kt)
1990	1.4	0.1	0.2	1.2	2.8
1991	1.5	0.1	0.2	1.2	2.9
1992	1.6	0.1	0.2	1.2	3.1
1993	1.4	0.1	0.2	1.2	2.9
1994	1.5	0.1	0.2	1.2	3.0
1995	1.6	0.1	0.2	1.2	3.1
1996	1.6	0.1	0.2	1.2	3.2
1997	1.6	0.1	0.2	1.2	3.2
1998	1.7	0.1	0.2	1.2	3.2
1999	1.5	0.1	0.3	1.2	3.1
2000	1.6	0.1	0.3	1.2	3.2
2001	1.6	0.1	0.3	1.2	3.3
2002	1.5	0.2	0.3	0.6	2.6
2003	1.6	0.2	0.3	0.6	2.7
2004	1.7	0.2	0.3	0.6	2.8
2005	1.7	0.2	0.3	0.6	2.8
2006	1.7	0.2	0.3	0.6	2.8
2007	1.7	0.2	0.3	0.6	2.8
2008	1.7	0.2	0.4	0.6	2.8
2009	1.6	0.2	0.4	0.6	2.7
2010	1.5	0.2	0.4	0.6	2.7
2011	1.5	0.2	0.4	0.6	2.7
2012	1.5	0.2	0.4	0.6	2.7
2013	1.5	0.2	0.5	0.6	2.8
2014	1.5	0.2	0.5	0.6	2.9
2015	1.6	0.2	0.5	0.6	2.9
2016	1.5	0.3	0.5	0.6	2.9
2017	1.5	0.3	0.5	0.6	2.9
2018	1.6	0.3	0.5	0.6	3.0

Year	Meat industries (excl poultry) N in effluent (kt)	Poultry N in effluent (kt)	Dairy processing N in effluent (kt)	Leather & skins N in effluent (kt)	Total industrial N in effluent (kt)
2019	1.6	0.3	0.5	0.6	3.0
2020	1.6	0.3	0.5	0.6	3.0
2021	1.6	0.3	0.5	0.6	3.0

Note: 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 that are as consistent as possible 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 for other meat processing (Cardno, unpublished).

Rendering loads are not separated out 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. Therefore, the unit COD load only 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 New Zealand Wine, which reports on the grape and wine sector. For the purpose 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. Note 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. Only one factory 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 (Beca Infrastructure Ltd, unpublished). Emissions from the biogas recovered from the Tirau dairy processing plant (*Industrial wastewater*) for energy recovery are reported as 'IE' under the Waste sector, and actual emissions are reported in *1.A.2.e – Biomass* under the Energy sector.

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 under 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). Emissions reduced 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)
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). Default values from the 2006 IPCC Guidelines (IPCC, 2006a) 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. Although one wastewater treatment plant in Auckland serves about a million people, 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 2006 IPCC Guidelines (IPCC, 2006a) indicate that, compared with domestic wastewater, the N_2O emissions from industrial wastewater are believed to be insignificant. Yet in New Zealand these emissions have greater significance, 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 summarises 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)
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)

Note: BOD = biochemical oxygen demand.

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 summarises 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)
Direct N_2O 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 summarises 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 methane-producing capacity (kg CH_4/kg COD)	0.25	IPCC default	IPCC (2006a)
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 industry

Table 7.5.9 summarises 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 methane-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 industry

Table 7.5.10 summarises 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 methane-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 summarises 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 methane-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 summarises 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 methane-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 summarises 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)	0.09	New Zealand specific	Cardno (unpublished)
Overall emission factor	Range of 0.0013–0.0019	New Zealand specific	Cardno (unpublished)

Note: COD = chemical oxygen demand; TN = total nitrogen.

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 summarises 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; TN = total nitrogen.

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 summarises 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 leather and skins 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$_b$)	0.08	New Zealand specific	SCS Wetherill Environmental (unpublished)
Overall emission factor	0.02	New Zealand specific	SCS Wetherill Environmental (unpublished)

Note: COD = chemical oxygen demand; TN = total nitrogen.

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 (see 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
- the quantities of wastewater handled by the different wastewater treatment plants
- the accuracy and completeness of the data relating to each plant
- the factors used to calculate the degradable organic content in the wastewater
- 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 increased by 0.1 kt CO_2-e in 1990 and decreased by 0.1 kt CO_2-e in 2020. This is the result of revising population data using the latest estimates available and applying these consistently across the time series where possible. A minor change to activity data for the paper and paperboard and the wood pulp industries in *Industrial wastewater* led to an increase of 1.5 kt CO_2-e in 1990 and a decrease of 1.6 kt CO_2-e in 2020. 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.

Chapter 7: References

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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, among other things, 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 in section 8.1.3. The information on quality assurance and quality control planning for Tokelau is included in annex 6.

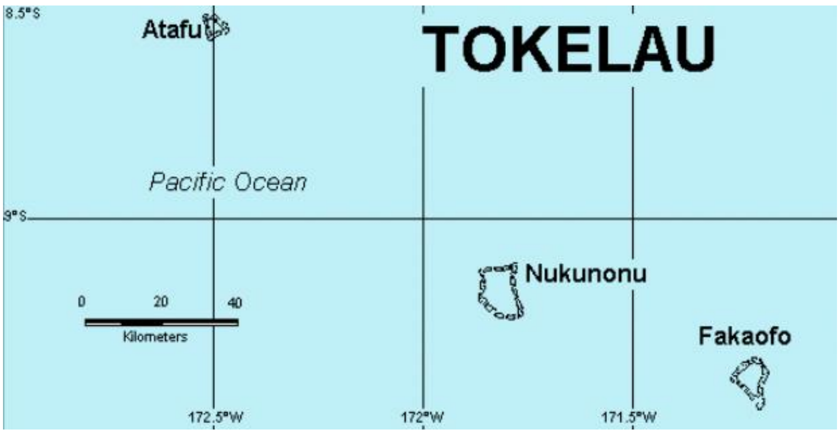
To maintain transparency of the inventory and visibility of the GHG data from Tokelau, common reporting format (CRF) sector 6 (Other) is used to present emissions from Tokelau by sector in the CRF. This chapter provides an overview of Tokelau's economy and industry. It includes information on emissions 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 and is made up of three small coral atolls: Atafu, Nukunonu and Fakaofo. The total land area is 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 (United Nations, 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 about 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 four censuses in Tokelau (2006, 2011, 2016 and the 2019 mini census) have used a precise definition of who is a '*de jure* Tokelauan'[70] and the people who actually lived in Tokelau during the census night ('*de facto*' population). The *de facto* population has been used for the purposes of estimating emissions, which was 1,295 people in 2019. From 1990 to 2019, the population was fluctuating but generally declined for both *de facto* and *de jure* measures. Around 15,000 of the people who identify as Tokelauan live overseas, most of whom live in New Zealand.

Tokelau has a subsistence economy in which the sharing (inati) of essential resources 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.

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 Intergovernmental Panel on Climate Change (IPCC) Tier 1 methodologies with default emission factors for all reported categories (IPCC, 2006a). The Land Use, Land-Use Change and Forestry (LULUCF) sector is not estimated because Tokelau has no planted or managed forests, 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 (the Ministry for the Environment) and Tokelau's Ministry of Climate, Oceans and Resilience, formerly known as the Climate Change Division within the Office of the Council for the Ongoing Government of Tokelau, have roles in inventory reporting.

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[70] A 'de jure' census tallies people according to their regular or legal residence.

New Zealand's Ministry for the Environment 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 issues associated with changes in the national inventory system
- production of the complete set of the data tables in agreed formats
- 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.

Tokelau's Ministry of Climate, Oceans and Resilience will take responsibility for the following:

- coordinating the project implementation in Tokelau by communicating with the relevant agencies, organisations and individuals involved in Tokelau's GHG inventory; coordinating their efforts and delegating responsibilities, to ensure sufficient information and support are provided to those agencies, organisations and individuals to enable the GHG inventory production
- providing timely advice on all cultural aspects of the project and helping to resolve any matters 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 a peer-reviewed draft of the Tokelau chapter based on the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006a) and the United Nations Framework Convention on Climate Change (UNFCCC) reporting guidelines for GHG inventories (UNFCCC, 2014) and in compliance with the Convention inventory quality principles and good practices.

Both the Ministry for the Environment and Ministry of Climate, Oceans and Resilience are responsible for adhering to the principles and protocols for producers of Tier 1 statistics (Stats NZ).

Methodological issues

Methods and emission factors

Tokelau is making its second 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 different technologies. There are also differences in the scale of operations, especially in the Agriculture sector, which 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 8.1.1 contains the key sources of the activity data from Tokelau used in Tokelau's GHG inventory.

Table 8.1.1 Key sources for activity data in Tokelau

Item	Name/abbreviation	Explanation	Used where
1	Census	Tokelau Census of Population and Dwellings 2006, 2011, 2016, 2019 (mini census). 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 and outboard motors, home appliances
2	Archives NZ	Archives New Zealand, Wellington	Historic Census records going back to 1951, at five-year intervals (Tokelau National Statistics Office 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, Stats NZ	Stats NZ, 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 panels 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

Item	Name/abbreviation	Explanation	Used where
11	PCTrade-Green	Excel version of PCTrade package developed by Stats NZ, 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, Papao J, Ketewai M, Sokota A. 2014. *Tokelau Mission Preliminary Report (Fieldwork undertaken from 8 August – 2 September 2013). SOPAC technical note (PR193)*. 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 with New Zealand Ministry for the Environment leading to the present inventory

Tokelau's data and information in the Common Reporting Format Reporter

The methodologies for estimating emissions in Tokelau and New Zealand differ, so 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 is 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 the creation of lower-level categories 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 2020 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.

8.1.3 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 2021 was 3.78 kilotonnes carbon dioxide equivalent (kt CO_2-e), contributing around 0.005 per cent to New Zealand's gross emissions. This is below the significance threshold as defined in paragraph 37(b) of the UNFCCC reporting guidelines for GHG inventories (UNFCCC, 2014). The emissions 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.

2021

In 2021, emissions from the Tokelau sector contributed 3.78 kt CO_2-e (0.005 per cent) of New Zealand's gross GHG emissions. The largest source category is *Domestic navigation*, which contributed 1.38 kt CO_2-e (69.0 per cent of all energy emissions and 36.6 per cent of gross emissions from Tokelau).

Carbon dioxide dominated emissions from Tokelau, contributing 53.6 per cent (2.03 kt CO_2-e) of its total emissions in 2021. At 1.99 kt CO_2, the Energy sector contributed 98.1 per cent of total CO_2 emissions, mostly from *Domestic navigation*; with the remaining 1.9 per cent (0.04 kt CO_2) coming from *Open burning of waste* in the Waste sector.

Methane emissions contributed 39.1 per cent (1.48 kt CO_2-e) to the total emissions from Tokelau. The Agriculture sector in Tokelau contributed 55.8 per cent of CH_4 emissions (0.82 kt CO_2-e), which mostly came from *Manure management*. A significant portion of CH_4 emissions, 43.8 per cent (0.65 kt CO_2-e), came from the Waste sector, largely from *Solid waste disposal*. The Energy sector contributed the remaining 0.4 per cent of CH_4 emissions (0.01 kt CO_2-e), which mostly came from *Domestic navigation*.

Nitrous oxide emissions contributed 1.2 per cent (0.05 kt CO_2-e) to the total emissions from Tokelau. The IPPU sector contributed the largest amount of N_2O, 47.9 per cent (0.02 kt CO_2-e) of the total N_2O, from *Medical applications.* The Energy sector contributed a further 27.3 per cent (0.01 kt CO_2-e), which comes largely from *Domestic navigation*. The Waste sector contributed the remaining 24.7 per cent of N_2O (0.01 kt CO_2-e) from *Open burning*.

Emissions of fluorinated gases from Tokelau consisted of hydrofluorocarbon (HFC) emissions only, contributing 6.2 per cent (0.23 kt CO_2-e) to the total emissions from Tokelau. These emissions largely came from the use of *Air conditioning*. 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 2021

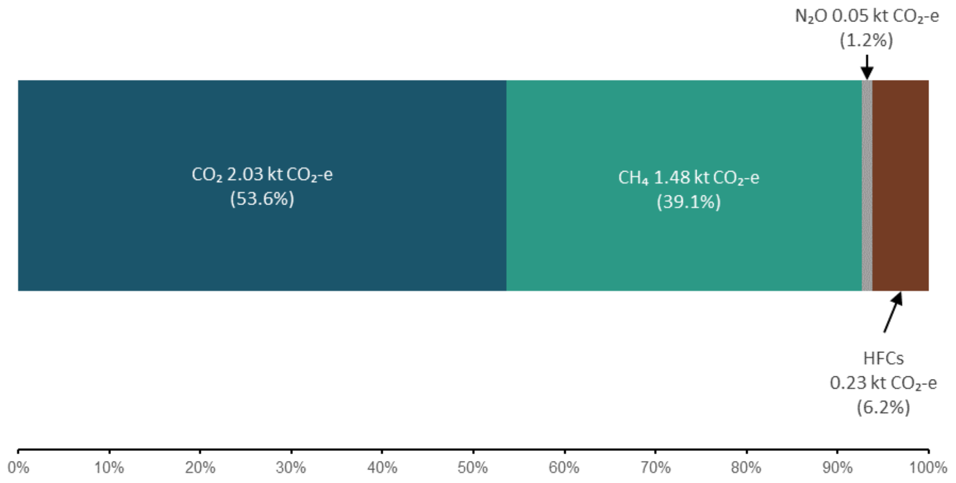
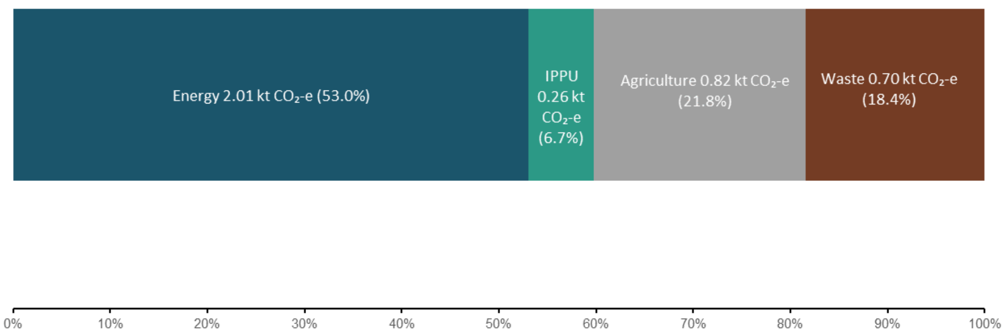


Figure 8.1.3 Tokelau's emissions by sector in 2021



1990–2021

In 1990, the total emissions from Tokelau were 3.17 kt CO_2-e. Between 1990 and 2021, the total emissions increased by 19.4 per cent (0.61 kt CO_2-e) to 3.78 kt CO_2-e (table 8.1.2 and figure 8.1.4). From 1990 to 2021, the average annual increase in gross emissions was 0.75 per cent.

The emission categories that contributed the most to this change were *Domestic navigation* and *Electricity generation*.

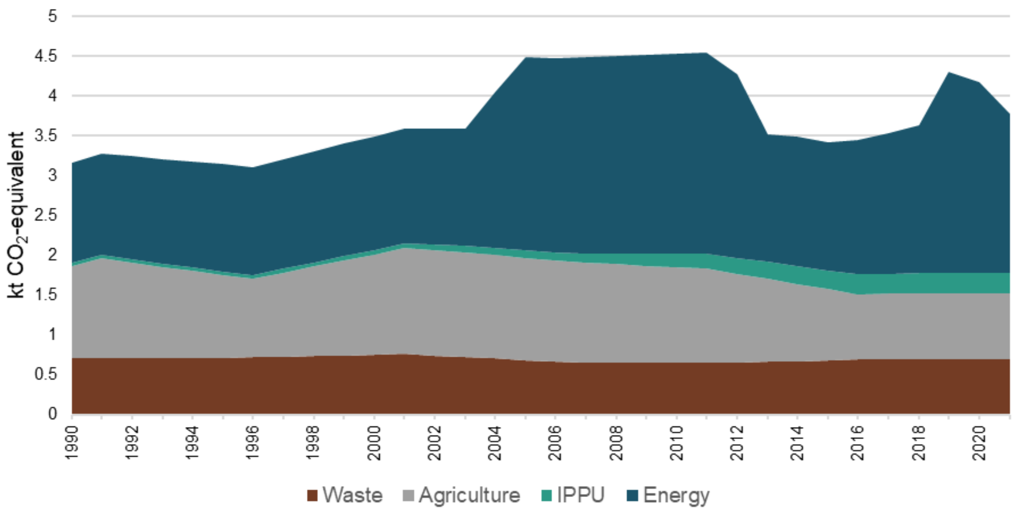
The changes in *Domestic navigation* are a result of Tokelau gaining ownership and use of the ferry *Mataliki* in 2016, cargo vessel *Kalopaga* in 2018 and *Fetu o te Moana* in 2019 leading to an increasing number of sea voyages between the atolls, which increased transport emissions. Emissions from Tokelau's IPPU sector have also increased mainly due to the introduction of air conditioning after 2006. Further changes in Tokelau's Energy sector emissions are a significant rise and then drop (by nearly 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 decreased slightly as a result of a reduced population of pigs.

Table 8.1.2 Gross emissions from Tokelau by gas in 1990 and 2021

Direct greenhouse gas emissions	kt CO_2-e 1990	kt CO_2-e 2021	Change from 1990 (kt CO_2-e)	Change from 1990 (%)
CO_2	1.30	2.03	0.73	56.1
CH_4	1.78	1.48	–0.31	–17.2
N_2O	0.09	0.05	–0.04	–41.5
HFCs	NO	0.23	0.23	NA
PFCs	NO	NO	NA	NA
SF_6	NO	NO	NA	NA
NF_3	NO	NO	NA	NA
Gross, all gases	**3.17**	**3.78**	**0.61**	**19.4**

Note: Emissions from the Land Use, Land-Use Change and Forestry sector are not estimated for Tokelau. The percentage change for hydrofluorocarbons (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.

Figure 8.1.4 Emissions by sector for Tokelau (kt CO_2-e) from 1990 to 2021



2020–2021

Total Tokelau emissions in 2021 were 0.40 kt CO_2-e (9.5 per cent) lower than emissions in 2020. The lower emissions are largely the result of decreases in CO_2 emissions in the *Domestic navigation* category.

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 2023 submission.

8.1.4 Recalculation and improvements

Recalculations made to emission estimates in Tokelau have resulted in no change for 1990 and a 0.004 per cent (0.0002 kt CO_2-e) increase in emissions in 2020. This increase in 2020 is the result of more accurate activity data.

8.2 Energy emissions from Tokelau (CRF 6. Tokelau_1)

The total amount of all energy emissions in Tokelau in 2021 was 2.01 kt CO_2-e. This contributed 53.0 per cent to the total emissions from Tokelau and 0.0026 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 *Other – Residential*.

For all energy categories, emissions were estimated using the IPCC 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.

Small 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*. Around 40 drums (205-litre capacity per drum) of oil are imported annually, the bulk of which is 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 are 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 to 6.4 from chapter 6 in the 2006 IPCC Guidelines were used for calculating consumption and estimating emissions (IPCC, 2006a). Gross calorific values were used for all calculations.

In 2021, total CO_2 emissions from the reference approach in Tokelau were 1.99 kt, which differs from the sectoral approach by 2.3 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

No fuel is used 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 no refuelling is done in Tokelau for the international routes.

Tokelau has no domestic or international aviation transportation.

8.2.3 Stationary combustion: Public electricity and heat production

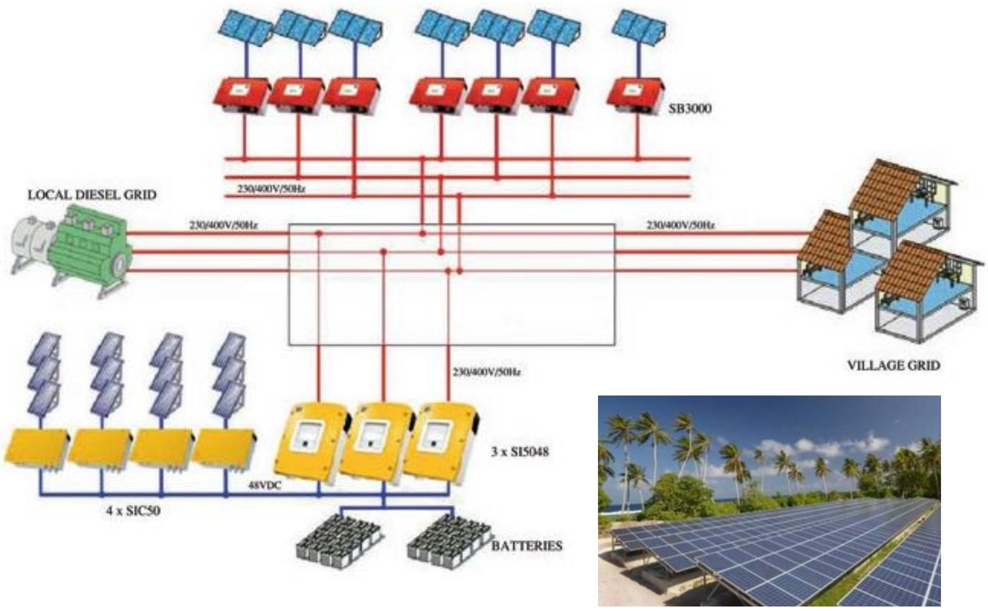
Description

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. Before 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 4,000 solar photovoltaics (PV) systems across the three atolls was completed (figure 8.2.1). Each of the three Tokelau atolls now has a significant array of solar PV systems 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 its installation of solar PV units.[71] The change resulted in a significant drop in liquid fossil fuels consumption for electricity production in Tokelau (by around 82.5 per cent) and a decrease in the total energy emissions by 36.4 per cent between 2011 and 2013. However, some power generation using diesel remains necessary as a back up, during the failure of solar PV units, prolonged cloudy spells, and to meet the steadily increasing demand from households and the public sector.

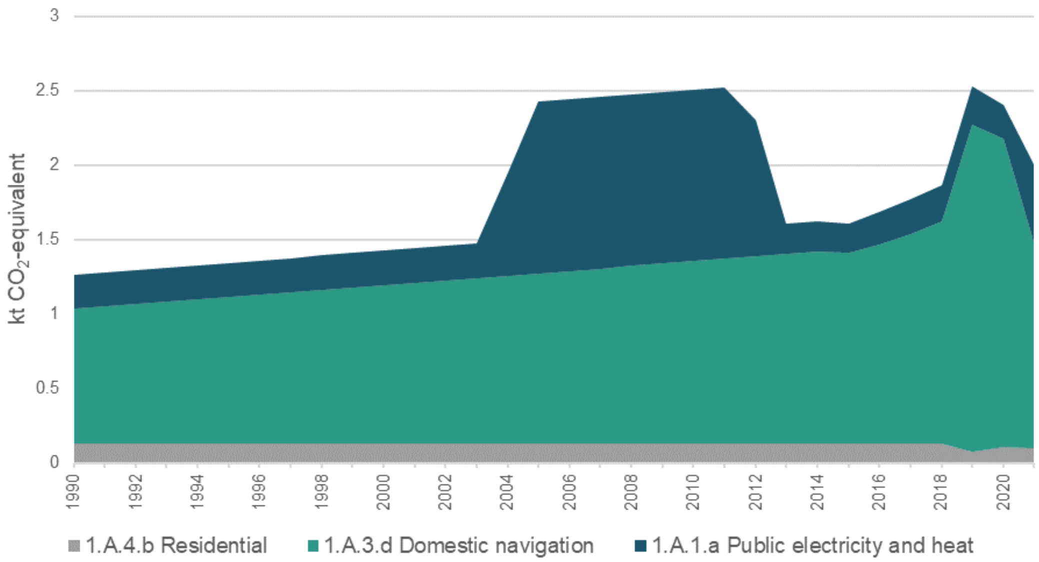
71 See page 46 on www.mfat.govt.nz/assets/Aid-Prog-docs/Evaluations/2015/Dec-2015/MFAT-Tokelau-Country-Programme-Eval-Final-v5-09122015.pdf.

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 2021, emissions from the *Energy industries* category totalled 0.52 kt CO_2-e (26.1 per cent of all energy emissions from Tokelau). Emissions from energy industries have increased by 0.29 kt CO_2-e (127.1 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 PV 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.

Figure 8.2.2 Energy emissions by category for Tokelau (kt CO_2-e) from 1990 to 2021



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 (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 (i.e., gas and diesel oil) are used in the *Energy industries* category. 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, 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 to 2020 (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 before that, at an estimated 20 per cent of the 24 hour, 7 days a week value in 2011); and second the introduction of solar PV-powered plants in 2012. The change during 2012, due to the installation of solar PV-powered plants, was reasonably well documented and, therefore, reflected in the time series. For the years 1990 to 2003, 2005 to 2011 and 2013 to 2015, the activity data (and corresponding emissions) are shown as constant.

The diesel data for 2013 to 2015 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 in each subsequent submission.

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 emission 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:

$$\text{Gross Emission Factor (liquid fuels)} = 0.95 \text{ x Net Emission Factor}$$

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 emission 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 planned improvements

No improvements are planned for energy industries. Some areas identified for possible improvements are better monitoring of diesel fuel 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 in 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 PV-powered plants may also be considered in future.

8.2.4 Stationary combustion: Other sectors – Residential

Description

Tokelau has no significant industry. 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 are not easily distinguishable from those coming from residential activities and are therefore included under the *Other sectors – Residential* category. Emissions from fishing are included under *Domestic navigation*. This is because it is 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 in the past funded a programme of replacing old inefficient fridges and freezers with new ones. Home appliances in Tokelau mainly use the power provided by solar PV-powered plants, 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 about 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 2021, emissions from the *Other sectors – Residential* category were 0.10 kt CO_2-e (4.8 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

An IPCC 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 emission 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:

$$\text{Gross Emission Factor (gaseous fuels)} = 0.90 \text{ x Net Emission Factor}$$

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 emission 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

No improvements are planned for the *Other sectors – Residential* category. One area identified for possible future 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 because 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 around 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. Up until 2018, the fraction (300/1300) is used to estimate *Domestic navigation* within Tokelau. For 2020, actual data on the number of inter-atoll trips was used.

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 PV 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. In 2020 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 delivered in 2019 that also provides general inter-atoll transport.

For Tokelau, the category *Domestic navigation* accounted for 100 per cent of the emissions from the *Transport* category for the entire time series. In 2021, emissions from the *Domestic navigation* category totalled 1.38 kt CO_2-e (69.0 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
- 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 (Jasperse, 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 to 2021 are not available. Some anecdotal transport data exist for the number of roundtrips Apia–Tokelau during the years 1990 to 2014; after this period actual records are available.

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 emission 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:

$$\text{Gross Emission Factor (liquid fuels)} = 0.95 \text{ x Net Emission Factor}$$

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 values 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 emission factor uncertainty across the Energy sector 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 *Domestic navigation* (diesel) 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

No improvements are planned 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)

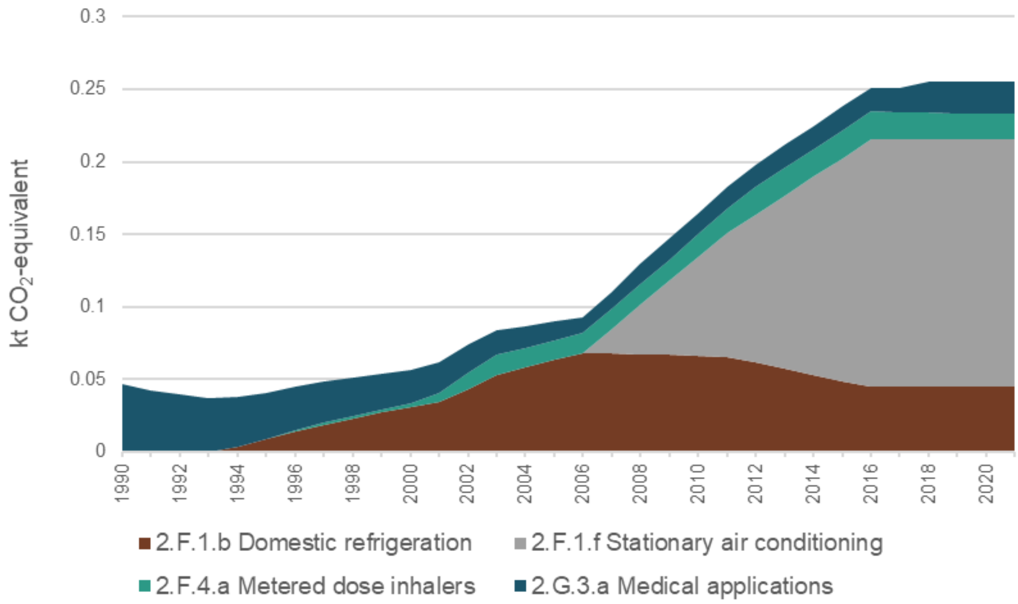
Tokelau has no significant industry. The emissions associated with the IPPU sector are coming from the following activities:

- 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 2021 was 0.26 kt CO_2-e. They contributed 6.7 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 66.8 per cent and 17.5 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 2021



8.3.1 Emissions from Refrigeration and 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 to 2016 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
- Stats NZ (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 emission 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 from volume 3 of the 2006 IPCC Guidelines (IPCC, 2006b))
- the average charge for an air conditioning unit is 10 kilograms (default value from the 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 below in table 7.9 from volume 3 of the 2006 IPCC Guidelines (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

$$Net\ Consumption = Production + Imports - Exports - Destruction$$

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

$$Annual\ Emissions = Net\ Consumption \bullet Composite\ EF$$

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 (see table 8.3.1). 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	CRF Category	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 2021, the *Metered dose inhalers* category contributed 7.2 per cent to total IPPU emissions from Tokelau, and the category *Medical applications* contributed 8.5 per cent to the sector, which amounted 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 4.8.3 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

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, rather than 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 (*Musa* sp. [2 varieties]), papaya (*Carica papaya*), pumpkin (*Cucurbita* sp.) and coconut (*Cocos nucifera*).

A small amount of subsistence agriculture occurs 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 (e.g., mats, hats, fans). A previous United Nations Development Programme-sponsored project for the establishment of keyhole gardens[72] by Tokelau youth has been abandoned.

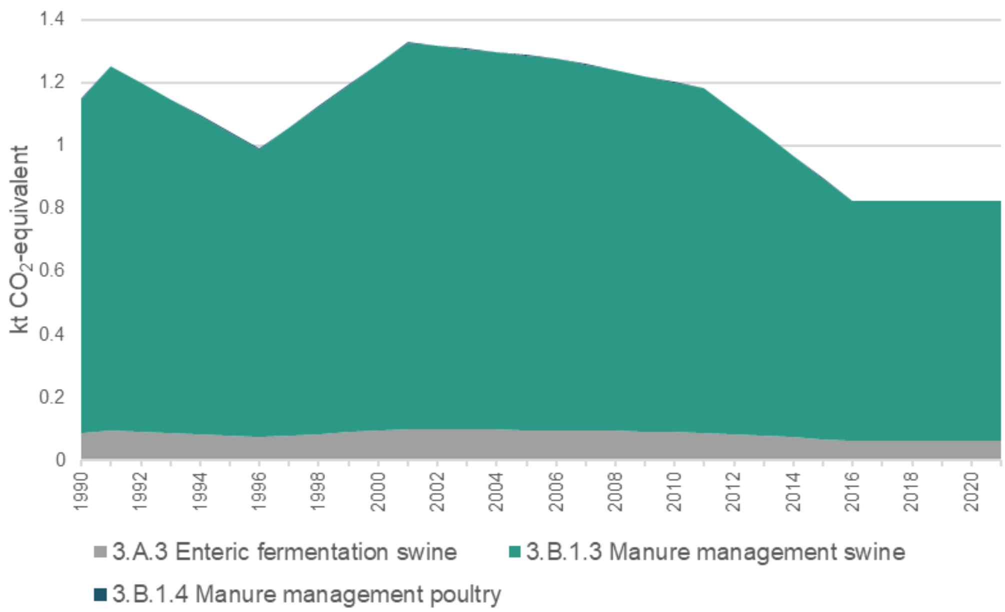
No industrial-scale farming occurs in Tokelau. Tokelau atolls do not have any large agricultural and horticultural development that would fall under New Zealand's definition of a farm. There are no cows, sheep or deer, with agricultural livestock represented by small numbers of pen-kept pigs and free-range chickens only.

Tokelau also has no pasture 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 amounted to 0.82 kt CO_2-e in 2021, making this sector the second biggest emitter in Tokelau: 21.8 per cent of the total emissions from Tokelau and 0.001 per cent of New Zealand's gross emissions. Figure 8.3.2 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 2021



Note: The emissions contribution from 3.B.1.4 *Manure management poultry* is too small to be shown in the figure.

Source-specific planned improvements

No improvements are planned 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.

72 A keyhole garden is a small (around 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 potential to generate energy from the piggery waste and reduce 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 contributed 7.5 per cent to the total Agriculture emissions in Tokelau in 2021, and amounted 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 in 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.

$$\text{Emissions (kt CH}_4\text{)} = \text{AAP (Swine) } 1.5\ [\text{kg CH}_4\ \text{head}^{-}1\ \text{year}^{-1}]/10^6[\text{kg/kt}]$$

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 $\pm$20 per cent (IPCC, 2006c). The default emission factor uncertainty is $\pm$30 per cent to 50 per cent (default mid-range is $\pm$40 per cent).

For this category, the default uncertainty value of $\pm$20 per cent for activity data and an upper range default emission factor uncertainty of $\pm$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 contributed 92.4 per cent to the total agriculture emissions in Tokelau in 2021 and amounted to 0.76 kt CO_2-e. *Manure management – Poultry* was 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 in volume 4 of the 2006 IPCC Guidelines was 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 in volume 4 of 2006 IPCC Guidelines for Oceania with a 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 emission factor uncertainty for *Manure management* is $\pm$30 per cent.

8.5 Emissions from the Waste sector in Tokelau (CRF 6 Tokelau_5)

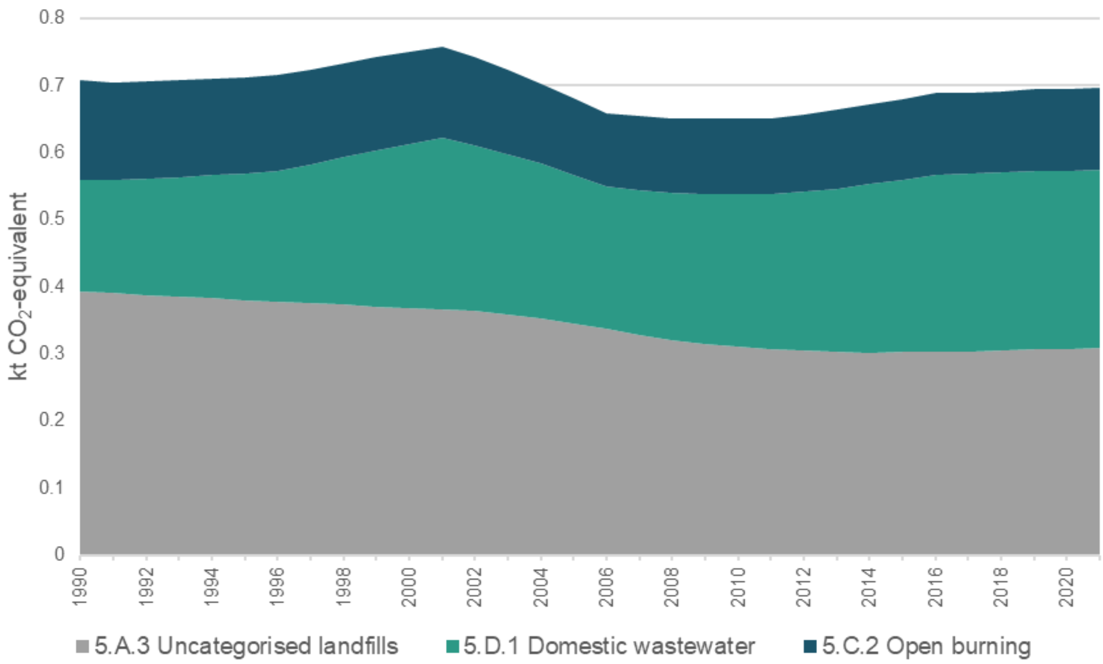
The total amount of all Waste sector emissions in Tokelau in 2021 was 0.70 kt CO_2-e, making the Waste sector the third-biggest emitter in Tokelau. The Waste sector contributed 18.4 per cent to the total emissions from Tokelau and 0.0009 per cent to New Zealand’s gross emissions including Tokelau. The sources of emissions in the Waste sector in Tokelau are from the categories *Solid waste disposal*, *Wastewater treatment and discharge* and *Incineration and open burning of waste*, which contributed 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 2021



Source-specific planned improvements

No improvements are planned 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 an MoU with a Samoan company.[73]

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. Tokelau has no dedicated categorised landfills, therefore, solid waste disposal is reported for uncategorised landfills only.

The *Solid waste disposal* category contributed 44.2 per cent to the total Waste emissions in Tokelau in 2021, which amounted to 0.31 kt CO_2-e.

[73] 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).

Methodological issues

Activity data

- The total amount of solid waste is based on the 2006 IPCC default of 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 (see table 7.2.9, chapter 7; for methodological notes, refer to the uncertainties for the *Solid waste* category, section 7.2.3, chapter 7, 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 Incineration and open burning in Tokelau

Because Tokelau has no major incineration facilities, 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 *Incineration and open burning* contributed 17.6 per cent to the total Waste sector emissions in Tokelau in 2021, which amounted 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 *Open burning of waste*.

Table 8.5.3 Composition data and carbon content used for estimating emissions from *Open burning of waste*

Waste type	Landfill composition (%)	CO_2 incineration composition (%)	Dry matter (%)	Total carbon (%)	Fossil carbon (%)
Paper/card	6.0		90	43	1
Textiles	0		80	50	20
Food waste	67.5		40	38	0
Wood	2.5		85	50	0
Garden and park waste	0		40	49	0
Nappies	0		40	70	10
Rubber and leather	24.0	0	84	67	20

Waste type	Landfill composition (%)	CO_2 incineration composition (%)	Dry matter (%)	Total carbon (%)	Fossil carbon (%)
Plastics	('inert')	0	100	75	100
Metal		0	100	NA	NA
Glass		0	100	NA	NA
Other, inert		24.0	90	3	100
		Calculated weighted average	**56.13**	**30.20**	**24.06**

Percentages in table 8.5.3 are defaults from table 2.3 and table 2.4 in 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 (see table 8.5.4) and New Zealand (see 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 of waste* 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 contributed 38.2 per cent to the total of Waste sector emissions from Tokelau in 2021, which amounted to 0.27 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 (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: BOD = biochemical oxygen demand; 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)	32.45	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 (see 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

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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 2023 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 2022 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.

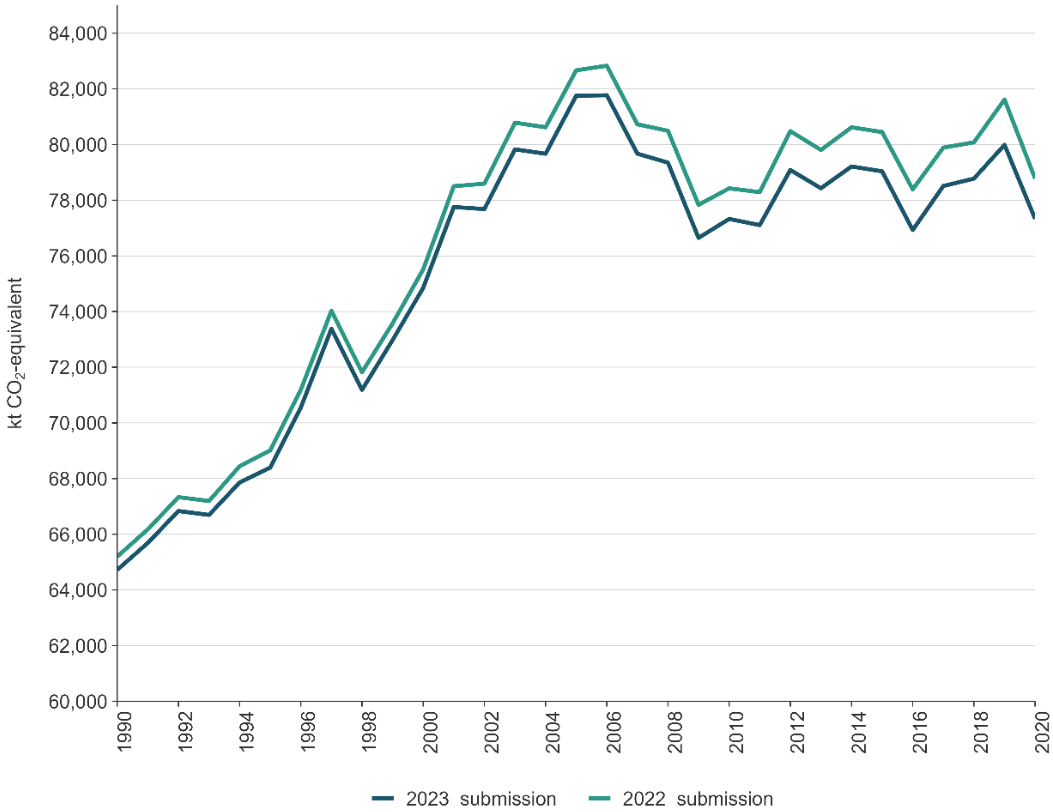
It is good practice to recalculate the whole time series from 1990 to the latest reporting year, to ensure consistency across the time series. This means some estimates of emissions and/or removals reported in this submission are different from estimates reported in the previous submission. There may be exceptions to recalculating the entire time series and, where this has occurred, explanations are provided.

Comparisons are made with the previous inventory's estimates for 1990 and the previous reporting year, to quantify the impact. This provides transparency of the emissions impact that each improvement makes on the inventory.

10.1 Implications and justifications

The effect of recalculations on New Zealand's gross emissions estimates is shown in figure 10.1.1. There was a 0.7 per cent (476.9 kilotonnes carbon dioxide equivalent (kt CO_2-e)) decrease in gross emissions in 1990 and a 1.8 per cent (1,447.7 kt CO_2-e) decrease for the 2020 year. The greatest contribution to the decrease in gross emissions estimates across the time series came from improvements made in the Agriculture sector. This decrease is mainly the result of including the impact of the use of non-pasture feeds for *Dairy cattle*, *Non-dairy* (beef) *cattle* and *Sheep* and an improved dairy cattle population model.

Figure 10.1.1 Effect of recalculations on New Zealand's gross greenhouse gas emissions estimates from 1990 to 2020



The effect of recalculations on net emissions estimates, which include the Land Use, Land-Use Change and Forestry (LULUCF) sector, was an increase of 5.2 per cent (1,058.0 kt CO_2-e) in net emissions in 1990 and an increase of 0.3 per cent (71.2 kt CO_2-e) in net emissions in 2020. This is the combined effect of a number of changes made to gross emissions and changes in the LULUCF sector emissions. These are mainly due to a range of modelling procedures that have been improved to ensure consistency of treatment of harvesting and deforestation activities between pre-1990 and post-1989 planted forests.

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 Recalculations that led to the greatest increase in emissions estimates in each sector

Sector	Category with the largest increase in estimated emissions across the entire time series	Largest single increase in emissions for the category (kt CO_2-e)	Year of the largest increase in estimated emissions
Energy	1.A.3.b.ii Gasoline	70.7	2001
IPPU	2.F.1.a HFC-143a	121.2	2014
Agriculture	3.D.2.2 Nitrogen Leaching and Run-off	54.8	2003
LULUCF	4.A.1.i Post-1989 Forest Remaining Post-1989 Forest	2,926.6	2019
Waste	5.D.2 Industrial Wastewater	2.2	2004
Tokelau	6. Tokelau_5. Waste	0.001	2018

Table 10.1.2 shows the recalculations that reduced emissions estimates the most for each sector.

Table 10.1.2 Recalculations that led to the greatest decrease in emissions estimates in each sector

Sector	Category with the largest reduction in estimated emissions across the entire time series	Largest single decrease in emissions for the category (kt CO_2-e)	Year of the largest decrease in estimated emissions
Energy	1.A.2.e Solid Fuels	–184.5	2019
IPPU	2.F.1.c HFC-134a	–137.2	2012
Agriculture	3.A.1 Dairy Cattle	–532.8	2016
LULUCF	4.A.1.i Pre-1990 Planted Forest Remaining Pre-1990 Planted Forest	–3,777.0	2019
Waste	5.D.2 Industrial Wastewater	–1.6	2020
Tokelau	NA	NA	NA

Note: NA = not available.

The following sections detail the effect of and reasons for recalculations for each sector and summarise the improvements that resulted in the recalculations.

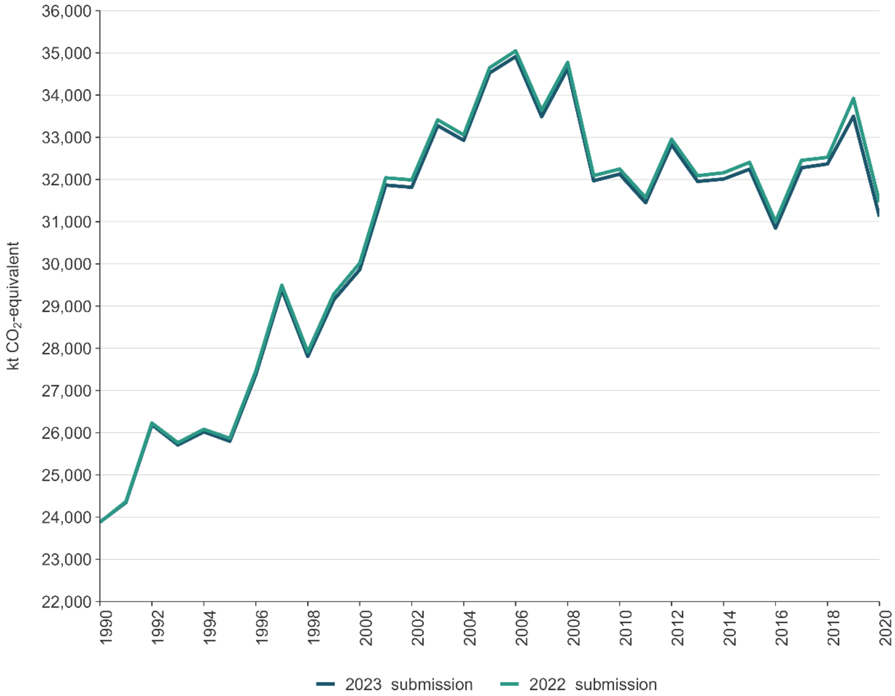
10.1.1 Energy

Changes to activity data in the Energy sector have resulted in a 0.01 per cent (2.4 kt CO_2-e) increase in energy emissions estimates in 1990 and a 1.1 per cent (344.5 kt CO_2-e) decrease in energy emissions estimates in 2020 (figure 10.1.2). The only significant methodological change made to the Energy sector was the improved estimation of fugitive emissions from natural gas distribution networks. This resulted in no change to 1990 emissions and a 147.4 kt CO_2-e decrease in 2020 emissions. Further changes in the level of emissions estimates have occurred due to small changes in the activity data, as detailed in table 10.1.3. Energy activity data for the years 1990 to 2020 have been updated according to the latest energy statistics published by the Ministry of Business, Innovation and Employment.

Table 10.1.3 Explanations and justifications for recalculations in the Energy sector

Explanation of recalculation	Underpinning IPCC principle	Additional justification
Fugitive emissions estimates for natural gas distribution networks have been revised. The new methodology represents a Tier 3 approach and takes into account the infrastructure improvements occurring over time.	Accuracy	Consistency

Figure 10.1.2 Effect of changes to activity data on emissions estimates from New Zealand's Energy sector from 1990 to 2020



10.1.2 Industrial Processes and Product Use

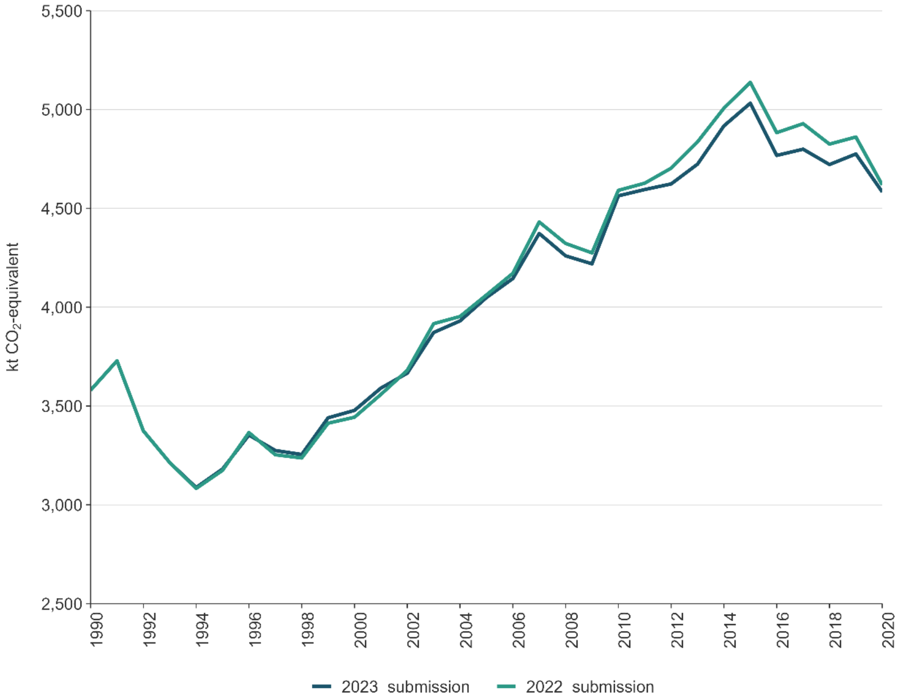
Improvements and recalculations made in the Industrial Processes and Product Use (IPPU) sector have resulted in no change for 1990 and a 0.8 per cent (35.5 kt CO_2-e) decrease in emissions estimates for 2020 (figure 10.1.3).

The decrease in 2020 emissions estimates is due to a recalculation of emissions from *Refrigeration and air conditioning*, with no recalculation of emissions from any other category. The decrease in reported emissions for 2020 (35.5 kt CO_2-e) is the net effect of detailed re-estimations of import amounts, equipment retirements and emission factors in all sub-applications. These changes were enabled by improvements to stock models to distinguish recovery for reuse from recovery for disposal. These and other minor recalculations are detailed in table 10.1.4.

Table 10.1.4 Explanations and justifications for recalculations in the IPPU sector

Explanation of recalculation	Underpinning IPCC principle	Additional justification
Rapidly increasing imports of refrigerants in stationary air conditioning equipment, and other changes indicated by survey results in 2022, have resulted in reassessments to earlier years. These allow better accounting for stocks held by importers and banks and, consequently, emissions.	Accuracy	Improved data available
Estimated amounts of imported refrigerant, which are not included in import levies and may represent illegal imports, have been reassessed.	Accuracy	Improved data available
The age range of domestic refrigerators has been reassessed, to reflect that they are disposed of after 10 to 24 years of use.	Accuracy	Improved data available
Emission factors for the *Transport refrigeration* and *Stationary air conditioning* sub-applications have been adjusted. These changes affect only the attribution of emissions between sub-applications with no change in total emissions.	Comparability	Improved data available
The weighted average charge in metered dose inhalers has been reassessed to reflect changing sales.	Accuracy	Improved data available
Minor errors in refrigerant imports shown by survey responses have been corrected.	Accuracy	Correction of an error

Figure 10.1.3 Effect of recalculations on emissions estimates from the IPPU sector from 1990 to 2020



10.1.3 Agriculture

Improvements and recalculations made to the Agriculture inventory in the 2023 submission have resulted in a 1.4 percent (480.8 kt CO_2-e) decrease in estimated agricultural emissions in 1990 and a 2.7 percent (1,065.4 kt CO_2-e) decrease in estimated agricultural emissions in 2020 (figure 10.1.4).

The improvements implemented for the Agriculture inventory in the 2023 submission are:

- the use of new $Frac_{LEACH}$ values for grazing systems and synthetic nitrogen
- improved estimates of within-year dairy cattle population change
- the use of new feed quality values for *Dairy cattle*, *Non-dairy* (beef) *cattle* and *Sheep* to reflect pasture and non-pasture feed use
- minor error corrections to the deer calculations
- revisions to agricultural statistics, using the latest available activity data from sources described in chapter 5, section 5.1.4.

Update to the $Frac_{LEACH}$ parameter

For the 2023 submission, the $Frac_{LEACH}$ parameter has been disaggregated into three values. A value of 0.10 is used for cropping systems and 0.08 for grazing systems. Based on these values, a new $Frac_{LEACH}$ value for synthetic nitrogen (F_{SN}) of 0.082 has been calculated.

The value of 0.10 for cropping systems was derived by Welten et al. (2021), using measured and modelled values from OVERSEER® (Wheeler et al., 2003) to estimate nitrogen leaching for a variety of arable and vegetable cropping systems. Variables in their analysis included cropping rotation sequences, regions, soil types and rainfall. This investigation produced a recommendation for a $Frac_{LEACH}$ value that is more representative of cropping systems in

New Zealand than the value of 0.07 that has been applied across all agricultural systems in previous submissions. This change was recommended by the Agriculture Inventory Advisory Panel (the Panel) at its meeting on 4 November 2021 and implemented in the 2022 submission.

Welten et al. (2021) also recommended adopting a $Frac_{LEACH}$ value of 0.08 for grazing systems, which the Panel also recommended in principle in 2021, subject to further investigation as to whether the pasture nutrition data in OVERSEER® are representative of pasture nutrition data in the Agriculture inventory. Researchers confirmed that, while OVERSEER® does use pasture quality values that are not completely consistent with the Agriculture greenhouse gas inventory model, the impact of this is minor and does not affect the final recommendation. Following this confirmation, this change was recommended by the Panel at its meeting on 26 October 2022 and implemented in the 2023 submission.

Based on the new $Frac_{LEACH}$ values for cropping and grazing systems, a new leaching value for synthetic nitrogen (F_{SN}) of 0.082 was calculated. This value is a weighted average based on the ratio of total nitrogen fertiliser applied to grazing and cropping systems (approximately 90:10 based on recent data from Stats NZ, which is also reasonably consistent across the entire reporting period). This approach was recommended by the Panel at its meeting on 26 October 2022 and has been implemented in the 2023 submission.

Previously, a uniform $Frac_{LEACH}$ value of 0.07 was used for all nitrogen fertiliser applied to agricultural soil in New Zealand. This value was sourced from Thomas et al. (2005), who compared nitrogen leaching estimates for different farm systems based on Intergovernmental Panel on Climate Change (IPCC) methodology (a value of 0.30 kg N/kg of fertiliser or manure) with estimates from OVERSEER®. The IPCC-based estimates were found, on average, to be 50 per cent higher than those based on the OVERSEER® nutrient budget model (using a $Frac_{LEACH}$ value of 0.15). However, the investigation by Welten et al. (2021) found that a $Frac_{LEACH}$ of 0.07 was not representative of all agricultural system types (particularly cropping), resulting in the recommended disaggregation of the $Frac_{LEACH}$ parameter for the 2022 submission.

The implementation of the 2023 changes increases estimated emissions from the Agriculture sector by 0.2 per cent (55.0 kt CO_2-e) in 1990 and 0.2 per cent (73.1 kt CO_2-e) in 2020 (see table 10.1.5).

Table 10.1.5 Comparison of current and previous emissions estimates before and after change to the $Frac_{LEACH}$ values

		1990	2020	Change in emission outputs between 1990 and 2020 (kt CO_2-e)	Percentage change in emission outputs between 1990 and 2020 (%)
Total emissions from Agriculture sector (kt CO_2-e)	Emissions estimate using previous $Frac_{LEACH}$ values	33,257.1	38,287.1	5,030.1	15.1
	Emissions estimate using new $Frac_{LEACH}$ values	33,312.0	38,360.2	5,048.1	15.2
	Difference in emissions estimates compared with current inventory	55.0	73.1	18.1	NA
	Percentage difference in emissions estimates	0.2	0.2	NA	NA

Note: NA = not applicable.

Improved estimates of within-year Dairy cattle population change

Emissions estimates in all categories relating to *Dairy cattle* since 1990 have been enhanced by a methodological update to estimates of within-year dairy cattle population change.

The Agriculture greenhouse gas inventory models the dairy cattle population of each production year (1 July to the following 30 June). Livestock population data derived from the Agricultural Production Survey for animals present on 30 June of each year for each region are used as a baseline. The number of animals present each month for the remainder of the production year (July to June) are then based on assumptions on timing and number of deaths (including culling and slaughter) as well as birth dates (with assumptions applied at a national level), along with the number present on 30 June the following year. Each of the four stock classes has a different set of methods and assumptions.

Recent research caried out by AgResearch[74] (Burggraaf et al., 2022) has used industry data to improve inventory population dynamics. A focus was placed on obtaining data sources from 1990 to present, in line with the timeline required for national greenhouse gas reporting. The study recommended improvements to population dynamics based on long-term averages in birth, death and slaughter timing, combined with monthly data for each year for dairy heifer exports.

Specific recommendations were:

- changing the weighted average calving birth date from 1 August to 13 August
- adding 1 per cent to the growing heifers (0 to 1 year) population from birth (August) and then gradually losing these additional calves to then reach the Agricultural Production Survey value in June. Previously, the growing heifers (0 to 1 year) population was constant through the year
- subtracting monthly dairy cattle exports from the growing heifers (1 to 2 years) population. Exports are assumed to come from the not-in calf and not-lactating heifers. Previously exports were not considered
- including a 1 per cent death rate for growing heifers (1 to 2 years) spread across the year
- retaining stock in the growing heifers (1 to 2 years) class until 1 July. Previously, stock were moved into the mature milking cow population in May
- using a 16.9 per cent annual mortality rate for the national mature dairy cow population including culling
- using the long-term average monthly cull distribution to determine the proportion of the starting population of mature cows still present each month. These data are shown in table 10.1.6.

Table 10.1.6 Long-term average monthly distribution of slaughter for mature cows

Month	Per cent of annual slaughter deaths	Per cent of the 1 July population remaining at the end of the month, using an annual loss of 16.9 per cent
Jul	5.3	99.1
Aug	5.3	98.2
Sep	5.4	97.3
Oct	5	96.4
Nov	3.9	95.8
Dec	4	95.1

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Month	Per cent of annual slaughter deaths	Per cent of the 1 July population remaining at the end of the month, using an annual loss of 16.9 per cent
Jan	5.1	94.3
Feb	7.2	93
Mar	11.9	91
Apr	14.9	88.5
May	21.4	84.9
Jun	10.7	83.1

The above changes were recommended by the Panel at its meeting on 26 October 2022 and implemented in the 2023 submission.

As part of the change to the growing heifer population, there has also been a change to the liveweight calculations for dairy cattle.

Previously, it was assumed that all dairy calves (growing heifers 0 to 1 year) are born on the first of August and have a birth weight equal to 9 per cent of an adult dairy cow weight. The weight of these animals was increased linearly until they were 638 days old, at which point their weight was assumed to be 90 per cent of the weight of an adult dairy cow. After 638 days, they joined the class of mature milking cows and made an instantaneous jump in weight to the full mature dairy cow weight.

In the improved calculation, it is assumed that all dairy calves (growing heifers 0 to 1 year) are born on 13 August and have a birth weight equal to 9 per cent of an adult dairy cow weight. The weight of these animals increases linearly until they are 730 days old, at which point their weight is assumed to be that of an adult dairy cow and they become *Mature milking cows*.

The implementation of the 2023 improvements reduced emissions estimates from the Agriculture sector by 0.7 per cent (231.5 kt CO_2-e) in 1990 and 1.3 per cent (488.1.0 kt CO_2-e) in 2020 (see table 10.1.7).

Table 10.1.7 Comparison of current and previous emissions estimates before and after the change to the dairy cattle population modelling

		1990	2020	Change in emission outputs between 1990 and 2020 (kt CO_2-e)	Percentage change in emission outputs between 1990 and 2020 (%)
Total emissions from Agriculture sector (kt CO_2-e)	2023 (1990–2020) emissions estimate using previous population model	33,543.5	38,848.3	5,304.7	15.8
	2023 (1990–2020) emissions estimate using new population model	33,312.0	38,360.2	5,048.1	15.2
	Difference in emissions estimates compared with current inventory	–231.5	–488.1	–256.6	NA
	Percentage difference in emissions estimates	–0.7	–1.3	NA	NA

Note: NA = not available.

Use of non-pasture feed

Emissions estimates for *Dairy cattle, Non-dairy* (beef) *cattle* and *Sheep* have been improved by a methodological update to account for the use of non-pasture feed (Sangster, 2022). Previously, the inventory assumed that *Dairy cattle, Non-dairy* (beef) *cattle* and *Sheep* consume only pasture to satisfy their energy requirements.

The use of non-pasture feed is accounted for by adjusting the current pasture feed quality values used in the inventory. Adjusted feed quality values are calculated using a weighted average dependent on the consumption of non-pasture feed by livestock. This methodology does not account for changes to the amount of methane produced per unit of feed consumed (methane yield).

The Agriculture inventory requires feed quality data to calculate methane and nitrous oxide emissions from dairy cattle, beef cattle, sheep and deer. For inventory purposes, there are three main components of feed quality:

1. metabolisable energy (ME), used to calculate dry-matter intake (DMI) and nitrogen intake
2. nitrogen (N%) content, used to calculate nitrogen intake and excretion
3. digestibility (DMD%), used to calculate faecal dry matter.

The feed quality values used for pasture are the values recommended by Giltrap and McNeill (2020). These pasture quality values were implemented in 2021, replacing values from research completed in the early 2000s (Litherland et al., 2002, and Ian Brooks (pers. comm.)). These are the same values used in the 2022 submission. The feed quality values used for non-pasture feed are recommended by Calvert (unpublished).

Activity data on the consumption of non-pasture feed by livestock are provided by DairyNZ (MPI, 2019) and AbacusBio (MPI, 2017, 2018b).

The 10 most-used non-pasture feeds were included in the analysis. These accounted for 90 per cent of non-pasture feed consumed by dairy cattle in 2019. To reduce the complexity of the analysis, and in recognition of the uncertainty in the source data, less common feeds were aggregated and assumed to have the same feed quality as pasture. The above changes were recommended by the Panel at its meeting on 26 October 2022 and implemented in the 2023 submission.

The implementation of the 2023 improvements reduced emissions estimates from the Agriculture sector by 1.1 per cent (360.8 kt CO_2-e) in 1990 and 2.0 per cent (769.1 kt CO_2-e) in 2020 (see table 10.1.8).

Table 10.1.8 Comparison of current and previous emissions estimates before and after the incorporation of supplementary feeds

		1990	2020	Change in emission outputs between 1990 and 2020 (kt CO_2-e)	Percentage change in emission outputs between 1990 and 2020 (%)
Total emissions from Agriculture sector (kt CO_2-e)	2023 (1990–2020) emissions estimate using pasture quality values	33,672.8	39,129.3	5,456.54,881.8	16.2
	2023 (1990–2020) emissions estimate using adjusted feed quality values	33,312.0	38,360.2	5,048.1	15.2
	Difference in emissions estimates compared with current inventory	–360.8	–769.1	–408.3	NA
	Percentage difference in emissions estimates	–1.1	–2.0	NA	NA

Note: NA = not available.

Minor error corrections to the Deer calculations and revision of agricultural statistics animal population estimates

Emissions estimates for *Deer* have been improved through minor corrections to ensure the inventory calculations match the published methodology.

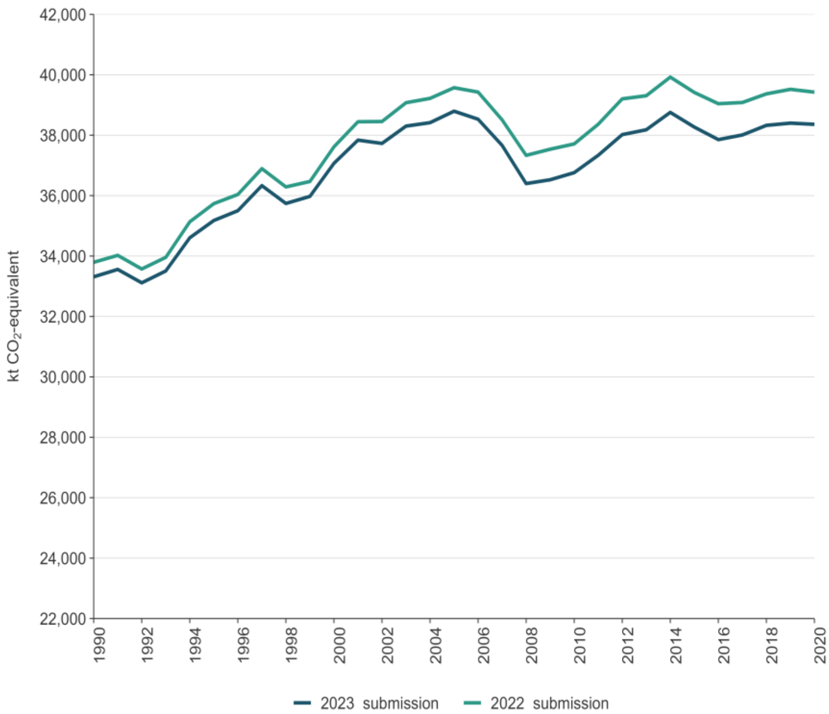
Revision and finalisation of agricultural animal population estimates data from Stats NZ can mean emissions estimates for the latest two years vary from the previous submission for certain source categories.

The calculation of emissions for the most recent year (2021) requires population estimates for 2022 that are only provisional at the time the inventory is compiled.

As part of Stats NZ's work on the Agricultural Production Survey, the Ministry for Primary Industries (MPI) provides estimates in an 'expectations report' of what it expects the survey to show. These estimates are based on a range of sources, including Beef + Lamb NZ and livestock slaughter statistics. The primary purpose of these data is to provide Stats NZ with a benchmark for its aggregated survey responses. These figures can change after receiving final animal numbers and data. The final figures will be taken into account in the 2024 (1990 to 2022) inventory submission.

The 2021 to 2022 New Zealand Dairy Statistics from the Livestock Improvement Corporation were not available in time to be used for the 2023 submission, therefore, values were estimated from other sources and historical records. These values will be revised for the 2024 submission because the Livestock Improvement Corporation data will be available at the end of 2023.

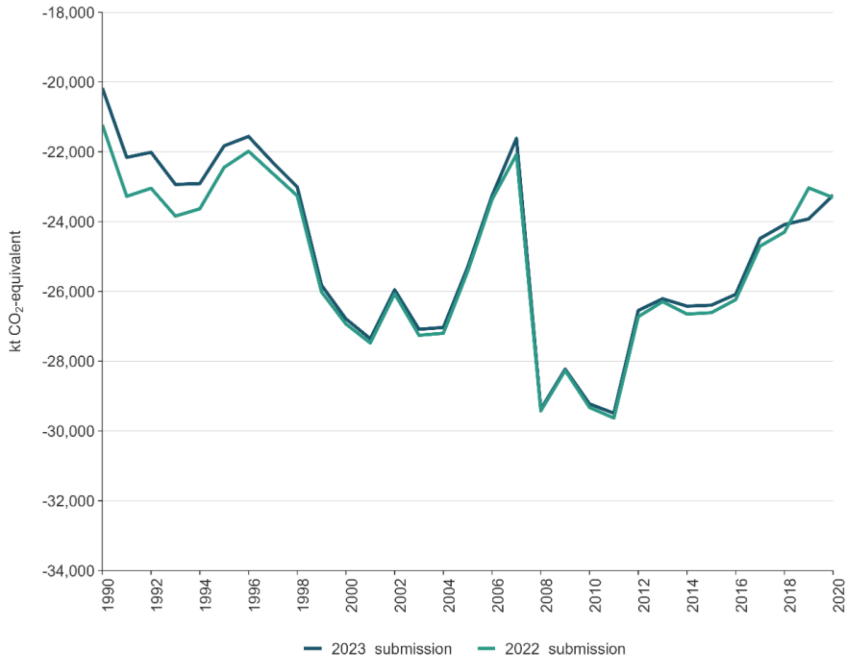
Figure 10.1.4 Effect of recalculations on emissions estimates from New Zealand's Agriculture sector from 1990 to 2020



10.1.4 Land Use, Land-Use Change and Forestry

Improvements made to the LULUCF sector have resulted in a 5.0 per cent (1,058.0 kt CO_2-e) decrease in estimated net LULUCF removals in 1990 and a 0.3 per cent (71.2 kt CO_2-e) decrease in estimated net LULUCF removals in 2020 (figure 10.1.5).

Figure 10.1.5 Effect of recalculations on net emissions estimates from New Zealand's LULUCF sector from 1990 to 2020



Note: Net emissions are expressed as a negative value to clarify that the value is a removal and not an emission.

Significant improvements to the 2023 submission for the LULUCF sector are summarised in table 10.1.9. Further details on these changes are given in chapter 6.

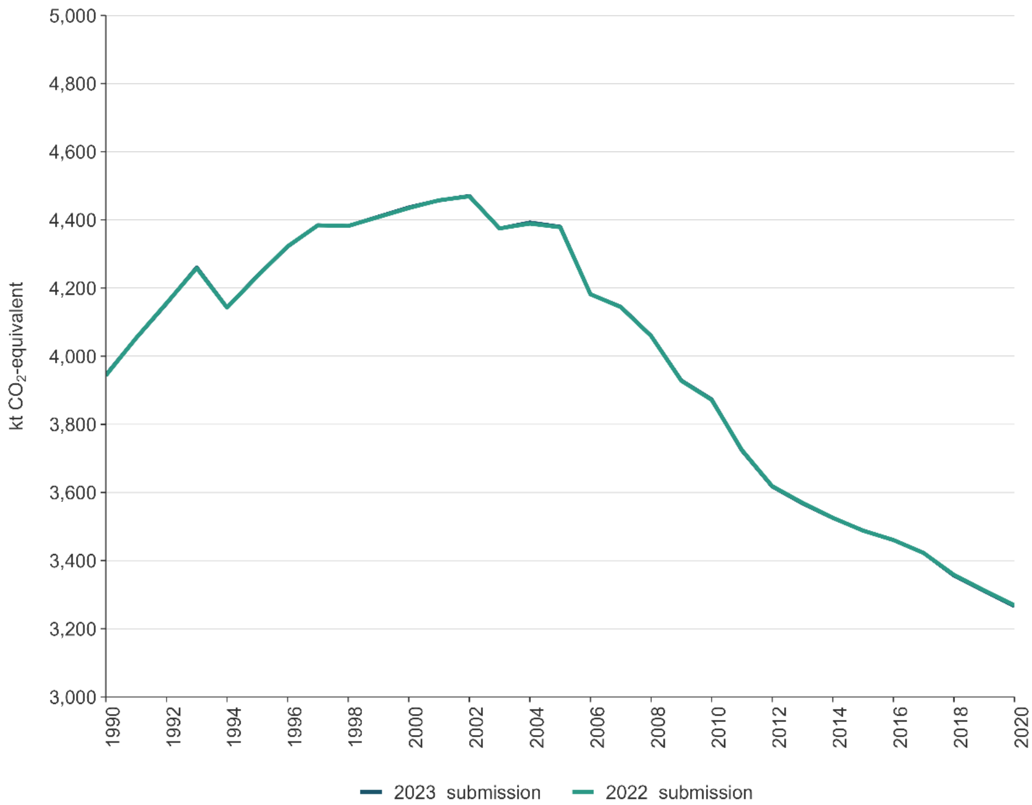
Table 10.1.9 Explanations and justifications for recalculations in the LULUCF sector

Explanation of recalculation	Underpinning IPCC principle	Additional justification
Improvements to the method used to estimate deforestation for unmapped years has led to an increase in the estimated deforestation area for 2020. The overall net impact of this change to the LULUCF sector is an increase of 209 kt CO_2-e in 2020. This improvement is also largely responsible for the 41.2 per cent increase in emissions reported in the *Grassland* category for 2020 (given most deforested land is converted to grassland) (further detail is provided in chapter 6, section 6.3.5).	Accuracy	Additional data available; key category improvement (*Land converted to grassland*)
A range of modelling procedures has been improved to ensure consistency of treatment of harvesting and deforestation activities between pre-1990 and post-1989 planted forests. Further detail is described in chapter 6, section 6.3.6. The overall net impact of this change to the LULUCF sector is a decrease of 106 kt CO_2-e in 2020 emissions and a decrease of 987 kt CO_2-e in 1990.	Accuracy	Consistency; key category improvement (*Forest land remaining forest land*, *Land converted to forest land*, *Land converted to grassland*)
Use of country-specific above- and below-ground biomass carbon stocks for vegetated wetlands (Easdale et al., unpublished). Above-ground biomass carbon stocks were estimated as 20.22 tC ha^{-1} (11.07 – 29.38, 95 per cent confidence interval) and below-ground estimated as 7.40 tC ha^{-1} (1.85 – 12.9, nominal error range). Previous submissions did not estimate the carbon stock and carbon stock change in vegetated wetlands, which meant any emissions and removals for land transitioning in to and out of this class were also not estimated (further detail is provided in chapter 6, section 6.6.5). The overall net impact of this change to the LULUCF sector is a decrease of 16 kt CO_2-e in 2020 and a decrease of 39 kt CO_2-e in 1990.	Accuracy	Completeness

10.1.5 Waste

Improvements and recalculations made to estimates in the Waste sector have resulted in a 0.04 per cent (1.5 kt CO_2-e) increase in emissions estimates in 1990 and a 0.1 per cent (2.4 kt CO_2-e) decrease in emissions estimates in 2020 (figure 10.1.6).

Figure 10.1.6 Effect of recalculations on emissions estimates from New Zealand's Waste sector from 1990 to 2020



Note: Due to the small size of the recalculation, the 2023 submission line is obscured by the 2022 submission line.

Minor changes have been made that affect emissions as follows.

- Activity data for *Managed waste disposal sites* were revised for 2018, 2019 and 2020 to remove small amounts of cover material that should not be included in the waste tonnage.
- The Coulson Road landfill within the *Managed waste disposal sites* category stopped accepting waste in 2019. As a result, the landfill gas capture rate was revised for the entire duration of gas capture, beginning in 2018, from 68 per cent to 52 per cent, which was the value for closed sites. Furthermore, the Victoria Flats landfill had a gas capture system installed during 2021, and the estimate for 2021 reflects this.
- Activity data for *Composting* was revised upward, to account for the effects of policy actions beginning in 2020.
- Activity data for *Industrial wastewater* was revised for the paper and paperboard and wood pulp industries, due to revised statistics.

A full list of recalculations is provided in table 10.1.10.

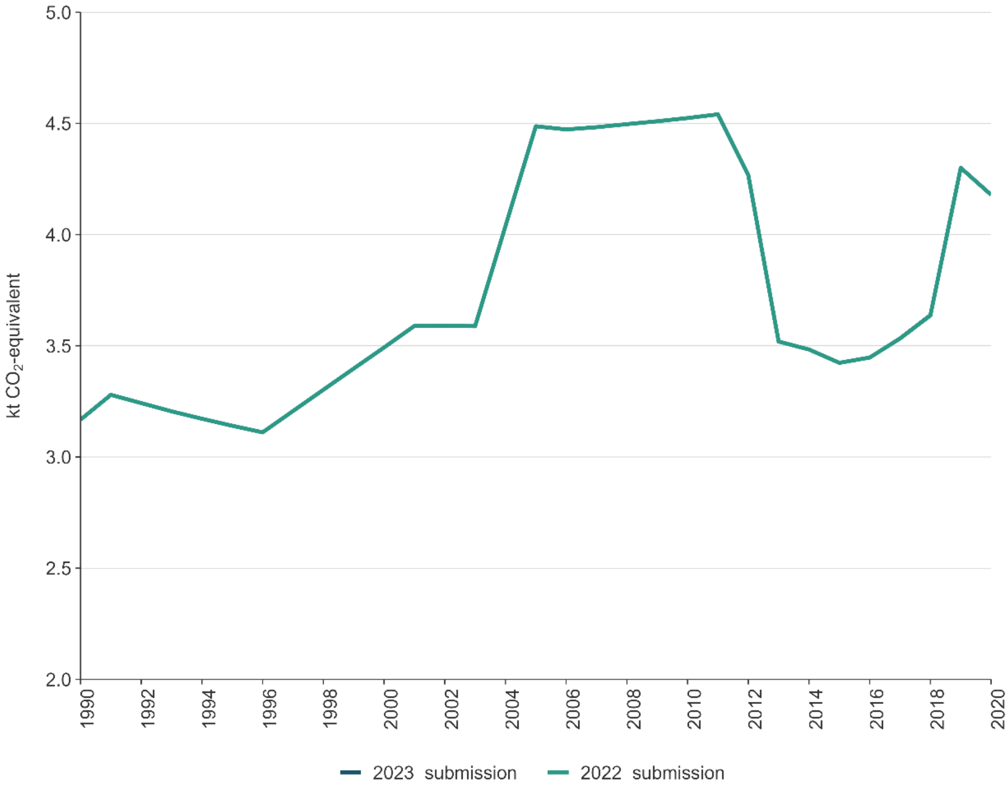
Table 10.1.10 Explanations and justifications for recalculations in the Waste sector

Explanation of recalculation	Underpinning IPCC principle	Additional justification
Estimated emissions from *Managed waste disposal sites* (5.A.1.a) have not changed in 1990 and have decreased by 1.0 kt CO_2-e (0.1%) in 2020. This is due to minor updates to activity data for managed landfills, after revisions have been made to historical levy data, and updated the gas capture status for two landfills.	Accuracy	Key category improvement: *Solid waste disposal*
Estimated emissions from *Composting* (5.B.1) have not changed in 1990 and have increased by 0.8 kt CO_2-e (1.2%) in 2020. This is due to the effect of policy actions beginning in 2020, which are now included in the activity data.	Completeness	
Estimated emissions from *Industrial wastewater* (5.D.2) have increased by 1.5 kt CO_2-e (1.6%) in 1990 and decreased by 1.6 kt CO_2-e (1.6%) in 2020 due to revised statistics for the paper and paperboard industries.	Accuracy	Key category improvement: *Wastewater treatment and discharge*

10.1.6 Other sector (Tokelau)

Recalculations made to emission estimates in Tokelau have resulted in no change for 1990 and a 0.004 per cent (0.0002 kt CO_2-e) increase in emissions in 2020 (figure 10.1.7). This increase in 2020 is the result of more accurate activity data.

Figure 10.1.7 Effect of recalculations on emissions estimates from the Tokelau sector from 1990 to 2020



Note: Due to the small size of the recalculation, the 2023 submission line is obscured by the 2022 submission line.

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.

Tables 3 and 4 of the assessment and review report of New Zealand's 2021 National Inventory Report (NIR) (UNFCCC, 2023) contain an assessment of progress in addressing recommendations provided by the expert review teams (ERTs) during the reviews of the 2019 and earlier submissions. These recommendations are detailed in table 10.2.1 along with New Zealand's latest responses to those recommendations.

Table 10.2.1 New Zealand's responses to recommendations in tables 3 and 4 of the 2021 assessment and review report that remain relevant as issues raised in earlier reviews

Sector	ID number	Expert review team recommendation	New Zealand response
General – Article 3.14 (G.3, 2019) KP reporting adherence	G.1, 2021	Report in the NIR information on changes in the reporting on the minimization of adverse impacts in accordance with Article 3, paragraph 14, of the Kyoto Protocol.	**Resolved.** New Zealand reported in its 2021 NIR (p. 503) on changes in its reporting on the minimisation of adverse impacts, in accordance with Article 3, paragraph 14, of the Kyoto Protocol.
General – Uncertainty analysis (G.7, 2019) Convention reporting adherence	G.2, 2021	Include in the NIR an uncertainty analysis for 1990 (the base year under the Convention).	**Resolved.** New Zealand included in its 2021 NIR (p. 50) and in the annex to its 2021 NIR (p. 27) an uncertainty analysis for 1990 (the base year under the Convention) using approach 1 from the 2006 IPCC Guidelines (IPCC, 2006a), consistent with paragraph 15 of the UNFCCC Annex I reporting guidelines.
Energy – Fuel combustion – reference approach – liquid fuels – CO_2 (E.2, 2019) (E.1 and E.2, 2017) (E.1 and E.8, 2016) (E.6 and E.21, 2015) (24, 2014) (27, 2013) Accuracy	E.1, 2021	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 NEU of fuels and feedstocks.	**Resolved**. New Zealand separated the reporting of naphtha and crude oil under the reference approach (CRF table 1.A(b)) across the time series. Previously, AD for these fuels were reported together under crude oil. The Party explained that such disaggregation was possible owing to the migration of its data system to a different programming language (2021 NIR, chapter 3, section 3.3.2, p. 93 and section 3.3.3, p. 94).
Energy – Fuel combustion – reference approach – CO_2 (E.3, 2019) (E.3, 2017) (E.9, 2016) (E.7 and E.22, 2015) (24, 2014) (27, 2013) Comparability	E.2, 2021	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.	**Resolved**. New Zealand reported disaggregated data for lubricants, petroleum coke and bitumen in CRF table 1.A(b) across the time series. Previously, AD for these fuels were reported together under bitumen. The Party explained that such disaggregation was possible owing to the migration of its data system to another programming language (2021 NIR, chapter 3, section 3.3.2, p. 93 and section 3.3.3, p. 94).
Energy – Fuel combustion – reference approach – all fuels – CO_2 (E.5, 2019) (E.24, 2017) Transparency	E.3, 2021	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.	**Resolved**. New Zealand included information in its 2021 NIR, chapter 3, section 3.2.6 (p. 88) on the cases in which the structure of CRF table 1.A(b) does not align with that of its energy balance: (1) crude oil and refinery feedstock are combined in the energy balance, but reported separately in CRF table 1.A(b); (2) indigenous production of LPG, which is considered a primary fuel, is included in the national energy balance, but the CRF table does not allow entry of LPG production, so it is included under natural

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			gas production and then allocated to LPG via stock change; and (3) the energy balance includes the production of synthetic gasoline from natural gas under energy transformation. The CRF table 1.A(b) does not allow entry of synthetic gasoline transformation, so it is included under natural gas production and then allocated to gasoline via stock change.
Energy – 1.A.1.a Public electricity and heat production – liquid fuels – CO_2, CH_4 and N_2O (E.23, 2019) Transparency	E.4, 2021	Include information on trends in liquid fuel consumption, especially by explaining the values for 2001 (reported as "NO") and 1992 and 2008 (where consumption and emissions were significantly higher than in other years since 1990).	**Resolved**. The Party explained in its 2021 NIR (p. 82) that the emissions from public electricity and heat production fluctuate considerably from year to year and that particularly dry meteorological conditions result in an increase in fossil electricity production to compensate for the shortfall in hydroelectric generation. In addition, because the storage capacity of hydro reservoirs is limited to around 10 per cent of New Zealand's production, fossil fuel electricity generation is used to balance supply and demand. Information provided in the 2021 NIR (table 10.2.2) indicates that AD were checked with the data system manager at MBIE and found to be correct.
Energy – 1.A.2 Manufacturing industries and construction – liquid fuels – CO_2, CH_4 and N_2O (E.24, 2019) Transparency	E.5, 2021	Include more detail on the method used for disaggregation of liquid fuels to the subcategories under manufacturing industries and construction (such as energy intensities in PJ per unit of GDP).	**Resolved.** New Zealand included in its 2021 NIR (chapter 3, section 3.3.7, p. 104) a full explanation of how liquid fuels are disaggregated by type of industry (manufacturing industries and construction subcategories), as well as table 3.3.5, which shows the energy intensity values (GJ per GDP) used to disaggregate liquid fuel consumption by type of industry.
Energy – 1.A.2 Manufacturing industries and construction – gaseous fuels – CO_2, CH_4 and N_2O (E.28, 2019) Comparability	E.6, 2021	Review the allocation of emissions for subcategories 1.A.2.f non-metallic minerals and 1.A.2.g.i manufacturing of machinery from gaseous fuel consumption for 2009–2015 and explain any recalculation in the NIR.	**Resolved.** New Zealand reviewed natural gas consumption under subcategories 1.A.2.f (non-metallic minerals) and 1.A.2.g.i (manufacturing of machinery) in conjunction with the MBIE (oil and gas data system manager) and concluded that, in the light of the available information, there is currently insufficient justification to reallocate energy sales data, noting that, to maintain consistency, the emission estimates should continue to be based directly on energy sales data (i.e., data reported directly by natural gas sellers already aggregated at the corresponding New Zealand Standard Industrial Classification code level). The ERT agreed with this conclusion.
Energy – 1.A.2.c Chemicals – gaseous fuels – CO_2, CH_4 and N_2O (E.26, 2019) Transparency	E.7, 2021	Explain the trend in fuel consumption and emissions from chemicals in the NIR.	**Resolved.** New Zealand explained in its 2021 NIR (chapter 3, section 3.2.3, p. 87) the required explanation, clarifying that the fluctuation in natural gas under subcategory 1.A.2.c is related to the national methanol production industry, which saw a reduction in its production levels in 2004 following a gas supply shortage in 2003, before increasing its capacity in 2008 and again in 2012, reaching full capacity again from December 2013 onward.

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Energy – 1.A.3.b Road transportation – liquid and gaseous fuels – CO_2, CH_4 and N_2O (E.29, 2019) Comparability	E.8, 2021	Report as "NO", instead of "IE", the AD and emissions for biomass for light- and heavy- duty trucks and buses, and diesel, liquefied petroleum gas and biomass for motorcycles for before 2000.	**Resolved.** The notation keys have been updated.
Energy – 1.A.3.b Road transportation – liquid and gaseous fuels – CO_2 (E.30, 2019) Convention reporting adherence	E.9, 2021	Continue to estimate the CO_2 emissions on the basis of fuel sold, but report the CO_2 emissions for before 2000 disaggregated by vehicle mode (cars, light-duty trucks, heavy-duty trucks and buses, and motorcycles) using the data collected for the estimation of CH_4 and N_2O emissions as a good practice to verify the CO_2 estimates obtained with a tier 1 approach.	**Addressing.** A project to disaggregate these emissions by vehicle mode is under way, noting that key progress in reconfiguring the related system codes has been made (see 2021 NIR, chapter 3, section 3.3.3). An update will be included in the next submission.
Energy – 1.A.3.b Road transportation – gaseous fuels – CO_2, CH_4 and N_2O (E.31, 2019) Transparency	E.10, 2021	Include in the NIR the description of the trend of gaseous fuels for cars and heavy-duty trucks and buses.	**Resolved.** New Zealand included in the 2021 NIR (chapter 3, section 3.3.8, p. 111) information on the trend of gaseous fuels used in road transportation, indicating that compressed natural gas and LPG began to be phased out of the market in 1987, owing to the cessation of government subsidies for bi-fuel vehicles, with just one bus company continuing to use compressed natural gas until 2017. No compressed natural gas or LPG have been used for road transportation since then.
Energy – 1.A.3.b Road transportation – biomass – CO_2, CH_4 and N_2O (E.32, 2019) Transparency	E.11, 2021	Explain the trend of biomass (biodiesel) used in road transportation, including the information that the biodiesel grant scheme ceased in June 2012.	**Resolved.** New Zealand included in the 2021 NIR (chapter 3, section 3.3.8, p. 114) information on the trend of biodiesel used in road transportation, indicating that two supporting schemes for biodiesel use (the Biofuel Sales Obligation and Biodiesels Grant Scheme) were discontinued in 2012, following which availability of AD for biodiesel fell significantly and has remained relatively stagnant since then.
Energy – 1.B.1.a Coal mining and handling – solid fuels – CH_4 (E.15, 2019) (E.14, 2017) (E.17, 2016) (E.31, 2015) Completeness	E.12, 2021	Estimate CH_4 emissions from abandoned underground mines (subcategory 1.B.1.a.i.3) or, if these emissions are considered insignificant, report them as "NE" 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.	**Addressing.** New Zealand reported 'NO' in CRF table 1.B.1 for subcategory 1.B.1.a.i.3 (abandoned underground mines). The Party explained in the 2021 NIR (chapter 3, section 3.4.1, p. 120) that a project is under way to identify whether activities under this subcategory occur in the country. To date, the results show that the activity does not take place in the North Island, with data still being collected or processed for the South island. During the review, the Party clarified that progress has been made in identifying old mines from historical mine records in the South Island, but these data still require significant manual processing before they can be used to meaningfully assess CH_4 fugitive emissions. The intention is to complete this work in time for the 2024 submission.
Energy – 1.B.1.a Coal mining and handling – solid fuels – CO_2 (E.33, 2019) Convention reporting adherence	E.13, 2021	Report CO_2 emissions for subcategory 1.B.1.a.i.3 abandoned underground mines as "NO" instead of "NE" in CRF table 1.B.1 if no recovery or flaring of CH_4 from abandoned underground mines occurred.	**Resolved.** New Zealand reported 'NO' for subcategory 1.B.1.a.i.3 (abandoned underground mines) in CRF table 1.B.1.

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Energy – 1.B.2.a Oil – liquid fuels – CO_2 (E.34, 2019) Comparability	E.14, 2021	Change the allocation of emissions from refinery flaring from subcategory 1.B.2.a.6 oil – other to subcategory 1.B.2.c.2 flaring – oil.	**Resolved.** New Zealand reallocated CO_2 emissions from refinery flaring from subcategory 1.B.2.a.6 (oil – other) to subcategory 1.B.2.c.2.i (flaring – oil). 'NO' is now reported for CO_2 emissions under subcategory 1.B.2.a.6.
Energy – 1.B.2.c Venting and flaring – gaseous fuels – CO_2 (E.35, 2019) Comparability	E.15, 2021	Report the AD from the Kapuni gas treatment plant for subcategory 1.B.2.c.1.ii venting – gas as confidential, "IE" or "NE", as appropriate, in CRF table 1.B.2, and review the information on AD reported in the documentation box of the same table.	**Resolved.** The notation keys have been changed to 'C'.
Energy – 1.B.2.c Venting and flaring – gaseous fuels – CH_4 (E.36, 2019) Comparability	E.16, 2021	Report the AD and emissions for subcategory 1.B.2.c.1.ii venting – gas as confidential, "IE" or "NE", as appropriate.	**Resolved.** New Zealand changed the notation key for CH_4 emissions from 'NA' to 'NE' in CRF table 1.B.2. For AD, see ID# E.15 above.
IPPU – 2. General – (I.1, 2019) (I.1, 2017) (I.1, 2016) (I.2, 2015) (37, 2014) (42, 2013) Transparency	I.1, 2021	Include in the NIR detailed information and methodological descriptions on how plant-specific data are estimated.	**Resolved.** New Zealand added information on plant-specific data collection and methods, as well as references to ETS regulations, in the 2018 inventory submission and has updated these over several years.
IPPU – 2. General – HFCs, PFCs and SF_6 (I.17, 2019) (I.16, 2017) (I.20, 2016) (I.23, 2015) Transparency	I.2, 2021	Include in the NIR all the information indicated in the section "Reporting and documentation" of the 2006 IPCC Guidelines for categories (a) 2.E electronic industry, (b) 2.F product use as substitutes ODS; and (c) 2.G other product manufacture and use.	**Resolved.** New Zealand reported in its 2021 NIR (chapter 4, section 4.6, p. 153) that no industries manufacture electronic products in the country, meaning that no emissions are reported in this category. New Zealand included more explanation in its 2021 NIR about the data sources used in 2.F and included information in the 2021 NIR concerning the EFs used for category 2.G.1. Other information requested is available to the ERT in a separate report, is not relevant, or is not available due to the methods used.
IPPU – 2. General – (I.23, 2019) Convention reporting adherence	I.3, 2021	Correct the following inconsistencies in the reporting of key categories and uncertainties within the NIR, including in the annexes to the NIR. (a) Cement production (CO_2) was reported as a key category in both the level and trend assessment in NIR table 4.1.2, but as a key category in the level assessment only in NIR section 4.2.1 and as a key category in the trend assessment only (including and excluding LULUCF) in CRF table 7; (b) Aluminium production (PFCs) was reported as a key category in the trend assessment only in NIR table 4.1.2, but it was identified as also being key in the level assessment for 2017 in tables A1.3.2(a) and A1.3.2(b) in the annexes to the NIR; (c) In the NIR (p. 125), methanol was reported as a key category in the trend assessment, but it was not identified as a key category in the annexes to the NIR; (d) In the NIR (section 4.3.4, p. 128), petrochemical and carbon black was reported as a key category, but it was	**Resolved.** Key category analysis and estimation of uncertainties have been repeated in the subsequent submissions and these discrepancies have been removed.

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		not identified as a key category in the annexes to the NIR; (e) Uncertainties reported in NIR table 4.7.3 were not reflected in table A.2.1.1 in the annexes to the NIR.	
IPPU – 2. General – CO_2 (I.26, 2019) Transparency	I.4, 2021	Explain how the AD for the chemical and metal industries (categories 2.B and 2.C) are obtained.	**Resolved.** For category 2.B, New Zealand provided in its 2021 NIR (chapter 4, section 4.3.2) information on the sources of AD for categories and subcategories 2.B.1, 2.B.8, 2.B.8.a and 2.B.10. For subcategory 2.B.5.b, the Party specified that the quantity of calcium carbide used to produce acetylene gas for welding is imported. For category 2.C, it provided all necessary information concerning how the AD for category 2.C.3 were obtained. For category 2.C.1 the Party explained that the AD (tonnes of steel produced) were provided to MBIE by two steel producers up to 2015 and have been provided by one producer since then, but this information is regarded as commercially confidential and thus reported as confidential in CRF table 2(I).A-Hs2. The 2021 NIR now notes (chapter 4, section 4.4.2) that such data are provided to MBIE by the industry.
IPPU – 2.A Mineral industry – CO_2 (I.3, 2019) (I.22, 2017) Convention reporting adherence	I.5, 2021	Review the calculation of the uncertainty for category 2.A and correct the values in NIR tables 4.2.1 and A2.1.1, if needed.	**Resolved.** New Zealand reviewed the uncertainty values related to the AD and EF for category 2.A reported in the 2021 NIR (annex) table A2.1.1 and made them consistent with those reported in 2021 NIR table 4.2.1 (p. 139) (1 per cent for AD and 1 per cent for EF).
IPPU – 2.A.2 Lime production – CO_2 (I.6, 2019) (I.23, 2017) Transparency	I.6, 2021	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 onward.	**Resolved.** New Zealand now reports CaO and MgO, net of impurities, for the entire time series, which results in consistent reporting. The 2021 NIR (chapter 4, section 4.2.2) describes the calculation of emissions for each part of the time series.
IPPU – 2.A.2 Lime production – CO_2 (I.24, 2019) Accuracy	I.7, 2021	Review and, if necessary, revise the CO_2 EF for kiln dust, noting that it cannot be the same as the CO_2 EF for CaO because the dust contains a mixture of CaO and MgO.	**Resolved.** New Zealand has now clarified that the lime companies report zero or undetectable MgO in kiln dust.
IPPU – 2.A.2 Lime production – CO_2 (I.25, 2019) Transparency	I.8, 2021	Explain in the NIR that burned lime was considered as high-calcium lime with an EF of 0.75 t CO_2/t lime and that the factor of 0.97 was the correction factor for hydrated lime for 1990–2013.	**Resolved.** New Zealand recalculated the AD and CO_2 emissions for this category and stopped using burned lime as the AD for 1990–2013 (see ID#s I.6 above and I.9 below).
IPPU – 2.A.2 Lime production – CO_2 (I.25, 2019) Comparability	I.9, 2021	Revert the changes in AD since 2014 to the original quantities of pure lime (CaO + MgO), noting that the IEF cannot be lower than 0.7848 according to the equation provided by the ETS regulation and presented in the NIR (p. 123).	**Resolved.** New Zealand reverted the changes in AD for 2014 onward and is now using pure lime, in accordance with the data from its ETS (the Party had previously converted the AD for 2014 onward from pure to burned lime, to make them consistent with the AD for 1990–2013). In addition, the Party recalculated emissions and also applied pure lime as the AD for 1990–2013 (see ID# I.6 above), and the EF applied is 0.784 t CO_2/t lime.
IPPU – 2.A.2 Lime production – CO_2 (I.25, 2019) Comparability	I.10, 2021	Continue reporting the same emissions but revise the AD as pure lime by dividing such emissions by a single IEF (that of 2014) for 1990–2013.	**Resolved.** New Zealand revised the AD for pure lime across the time series (see ID# I.6 above).

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IPPU – 2.B.1 Ammonia production – CO_2 (I.9, 2019) (I.24, 2017) Transparency	I.11, 2021	Clarify in the NIR (section 4.3.2) that urea used as fertilizer is reported under category 3.H (urea application).	**Resolved.** New Zealand reported in its 2021 NIR (chapter 4, section. 4.3.1, p. 140) that emissions from urea used as fertiliser (both manufactured in New Zealand and imported) are reported under category 3.H (urea application).
IPPU – 2.B.1 Ammonia production – CO_2 (I.9, 2019) (I.24, 2017) Transparency	I.12, 2021	Either provide an estimate for urea use in selective catalytic reduction (under category 2.D.3) in line with the 2006 IPCC Guidelines or 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.** New Zealand updated the information in its 2021 NIR (chapter 4, section 4.3.1, p. 140) to reflect correctly that CO_2 emissions from the use of urea in selective catalytic reduction are reported under category 2.D.3. In the 2021 NIR (p. 151), the Party also provided a description of the methodology used to estimate such CO_2 emissions.
IPPU – 2.B.1 Ammonia production – CO_2 (I.27, 2019) Comparability	I.13, 2021	Subtract the total quantities of oil and gas used (fuel plus feedstock) in ammonia production from the quantity reported under energy use in the energy sector, include the emissions accordingly in the IPPU sector and explain this reallocation in the NIR.	**Resolved.** It has not been feasible to make this change, owing to concerns about data confidentiality, with all data coming from a single company. The 2021 NIR (chapter 4, section 4.1.4) explains that this method has been retained due to confidentiality concerns.
IPPU – 2.C.1 Iron and steel production – CO_2 (I.11, 2019) (I.26, 2017) Completeness	I.14, 2021	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.** New Zealand estimates CO_2 emissions from electric steel production at the Pacific Steel plant using an approximate carbon balance. This is described in the 2021 NIR (chapter 4, section 4.4.2).
IPPU – 2.C.4 Magnesium production – SF_6 (I.14, 2019) (I.28, 2017) Transparency	I.15, 2021	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 its use.	**Resolved.** New Zealand now explains in the 2021 NIR (chapter 4, section 4.4.3) that it uses a country-specific uncertainty value for AD in SF_6 emissions from magnesium casting due to the historical estimates available when the data were collected.
IPPU – 2.D.1 Lubricant use – CO_2 (I.28, 2019) Transparency	I.16, 2021	Improve the information on the CO_2 EF for lubricant use, including the source of the EF.	**Resolved.** New Zealand reported in its 2021 NIR (chapter 4, section 4.5.2) that for the CO_2 EF for lubricant use it uses IPCC default parameters.
IPPU – 2.F Product uses as substitutes for ozone-depleting substances – HFCs (I.18, 2019) (I.30, 2017) Transparency	I.17. 2021	Explain, in NIR section 4.7.3, 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.** New Zealand updates its reporting on uncertainties for this category annually. The 2021 NIR (chapter 4, section 4.7.3) explains the method, and further information is available to the ERT. For refrigeration and air conditioning, uncertainties were estimated for each of the seven equipment types (±20 per cent for household refrigerators, 30 per cent for self-contained refrigerators, 30 per cent for remote cabinets, 40 per cent for dairy refrigerators, 70 per cent for cool stores, 50–80 per cent for three refrigerated transport components, and 30 per cent for other types of air conditioning), with the overall uncertainty recalculated for each annual submission. For the other sub-applications, these estimates do not change from year to year.

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IPPU – 2.F Product uses as substitutes for ozone-depleting substances – HFCs (I.29, 2019) Transparency	I.18, 2021	Explain the model used to estimate emissions in this category in more detail, including the assumptions made, in the NIR.	**Resolved.** New Zealand has expanded the explanations provided in the 2021 NIR (chapter 4, section 4.7.2) and can make further information available to the ERT.
IPPU – 2.F Product uses as substitutes for ozone-depleting substances – HFCs (I.29, 2019) Transparency	I.19, 2021	Improve the QA/QC for this category by comparing the results of the bottom-up model with the results of a top-down approach, as the import data are based on comprehensive annual surveys, to allow a clear comparison of the two results, as recommended by the 2006 IPCC Guidelines (vol. 3, chap. 7.1.4.1).	**Resolved.** The 2006 IPCC Guidelines (IPCC, 2006a) recommend a comparison of the results of a bottom-up model with the results of a top-down approach only where applicable. Uncertainties in the stock models used, and the use of a Tier 2b mass balance method, make such a comparison inapplicable for New Zealand.
IPPU – 2.F.1 Refrigeration and air conditioning – HFCs (I.19, 2019) (I.17, 2017) (I.37, 2016) Transparency	I.20, 2021	Describe in the NIR the methodology 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.** New Zealand includes a description of the methodology in the 2021 NIR (chapter 4, section 4.7.2) and further details can be made available to the ERT.
IPPU – 2.F.1 Refrigeration and air conditioning – HFCs (I.21, 2019) (I.32, 2017) Accuracy	I.21, 2021	Update the average charge of HFC-134a for the years from 2010 onward by taking into consideration the cars added to the fleet in recent years on the basis of data available from importers and/or from fleet statistics.	**Resolved.** New Zealand reports in its 2021 NIR (chapter 4, section 4.7.2) that the ongoing trend towards reduced HFC-134a charges continued after 2009. During the review, the Party clarified that when the Verum Group updated its 2018 estimate of imported car models, it reviewed a range of information, including reports on the composition of the Australian vehicle fleet, and discussed this matter with importers. The Party also reports that the variety of vehicles imported makes obtaining more accurate and up-to-date statistics on their refrigerant change infeasible.
IPPU – 2.F.1 Refrigeration and air conditioning – HFCs (I.30, 2019) Transparency	I.22, 2021	Update the equation in box 4.1 of the NIR to clarify that all calculations of the total charge of new equipment include the charge for equipment that is later exported.	**Resolved.** New Zealand included text above box 4.1 of the 2021 NIR (chapter 4, p. 154) explaining that the total charge of new equipment includes the charge for equipment that is later exported.
IPPU – 2.F.1 Refrigeration and air conditioning – HFCs (I.31, 2019) Transparency	I.23, 2021	Explain, for category 2.F.1.e mobile air conditioning, the trend of HFC-134a filled into new manufactured products, especially the decrease between 2003 and 2004, in the NIR.	**Resolved.** Responses to enquiries to importers indicate that obtaining more detailed data to achieve this clarification is not feasible.
IPPU – 2.G.2 SF6 and PFCs from other product use – SF_6 (I.22, 2019) (I.21, 2017) (I.23, 2016) (I.26, 2015) Transparency	I.24, 2021	Include in the NIR an explanation of the analysis of SF_6 emissions from SF_6 use in shoe and double-glazed window manufacture based on the information that was provided to the 2015 ERT as responses to questions and a background report.	**Resolved.** New Zealand reports in the 2021 NIR (chapter 4, section 4.8.2) that SF_6 is not used in the country for any of these applications.
Agriculture – 3. General (agriculture) – CH_4 and N_2O (A.4, 2019) Transparency	A.1 2021	Improve the description in the NIR to demonstrate clearly that the procedures for the agricultural production census and survey are aligned and no significant deviations have occurred in the time series since 1990.	**Resolved.** A more detailed explanation on the Agricultural Production Census and survey is included in chapter 5, section 5.1.4.

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Agriculture – 3. General (agriculture) – CH_4 and N_2O (A.5, 2019) Convention reporting adherence	A.2 2021	Correct the uncertainty values reported for enteric fermentation and agricultural soils in section 1.6 of the NIR so that they are consistent with the values reported in sections 5.2.3 and 5.5.3 of the NIR.	**Resolved.** The text on uncertainty in chapter 1, section 1.6 for enteric fermentation and agricultural soils has been corrected.
Agriculture – 3. General (agriculture) – CH_4 and N_2O (A.9, 2019) Transparency	A.3, 2021	Revise the text that refers to the year for which provisional population data are used in the NIR (p. 158).	**Resolved.** Updated text on the use of provisional Agricultural Production Survey data has been included in section 10.1.3. Emissions estimates have been updated with revised population figures.
Agriculture – 3. General (agriculture) – CH_4 and N_2O (A.9, 2019) Accuracy	A.4, 2021	Update the animal populations for 2018 and revise the estimates reported for 2017 in the CRF tables and explain this recalculation in the NIR.	**Resolved.** New Zealand updated the animal populations for 2017 and 2018 and recalculated the corresponding emissions. During the review, it explained that, because official animal population statistics are presented as estimated as at June each year, provisional population estimates are required for the second half of each year. The Party explained how these provisional estimates are calculated in the 2021 NIR (p. 175 and p. 441), showing in figure 10.1.4 (p. 441) the effects of the recalculations after receiving final animal numbers and data for 1990 to 2018.
Agriculture – 3. General (agriculture) – CH_4 and N_2O (A.10, 2019) Transparency	A.5, 2021	Provide additional information on the assumption that all growing beef animals are slaughtered at two years of age and refer to the MPI (2018a) report on animal live weights in the NIR.	**Resolved.** More information on the slaughter age of beef cattle assumption is provided in chapter 5, section 5.1.4 (under Animal productivity data – Beef cattle).
Agriculture – 3.A.1 Cattle – CH_4 (A.11, 2019) Transparency	A.6 2021	To improve the transparency of the comparison between the country-specific CH_4 EF and the IPCC default values, report, in that comparison, the EF calculated for milking cows only.	**Resolved.** Information on the IEF for mature milking dairy cattle only has been provided in chapter 5, table 5.3.2.
Agriculture – 3.A.2 Sheep – CH_4 (A.12, 2019) Convention reporting adherence	A.7, 2021	Correct the reference to the population of sheep older than one year in the equation describing the method used to estimate emissions from enteric fermentation for sheep of less than one year of age reported in the NIR (p. 172).	**Resolved.** These equations (in chapter 5, section 5.2.2) have been corrected.
Agriculture – Other livestock – CH_4 (A.2, 2019) (A.5, 2017) Transparency	A.8, 2021	Provide in the NIR information on the breeding of rabbits and fur-bearing animals.	**Resolved.** New Zealand has investigated this issue. Rabbits are considered an agricultural pest and only a very small number of rabbits are farmed. 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.
Agriculture – 3.2.4 Other livestock – CH_4 (A.13, 2019) Accuracy	A.9, 2021	Implement the planned methodological changes regarding revising the assumptions about the population of dairy goats and the total goat population, recalculate the emissions and explain them in the NIR.	**Addressing.** The population of goats is sourced from the Agricultural Production Survey, and data from Burggraaf et al. (unpublished) on the proportion of dairy goats in the overall farmed population has been included in the emissions calculations. New Zealand has further work planned in 2023 to develop the emissions methodology for goats. For more information, see chapter 5, section 5.2.6 (Improving emissions from minor animal categories).

Sector	ID number	Expert review team recommendation	New Zealand response
Agriculture – 3.B Manure management – CH_4 and N_2O (A.14, 2019) Convention reporting adherence	A.10, 2021	Correct the references to CRF tables on pages 180 and 182 of the NIR to read "Methane from manure management systems (CRF table 3.B(a))" and "Nitrous oxide from manure management systems (CRF table 3.B(b))".	**Resolved.** The section titles have been changed. See chapter 5, section 5.3.2.
Agriculture – 3.B Manure management – N_2O (A.15, 2019) Accuracy	A.11 2021,	Review the N intake for dairy cattle, non-dairy cattle, sheep and deer to check if it is still applicable to the most recent years of the time series and, if necessary, revise its estimates.	**Resolved.** Updated pasture quality values were included in the 2021 inventory. For more information, see section 10.1.3 of the 2021 NIR.
Agriculture – 3.B.4 Other livestock (deer) – CH_4 (A.16, 2019) Accuracy	A.12, 2021	Revise the calculation procedures for the CH_4 EF for deer and explain the revisions in the NIR. If the Party continues to use three studies from 2003 as the basis for its calculation, the ERT recommends that the Party (1) consider using a more appropriate average value than a simple arithmetic average, such as a weighted average, to estimate the CH4 EF for deer; and (2) justify that the obtained value is more appropriate that the IPCC default value.	**Not Resolved.** The current calculation procedures for CH_4 EF (methane per unit of feed intake) for deer are appropriate, given the current information available. While the studies are older, it is expensive and difficult to obtain the required data for farmed deer in New Zealand, and the farming systems for them have not significantly changed. Given that deer weights are approximately half-way between sheep and beef, using an average between the two is valid. Because these values for beef cattle and sheep are based on robust, country-specific research, basing the CH_4 EF for deer on these values is more appropriate and provides more accurate emissions estimates for New Zealand farmed deer than using the IPCC default value.
Agriculture – 3.D.a.1 Inorganic N fertilisers – N_2O (A.17, 2019) Transparency	A.13, 2021	Explain in more detail in the NIR how the country-specific N_2O EF for urea was obtained by including a reference to the report that forms the basis for country-specific values (0.0059 and 0.01 kg N_2O N/kg N for urea and other synthetic fertilizer, respectively) and summarizing how the Agricultural Inventory Advisory Panel endorsed its application to the inventory.	**Resolved.** More detailed information on the EF for urea fertiliser, including a comparison with overseas studies, is included in chapter 5, section 5.5.2 (under Direct nitrous oxide emissions from managed soils – Synthetic nitrogen fertiliser).
Agriculture – 3.D.a.2 Organic N fertilisers – N_2O (A.18, 2019) Transparency	A.14, 2021	Explain in more detail how the country specific N_2O EFs for organic fertilizers (urine and dung) were obtained, summarize to what extent the studies conducted can be deemed comprehensive and describe how the Agricultural Inventory Advisory Panel endorsed their application to the inventory.	**Resolved.** More detailed information on the EF for dairy cattle manure (organic fertiliser) is included in chapter 5, section 5.5.2 (under Direct nitrous oxide emissions from managed soils – Organic nitrogen fertilisers).
Agriculture – 3.D.b Indirect N_2O emissions from managed soils – N_2O (A.19, 2019) Transparency	A.15, 2021	Revise the description in the NIR of the country-specific values for $Frac_{LEACH}$ and for the fraction of applied organic N fertilizer materials and of urine and dung N deposited by grazing animals that volatilizes as ammonia and nitrogen oxides in kg N volatilized.	**Addressing.** Information on the country-specific $Frac_{LEACH}$ parameter used in the inventory is included in chapter 5, section 5.5.2 (under Indirect nitrous oxide emissions from managed soils – Leaching and runoff (CRF 3.D.2.2)). Recent research has also led to an update to the country-specific $Frac_{LEACH}$ parameter. For more detail, see chapter 5, section 5.5.5.
LULUCF – 4. General – CO_2 and N_2O (L.10, 2019) Accuracy	L.1, 2021	Either provide evidence that the estimated SOC changes do not result in systematic over- or underestimations, given that land-use changes occur randomly across the entire SOC variability of a land-use category or subcategory, or replace the current	**Addressing.** New Zealand has recently assigned a multi-year budget to conduct work on improving mineral soil estimates. Due to the nature of the research required, however, results will not be available for reporting purposes for several years yet.

Sector	ID number	Expert review team recommendation	New Zealand response
		method with one consistent with good practice as defined by the 2006 IPCC Guidelines (vol. 4, chap. 2.3.3.1).	
LULUCF – 4. General – CO_2 (L.11, 2019) Convention reporting adherence	L.2, 2021	Provide a comparison across the available time series of data of roundwood statistics reported by MPI and the quantities estimated by the LUCAS model based on the harvested area as allocated to age classes and provide justification for any discrepancies.	**Resolved.** An additional section was added in annex 3 to the 2021 NIR (under A3.2.5) describing forest land model validations and, specifically, the differences between LUCAS model harvest losses and the roundwood statistics reported by the Ministry for Primary Industries.
LULUCF – 4. General – CO_2 (L.12, 2019) Convention reporting adherence	L.3, 2021	Replace "IE" with estimates of biomass carbon stock losses only in the year in which an area conversion occurs, and with "NO" in any year in which conversion of additional areas does not occur, in CRF tables 4.A and 4.B.	**Resolved.** Where this conversion has not occurred during the time series, for example, for conversions from *post-1989 forest* to *Cropland*, the notation key 'NO' has been applied. Where the land-use conversion has previously occurred but there are years when conversions of additional areas do not occur, the notation key 'NA' has been applied. The ERT agreed with the use of 'NA' in these circumstances
LULUCF – 4. General – CO_2 (L.13, 2019) Transparency	L.4, 2021	Report updated information regarding the country-specific wood carbon content value used in the harvested wood products model in the NIR.	**Resolved.** The default wood carbon content value of 50 per cent, from table 12.4 of the 2006 IPCC Guidelines (IPCC, 2006b), is used in the harvested wood products model. This value is consistent with the planted forest model that uses a country-specific value of 50 per cent.
LULUCF – Land representation – CO_2, CH_4 and N_2O (L.14, 2019) Accuracy	L.5, 2021	Either report information that demonstrates that the biomass carbon pool of radiata pine plantations achieves its steady state at 28 years or, if not at 28 years but at over 20 years, provide information that demonstrates that this longer period is needed to achieve equilibrium of carbon stocks. Otherwise, apply the IPCC default conversion period of 20 years and explain the recalculations in the NIR.	**Resolved.** The default transition period of 20 years has been applied since the 2021 submission. The impact of this change in emissions between the *Forest land remaining forest land* category and *Land converted to forest land* category was described in the 2021 submission.
LULUCF – Land representation – CO_2, CH_4 and N_2O (L.15, 2019) Comparability	L.6, 2021	Compile CRF table 4.1 using annual area change data.	**Resolved.** CRF table 4.1 has been compiled using annual area change data consistent with 2021 NIR annex 3, table A3.2.1.
LULUCF – Land representation – CO_2, CH_4 and N_2O (L.16, 2019) Accuracy	L7, 2021	Plan to undertake an accuracy assessment of the national land-use maps, with a focus on determining the accuracy of mapping changes between mapping dates.	**Resolved.** New Zealand reported in its 2021 NIR (see annex 3, section A3.2.2) the results of several accuracy assessments of its national land use maps, including an assessment of mapping changes between mapping dates.
LULUCF – Land representation – CO_2, CH_4 and N_2O (L.16, 2019) Accuracy	L.8, 2021	Investigate how to use the results of the accuracy assessment, once available, to adjust the reported AD for the land representation.	**Addressing.** A confusion matrix for the 2012 map has been undertaken (see annex 3, section A3.2.2) demonstrating that mapping errors and biases were very limited for all land categories except for *Grassland* and *Grassland with woody biomass*. A new land use map using imagery acquired over 2020 to 2021 is being procured. Once the map has been produced, an accuracy assessment of the map series with a focus on the accuracy of land-use change mapping is planned. See chapter 6, section 6.2.5, for more information.

Sector	ID number	Expert review team recommendation	New Zealand response
LULUCF – 4.A Forest land – CO_2 (L.3, 2019) (L.4, 2017) Accuracy	L.9, 2021	Consider ways to reduce uncertainties in the stock change estimates when further developing the methods for estimating CSC in pre-1990 natural forests.	**Resolved.** Uncertainties in the carbon stock change estimates for pre-1990 natural forests were reduced by applying the methods described in 2021 NIR, chapter 6, section 6.4.2. New Zealand clarified during the review that it has undertaken four of the seven ways to reduce uncertainties mentioned in the 2006 IPCC Guidelines (IPCC, 2006b, p. 3.12). It is worth noting that, even though several methods to reduce uncertainty were applied, this does not necessarily result in a lower uncertainty estimate. This is because the uncertainty is calculated as a percentage of the CSC confidence interval to the estimate of CSC. Consequently, as the CSC estimate has decreased (is closer to zero), the overall uncertainty (as a percentage) has increased.
LULUCF – 4.A Forest land – CO_2 (L.17, 2019) Transparency	L.10, 2021	Provide information on the actual age of harvest of forest plantations, as derived from information collected through the National Exotic Forest Description.	**Resolved.** Information on actual age of harvest and on the actual age profile of forest plantations (annex 3, figure A.3.2.11) was added in annex 3, section A3.2.5 of the 2021 NIR.
LULUCF – 4.A.1 Forest land remaining forest land – CO_2 (L.4, 2019) (L.5, 2017) Accuracy	L.11, 2021	Update the below-ground biomass ratios, noting that choosing a value above the median in the range of 9–33 per cent without further documentation entails the risk of overestimation of removals from forest land remaining forest land, 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.** The below-ground biomass ratios have been updated and reported in 2021 NIR, annex 3, table A3.2.10) on the basis of peer reviewed literature (Easdale et al., 2019).
LULUCF – 4.A.1 Forest land remaining forest land – CO_2 (L.18, 2019) Completeness	L.12, 2021	Report estimates of above-ground biomass CSCs, noting that those estimates should include all gains and losses in tall natural forest remaining tall natural forest; however, carbon stock losses as a result of stand-replacing disturbances (such as storms or destructive wildfires) that lead to a subsequent regeneration of the natural forest, and carbon stock gains up to the average carbon stock of tall forests, should be reported within the regenerating natural forest category, including the entire transition of regenerating natural forest to tall natural forest.	**Resolved.** Estimates of CSC for tall and regenerating forests are reported in CRF table 4.A.
LULUCF – 4.A.1 Forest land remaining forest land – CO_2 (L.19, 2019) Accuracy	L.13, 2021	Provide evidence that national circumstances make the collection of data on SOC in mineral soils and on its variation across time in forest land remaining forest land impracticable or, if this is not possible, plan activities to be implemented in the next few years to collect the data needed to apply a tier 2 estimate to SOC changes in mineral soils of tall natural forest remaining tall natural forest.	**Resolved.** New Zealand has recently assigned a multi-year budget to conduct work on improving mineral soil estimates and that, due to the nature of the research required, results will not be available for reporting purposes for several years yet.

Sector	ID number	Expert review team recommendation	New Zealand response
LULUCF – 4.A.2 Land converted to forest land – CO_2 and N_2O (L.20, 2019) Transparency	L.14, 2021	Report disaggregated information for the two subcategories of post-1989 natural forest and post-1989 plantations.	**Addressing.** New Zealand has identified a solution to disaggregate reporting in CRF table 4(III), which will be implemented in the 2024 NIR submission.
LULUCF – 4.B.1 Cropland remaining cropland – CO_2 (L.21, 2019) Completeness	L.15, 2021	Identify the main subdivisions for perennial cropland on the basis of the harvesting cycle and the biomass carbon stock at the end of the harvesting cycle, and build an age-class distribution for each subdivision, estimate and report annual biomass carbon stock gains and losses accordingly and report the estimation and all additional information in the NIR.	**Not resolved.** Emissions from *Cropland remaining cropland* are low relative to those for other categories, such as *Forest land* and *Harvested wood products*. The category is therefore a low research priority and funding is unable to be directed to this at present.
LULUCF – 4.B.1 Cropland remaining cropland – CO_2 (L.22, 2019) Completeness	L.16, 2021	Plan the activities needed to collect data and prepare estimates of SOC changes in cropland associated with changes in management practices.	**Addressing.** A longitudinal agricultural land soils study is currently under way. The collection of baseline data for the national 500 soils programme will be completed by 2023/24 and a 12-year timeline for resampling the 500 sites will inform and refine estimates of change through time within one land use. New Zealand also aims to improve mineral SOC stock change estimates for all agricultural land uses with the baseline data by the 2026 submission.
LULUCF – 4.C.2 Land converted to grassland – CO_2 (L.23, 2019) Convention reporting adherence	L.17, 2021	Use “NE” for biomass carbon stock losses in wetlands converted to grassland, providing relevant references to the 2006 IPCC Guidelines for justification, or revise the methodology by assigning a biomass carbon stock value to wetlands before conversion, in particular for the subcategory vegetated wetlands.	**Resolved.** A literature review was conducted on available research on biomass carbon stocks in vegetated wetlands. This research means New Zealand has been able to assign biomass carbon stock values to vegetated wetlands in this submission.
LULUCF – 4.D Wetlands – CO_2 (L.6, 2019) (L.7, 2017) Completeness	L.18, 2021	Continue the ongoing work to improve estimates for wetlands and report the emissions for subcategories 4.D.1.1 (peat extraction remaining peat extraction) and 4.D.2.1 (land converted to peat extraction).	**Resolved.** New Zealand has noted in CRF table 4.D that “New Zealand does not have activity data available to reliably report on this activity”, so that the use of notation key ‘NE’ is appropriate.
LULUCF – 4.D Wetlands – CO_2 (L.24, 2019) Accuracy	L.19, 2021	Revise the biomass carbon stock of vegetated wetlands using data available in literature (e.g. Morrisey et al., 2010).	**Resolved.** A literature review was conducted on available research on biomass carbon stocks in vegetated wetlands. This research means New Zealand has been able to assign biomass carbon stock values to vegetated wetlands in this submission.
LULUCF – 4.F Other land – CO_2, CH_4 and N_2O (L.27, 2019) Accuracy	L.20, 2021	Reclassify all other land with significant SOC content under the most appropriate land-use category and recalculate land representation and SOC changes for the revised area of conversion to and from other land.	**Not resolved.** New Zealand aims to narrow the definition of other land and ensure estimates of mineral SOC stock changes are aligned with this category, through improving mapping and additional sampling.
LULUCF – 4.F.2 Land converted to other land – CO_2 (L.28, 2019) Accuracy	L.21, 2021	Verify the occurrence of the conversion of land with organic soils to other land and, if SOC losses in organic soils converted to other land are not reported, use “NA” in the CRF table.	**Not resolved.** The 1990 classification of *Other land* is a scheduled improved activity. See chapter 6, section 6.8.6, for further information.

Sector	ID number	Expert review team recommendation	New Zealand response
LULUCF – 4(II) Emissions/removals from drainage and rewetting and other management of organic/mineral soils – N_2O (L.29, 2019) Completeness	L.22, 2021	Report N_2O emissions from drainage of non-agricultural organic soils in CRF table 4(II) for each land category for which a SOC loss in organic soils is reported in CRF tables 4.A, 4.D and 4.E.	**Addressing.** Emissions from drained organic soils in *Forest land* have been calculated for this and the 2022 submission (see chapter 6, section 6.10.2). Note that during the review of the 2021 submission, the ERT acknowledged that there is no default method in the 2006 IPCC Guidelines (IPCC, 2006b) that can be applied to *Wetlands* or *Settlements*. However, the ERT suggested that, because New Zealand considers most of its *Settlements* area can be assimilated to *Grassland* when it comes to soil carbon, the emission factors for *Grassland* should be applied to *Settlements*. For this submission, these emissions have been calculated but not included in the CRF or emissions totals. For more information, see chapter 6, section 6.7.6.
LULUCF – 4(III) Direct N_2O emissions from N mineralization/ immobilization – N_2O (L.7, 2019) (L.9, 2017) Convention reporting adherence	L.23, 2021	Correct the C/N ratio to 15:1 in the NIR (p. 300).	**Resolved.** New Zealand has reported in chapter 6, section 6.10.3 that it used the default C/N ratio of 15:1.
LULUCF – 4(III) Direct N_2O emissions from N mineralization/ immobilization – N_2O (L.30, 2019) Accuracy	L.24, 2021	Revise the information reported in CRF table 4(III), ensuring that the area of each category reported corresponds to the area of the category where a SOC loss, resulting from a change of land use or management, actually occurred.	**Resolved.** New Zealand revised the areas reported in CRF table 4(III), ensuring that the area of each category reported corresponds to the area of the category where a SOC loss occurred.
LULUCF – 4(IV) Indirect N_2O emissions from managed soils – N_2O (L.31, 2019) Completeness	L.25, 2021	Report indirect N_2O emissions from leaching and run-off of N mineralization associated with SOC losses in mineral soils in CRF table 4(IV).	**Resolved.** New Zealand has reported in CRF table 4(IV) indirect N_2O emissions from leaching and run-off for all land use categories other than *Cropland remaining cropland*.
5. General (waste) – CO_2, CH_4 and N_2O (W.17, 2019) Transparency	W.1, 2021	Include more information on current waste management, such as an overview of MSW generation and its treatment method (recycling, composting, incineration or disposal) in NIR section 7.1.1, and its impact on the composition of waste disposed of at landfills.	**Resolved.** Figure 7.1.1 has been added to chapter 7 in this NIR, to show key waste generation sources and disposal pathways.
5. General (waste) – CO_2, CH_4 and N_2O (W.17, 2019) Accuracy	W.2, 2021	Consider whether the potential changes in the composition of landfilled waste are appropriately reflected in the estimated emissions for category 5.A and if not, recalculate the emissions and explain those recalculations in the NIR.	**Resolved.** Average waste composition for municipal landfills has been collected for 2018 that accounts for changing waste disposal practices for compostable materials (see chapter 7, table 7.2.5).
Waste – 5.A Solid waste disposal on land – CH_4 (W.4, 2019) (W.5, 2017) (W.4, 2016) (W.7, 2015) Accuracy	W.3, 2021	Provide substantive justification for the country-specific default values on CH_4 recovery efficiency, including justification for the factors that can enhance the recovery, or revise estimates for CH_4 recovery at SWDS 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.** Methane recovery efficiency was revised for the 2021 submission according to Eunomia (unpublished). See chapter 7, section 7.2.2.
Waste – 5.A Solid waste disposal on land – CO_2 (W.18, 2019) Convention reporting adherence	W.4, 2021	Correct the value for carbon storage for managed landfills without landfill gas capture.	**Resolved.** This was corrected in CRF table 5.F.1 in the 2020 submission and was subsequently revised for the 2021 submission.

Sector	ID number	Expert review team recommendation	New Zealand response
Waste – 5.A Solid waste disposal on land – CH_4 (W.19, 2019) Transparency	W.5, 2021	Explain how many landfills are currently reporting under the ETS and how data on CH_4 recovery are estimated and reported for both active and closed landfills with gas recovery.	**Resolved.** Table 7.2.2 in chapter 7 reports the amount of managed landfills for each type.
Waste – 5.A Solid waste disposal on land – CH_4 (W.20, 2019) Transparency	W.6, 2021	Include in the NIR further explanation of the specific approach to calculating the gas recovery rate, including the source of the waste composition data, EF and recovery rates, as well as a description of the ETS, providing relevant reference sources.	**Resolved.** Chapter 7, section 7.2.2 (under Gas recovery), explains the revised gas recovery methodology. Waste composition data are provided in table 7.2.5 and a summary of parameters is in table 7.2.8.
Waste – 5.A.1 Managed waste disposal sites – CH_4 (W.8, 2019) (W.9, 2017) (W.11, 2016) Transparency	W.7, 2021	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 k for biodegradation from the 2006 IPCC Guidelines.	**Resolved.** The k-values were revised for the 2021 submission according to Eunomia (unpublished). See chapter 7, section 7.2.2.
Waste – 5.C.1 Waste incineration – CO_2 (W.21, 2019) Convention reporting adherence	W.8, 2021	Investigate historical data on waste incineration in schools and revise the estimates, if appropriate.	**Resolved.** New Zealand has investigated historical data on waste incineration in schools. There is no additional data on the practice of incinerating waste in rural schools. New Zealand has corrected its reporting of this source in CRF table 5.C so that it is in accordance with the explanation provided in the 2021 NIR.
Waste – 5.C.1 Waste incineration – CO_2 (W.21, 2019) Transparency	W.9, 2021	Include a relevant description on waste incineration in schools in the NIR or revise the NIR text, as appropriate.	**Resolved.** Incineration of waste in rural schools is not estimated. See annex 6, section A6.2, for detail.
Waste – 5.D Wastewater treatment and discharge – N_2O (W.22, 2019) Accuracy	W.10, 2021	Revise the reporting of N_2O emissions from industrial wastewater and sewage sludge applied to soils in the agriculture and waste chapters of the NIR and in CRF table 3.D, and explain any recalculation in the NIR.	**Not resolved.** This will be addressed in a future submission. It has not been prioritised due to the insignificant emissions associated with sludge.
Waste – 5.D Wastewater treatment and discharge – CH_4 and N_2O (W.23, 2019) Accuracy	W.11, 2021	Clarify and report consistent information on the final treatment or disposal for sludge, including incineration and disposal in municipal landfills, review the estimates and explain any recalculation in the NIR.	**Addressing.** Volumes of sludge disposed of in managed landfills have been updated according to Eunomia (unpublished). Further improvements will be included in a future submission.
Waste – 5.D.2 Industrial wastewater – CH_4 (W.24, 2019) Comparability	W.12, 2021	Estimate and report the amount of CH_4 flared and for energy recovery, respectively, in CRF table 5.D, noting that the amount of CH_4 for energy recovery, if occurring, should probably be reported as "IE" in that table and the estimates reported under the energy sector.	**Resolved.** The amount of CH_4 recovered for flaring is reported as 'NE' because no information is available. The amount of CH_4 recovered for energy generation is now reported as 'IE' in CRF table 5.D.2, and emissions are reported in the Energy sector under 1.A.2.e – Biomass.

Note: AD = activity data; C/N ratio = the ratio of the mass of carbon to the mass of nitrogen in organic residues; CRF = common reporting format; CSC = carbon stock change; EF = emission factor; ERT = expert review team; ETS = Emissions Trading Scheme; GDP = gross domestic product; GJ = gigajoule; HFC = hydrofluorocarbon; IE = included elsewhere; IEF = implied emission factor; IPCC = Intergovernmental Panel on Climate Change; IPPU = Industrial Processes and Product Use; KP = Kyoto Protocol; LPG = liquefied petroleum gas; LUCAS = Land Use and Carbon Analysis System; LULUCF = Land Use, Land-Use Change and Forestry; MBIE = Ministry of Business, Innovation and Employment; MPI = Ministry for Primary Industries; MSW = municipal waste disposal; NE = not estimated; NEU = non-energy use; NIR = National Inventory Report; 2021 NIR = 2021 National Inventory Report (1990–2019); NO = not occurring; PFC = perfluorocarbon; PJ = petajoule; QA/QC = quality assurance/quality control; SOC = soil organic carbon; SWDS = solid waste disposal site; UNFCCC = United Nations Framework Convention on Climate Change.

Table 5 of the assessment and review report of New Zealand's 2021 NIR contains new recommendations related to the review of the 2021 submission. These recommendations, along with New Zealand's latest responses to date, are detailed in table 10.2.2.

Table 10.2.2 New Zealand's responses to recommendations in table 5 of the 2021 assessment review report from the review of New Zealand's 2021 inventory submission

Sector	ID number	Expert review team recommendation	New Zealand response
General		No general findings additional to those included in table 3 were made by the ERT during the review.	
Energy – 1.A.1.a Public electricity and heat production – gaseous fuels – CO_2	E.18, 2021	The ERT recommends that New Zealand check the value of the CO_2 IEF for gaseous fuels for 2005 and either justify the inconsistency in the NIR or correct its value for the emission estimates in 2005.	**Resolved.** The AD for natural gas consumption for electricity generation have been updated. This resulted in revised CO_2 IEFs for the entire time series.
Energy – 1.A.2.e Food processing, beverages and tobacco – gaseous fuels – CO_2	E.19, 2021	The ERT recommends that New Zealand explain in the NIR why the AD for gaseous fuels were revised for 2013 and why the CO_2 IEF was lower between 1996 and 2012 after the recalculation performed by the Party. The ERT also recommends that the Party report in the NIR why the CO_2 IEF was lower for 2003.	**Resolved.** We recalculated the CO_2 EF for gaseous fuels and reported revised emission estimates in CRF table 1.A(a)s2.
Energy – 1.A.4 Other sectors – gaseous fuels – CO_2	E.20, 2021	The ERT recommends that New Zealand explain in the NIR the reasons for the lower CO_2 IEFs between 1996–2012 after the recalculation performed by the Party. The ERT also recommends that the Party report in the NIR the reason for the lower value in the CO_2 IEF in 2003.	**Resolved.** We recalculated the CO_2 EF for gaseous fuels and reported revised emission estimates in CRF table 1.A(a)s2.
Energy – 1.A.4.a Commercial/ institutional – liquid fuels – CO_2	E.21, 2021	The ERT recommends that New Zealand, when performing recalculations, report fully and transparently on these recalculations in the NIR in accordance with paragraphs 43–45 of the UNFCCC Annex I inventory reporting guidelines.	**Resolved.** There was a historical reallocation of AD from *Commercial/institutional* (category 1.A.4.a) to *Road transportation* (category 1.A.3.b), however, this reallocation was subsequently reversed in the national oil data system.
IPPU – 2.C.1 Iron and steel production – CH_4	I.25, 2021	The ERT recommends that New Zealand investigate all potential CH_4 sources and report CH_4 emissions from iron and steel production under category 2.C.1 for the entire time series using a methodology consistent with the decision tree in the 2006 IPCC Guidelines (vol. 3, chap. 4, figure 4.8, p.4.20). The ERT also recommends that the Party include a description of the methodologies, AD and EFs used for the estimates. Alternatively, if the Party considers these emissions to be insignificant, the ERT recommends that the Party report them as "NE" and demonstrate in the NIR that the likely level of emissions is below the significance threshold indicated in paragraph 37(b) of the UNFCCC Annex I inventory reporting guidelines.	**Resolved.** The inconsistent reporting has been corrected in chapter 4, table 4.1.2, section 4.2.1, section 4.3.1, section 4.3.4 and table 4.7.3.

Sector	ID number	Expert review team recommendation	New Zealand response
IPPU – 2.C.1 Iron and steel production – CO_2	I.26, 2021	The ERT recommends that New Zealand investigate the source of the significant changes in the CO_2 IEFs for steel production across the time series and include in the NIR information concerning the trend and the reasons for the changes. The ERT encourages New Zealand to review the confidentiality status of the AD for subcategory 2.C.1.a (steel) considering that steel production data are provided by New Zealand Steel to international organizations (e.g. World Steel Association).	**Resolved.** The CaO plus MgO amounts are now reported for the entire time series as recommended. See chapter 4, sections 4.2.3 and 4.2.5.
Agriculture – Enteric fermentation – CH_4	A.16, 2021	The ERT recommends that New Zealand, using the data and results of the research, improve the model trends or changes in death rates over the time series for estimating emissions for enteric fermentation from dairy cattle, beef cattle, sheep and deer, and document any recalculation in the NIR.	**Addressing.** This research is still being finalised. The findings for dairy cattle are included in the 2023 NIR submission as a part of an improved *Dairy cattle* population model. See chapter 5, section 5.2.5 for more detail.
Agriculture – Cattle – CH_4, N_2O	A.17, 2021	The ERT recommends that New Zealand review if a lactation length of six months and milk yield of 800 l for beef cows are appropriate for the emission estimates and either provide justification for these values in the NIR or recalculate emissions using more appropriate values for the milk yield for beef cows.	**Not resolved.** New Zealand currently does not have data to provide further justification for these values in its reporting. We will engage with the sector to determine (a) if they are appropriate, and, if not, (b) what values should be used instead, or (c) if new research is required to determine more accurate values for this.
Agriculture – Cattle – CH_4	A.18, 2021	The ERT recommends that New Zealand include a clearer description in the NIR of how productivity data for milk production from the Livestock Improvement Corporation are matched with terrestrial livestock data, including for those instances where Livestock Improvement Corporation data combines geographically close regions to obtain a single value on productivity data that is then used for the livestock population of these regions.	**Addressing.** A clearer description has been added in chapter 5, section 5.1.4.
Agriculture – Cattle – CH_4 and N_2O	A.19, 2021	The ERT recommends that New Zealand incorporate the data and results of its ongoing research in order to provide more up to date data on the proportion of dry cows and update the parameter POPdnmct (total number of dairy cows and heifers not in milk or calf in year t), recalculate emission estimates and explain the recalculation in the NIR.	**Not resolved**. Research will be incorporated when available.
Agriculture – Cattle – CH_4	A.20, 2021	The ERT recommends that New Zealand improve the methodology related to the instantaneous gain of 10 per cent of the weight of mature cows to account for their higher energy requirements and recalculate the associated emission estimates. The ERT also recommends that the Party document clearly these recalculations in the NIR.	**Addressing**. This was adjusted as a part of the improved estimates of within-year *Dairy cattle* population change. See chapter 5, section 5.2.5 for details.

Sector	ID number	Expert review team recommendation	New Zealand response
Agriculture – Cattle – N_2O	A.21, 2021	The ERT recommends that New Zealand correct the description of nitrogen excretion in the first two months of life for dairy cattle in section 5.1 of the MPI technical report in order to resolve the inconsistency with section 5.1.1.2 of the same technical report.	**Addressing.** Section 5.2 (previously section 5.1) of the MPI technical report on the methodology for calculation of New Zealand's agricultural greenhouse gas emissions (van der Weerden et al., 2014) has been updated for consistency.
Agriculture – Animal manure applied to soils – N_2O	A.22, 2021	The ERT recommends that New Zealand provide additional information describing the manure management systems used for dairy cattle in the NIR, including the information from Rollo et al. (2017).	**Not resolved.** Chapter 5, section 5.3.2 will be updated in a future NIR.
Agriculture – Other organic fertilizers applied to soils – N_2O	A.23, 2021	The ERT recommends that New Zealand undertake an updated analysis of the AD related to N applied to soil for non-manure components of organic fertilizers and estimate and report N_2O emissions for this subcategory. In case New Zealand consider such emissions to fall below the threshold of significance, the ERT recommends that the Party report in the NIR information in accordance with paragraph 37(b) of the UNFCCC Annex I inventory reporting guidelines on the likely level of N_2O emissions, demonstrating that they account for less than 0.05 per cent of the total national emissions and do not exceed 500 t CO_2 eq.	**Addressing.** Research has been contracted and work will begin in 2023. Research will be incorporated when available.
LULUCF – 4.A Forest land – CO_2	L.26, 2021	The ERT recommends that New Zealand include in its NIR definitions of tall and regenerating forests, their respective areas and how this distinction and the associated calculations result in complete estimates of CSC, in particular in the event of natural disturbances (see ID# L.12 in table 3).	**Resolved**. New Zealand has now reported in its 2021 NIR the definitions (chapter 6, table 6.3.5) and areas (table 6.3.6) of tall and regenerating forests. Forest areas are classified spatially as either tall or regenerating and, accordingly, CSC is calculated separately. Natural disturbances affect the carbon stocks measured in the national forest inventory plot network and therefore are implicitly included in the CSC calculations.
LULUCF – 4.E.2 Land converted to settlements – CO_2	L.27, 2021	The ERT recommends that New Zealand assess the share of impervious surfaces within the settlement category and estimate soil CSC for land converted to settlements on the basis of this share and in accordance with the 2006 IPCC Guidelines.	**Not Resolved.** Research on settlements is low priority due to the small emissions associated with this category. Therefore it has not been possible to direct funding into this area.
LULUCF – 4(V) Biomass burning – CO_2	L.28, 2021	The ERT recommends that New Zealand transparently describe in its NIR how CO_2 emissions from wildfires are captured in its estimates for planted forests by the general stock change calculation, specifying in particular what share of salvage logging is assumed, whether it is entirely or partly deducted from the estimated "non-salvage" harvest area, and whether age-distribution is impacted by wildfire.	**Resolved.** New Zealand now reports in its 2021 NIR (chapter 6, section 6.10.8) that CO_2 emissions 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. For both natural and planted forests, emissions from areas burned are captured within the forest plot networks that New Zealand uses to estimate CSC. In these cases, to avoid double counting of CO_2 emissions, 'IE' is reported in CRF table 4(V).

Sector	ID number	Expert review team recommendation	New Zealand response
LULUCF – 4(V) Biomass burning – CH_4, N_2O	L.29, 2021	The ERT recommends that New Zealand provide explanations in its NIR on how the Fire and Emergency New Zealand database is fed, whether by remote-sensing data or field reports, together with information on the time series of annually burned areas.	**Resolved.** New Zealand now reports in its 2021 NIR (chapter 6, section 6.10.8) that wildfire AD are sourced from Fire and Emergency New Zealand, which maintains a database in which wildfire events are recorded. Historically, burned areas were estimated and allocated by field staff by vegetation type: grass, tussock, gorse, scrub, wetlands, plantation forest and indigenous forest. The process was updated in 2017 and now involves mapping the burned area and overlaying land cover categories to identify vegetation types.
Waste – 5.A Solid waste disposal on land – CH_4	W.13, 2021	The ERT recommends that New Zealand include information in the NIR on the consolidation of MSW landfill sites from numerous small and poor managed to fewer large scale and well managed landfills and any additional information on the changing trends in waste generation and waste management in the country.	**Resolved.** The 2021 NIR has been revised to add additional clarification in chapter 7, section 7.2.2.
Waste – 5.A.3 Uncategorized waste disposal sites – CH_4	W.14, 2021	The ERT recommends that New Zealand provide additional information in NIR section 7.1.1 on its current waste management practices, including a higher-resolution of figure 7.1.1 with an overview of MSW generation and its treatment method (recycling, composting, incineration, or disposal) and its impact on the composition of waste disposed of at landfills.	**Addressing.** Section 7.1.1, chapter 7, includes minor improvements, and further improvements will be included in future submissions.
Waste – 5.B.1 Composting – CH_4	W.15, 2021	The ERT recommends that New Zealand correct the text in the NIR (p. 381) to refer to the correct number of table 7.2.3 (which reflects total municipal solid waste) and provide a description of the AD on composting used for the estimates.	**Resolved.** The reference to table 7.2.3, chapter 7, is now correct.
Waste – 5.C.1 Waste incineration – CO_2, CH_4 and N_2O	W.16, 2021	The ERT recommends that New Zealand include information in the NIR to clarify how it defines clinical waste in line with national circumstances, and encourages the Party to use a single, common terminology in line with the 2006 IPCC Guidelines in defining this type of waste.	**Resolved.** Since the 2022 NIR submission, New Zealand has included information on how it defines clinical waste in chapter 7, section 7.4.1.
Waste – 5.C.2 Open burning of waste – CO_2, CH_4 and N_2O	W.17, 2022	The ERT recommends that the Party clarify in the NIR that farm fills are disposed of in two different treatment pathways (i.e. under unmanaged landfills and under open burning) and that the AD for both pathways have the same value. The ERT also recommends that the Party provide some basis on which to justify why the same value of AD is applied for both farms fills and open burning.	**Resolved.** New Zealand has provided the additional information on how farm fills are disposed of, and that the activity data for both pathways have the same value in chapter 7, table 7.2.4 and section 7.4.2.

Note: AD = activity data; CRF = common reporting format; CSC = carbon stock change; EF = emission factor; ERT = expert review team; IE = included elsewhere; IEF = implied emission factor; IPCC = Intergovernmental Panel on Climate Change; IPPU = Industrial Processes and Product Use; LULUCF = Land Use, Land-Use Change and Forestry; MPI = Ministry for Primary Industries; MSW = municipal waste disposal; NE = not estimated; NIR = National Inventory Report; 2021 NIR = National Inventory Report (1990–2019); UNFCCC = United Nations Framework Convention on Climate Change.

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Chapter 11: KP-LULUCF

11.1 General information

This chapter provides the supplementary information required under Article 7, paragraph 1, of the Kyoto Protocol. Reporting for the second commitment period (CP2) of the Kyoto Protocol (2013-2020) was covered in the previous inventory submission. While no further commitments have been taken under the Kyoto Protocol, it remains in force and reporting requirements, therefore, remain in place.

Given that the LULUCF accounting rules New Zealand elected under commitment period two of the Kyoto Protocol differ from those New Zealand will use under the Paris Agreement, the numbers provided in this chapter will not reflect progress towards New Zealand's first Nationally Determined Contribution. New Zealand's approach to LULUCF accounting under the Paris Agreement is outlined in its first Nationally Determined Contribution[75] and will be fully described in its first communication under the Paris Agreement. [76]

Emissions summary

2021

In 2021, net emissions from land subject to Article 3.3 and Article 3.4 activities under the Kyoto Protocol were –26,854.5 kilotonnes carbon dioxide equivalent (kt CO_2-e) (table 11.1.1).

In 2021, net emissions from *Afforestation and reforestation* and *Deforestation* activities were –10,097.3 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 forest growth
- emissions from harvesting
- emissions and removals from harvested wood products in post-1989 forests
- emissions from the conversion of land to post-1989 forest
- emissions from deforestation of all forest land
- emissions from biomass burning
- emissions from the mineralisation of soil nitrogen and the emissions from the drainage of managed soils associated with afforestation, reforestation or deforestation activities since 1990.

[75] *Submission under the Paris Agreement New Zealand's first Nationally Determined Contribution: Updated 4 November 2021*. unfccc.int/sites/default/files/NDC/2022-06/New%20Zealand%20NDC%20November%202021.pdf.

[76] The first communication being the submission of the first biennial transparency report and national inventory report, as required under the Paris Agreement, at the latest by 31 December 2024.

In 2021, net emissions from *Forest management* were –16,757.3 kt CO_2-e (table 11.1.1). This includes:

- removals from the 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
- emissions from biomass burning
- emissions from the drainage of managed soils on land classified under *Forest management*.

Table 11.1.1 New Zealand's emissions under Article 3.3 and Article 3.4 of the Kyoto Protocol, in 2021

Activity	2021[P]
Afforestation and reforestation	
Net cumulative area since 1990 (ha)	824,073
Area in calendar year (ha)	54,268
Net emissions in calendar year (kt CO_2-e)	–11,488.3
Deforestation	
Net cumulative area since 1990 (ha)	224,591
Area in calendar year (ha)	2,493
Net emissions in calendar year (kt CO_2-e)	1,391.0
Forest management	
Area included (ha)	9,195,721
Net emissions in calendar year (kt CO_2-e)	–16,757.3
Total area included (ha)	**10,360,974**
Net emissions in calendar year (kt CO_2-e)	**–26,854.5**

Note: Where net emissions result in removals, they are expressed as a negative value as per section 2.2.3 of the Intergovernmental Panel on Climate Change Guidelines (IPCC, 2006a). Columns may not total due to rounding. P = figures for 2021 are provisional. Afforestation and deforestation differs from that in chapter 6 due to carbon equivalent forests being reported separately.

1990–2021

Between 1990 and 2021, it is estimated that 872,546 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 2021 was 824,073 hectares. This figure includes 48,473 hectares of deforestation activity that has occurred in these forests since 1990. The average annual increase of *Afforestation and reforestation* activity is 27,267 hectares. During 2021, an estimated 54,268 hectares of new forest was established (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 natural, post-1989 planted, pre-1990 planted and pre-1990 natural forest) during 2021 was estimated at 2,493 hectares.

Since 1990, the area of deforestation of all subcategories of *Forest land* is estimated as 224,591 hectares.

Between 1 January 1990 and 31 December 2021, the total area of *Forest management* land deforested was 176,118 hectares. However, due to the application of the carbon equivalent forest provision (Kyoto Protocol Supplement, IPCC, 2014, section 2.7.2), the net area under *Forest management* only decreased by 171,223 hectares or 1.8 per cent. This is the result of:

- 171,223 hectares of land being transferred from Article 3.4 – *Forest management* reporting to Article 3.3 – *Deforestation* reporting due to deforestation
- 3,995 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, 2014, section 2.7.2)
- 4,896 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, 2014, 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 2021.

Table 11.1.2 New Zealand's emissions for 2021 by greenhouse gas source category

Greenhouse gas source category	Net emissions for 2021 (kt)		
	Source form	Source emission	CO_2-equivalent
Emissions from afforestation and reforestation	CO_2	–11,607.1	–11,607.1
Emissions from deforestation	CO_2	1,349.6	1,349.6
Emissions from forest management activities	CO_2	–16,832.5	–16,832.5
Emissions from soil nitrogen associated with land-use change	N_2O	0.7	204.4
Biomass burning	CH_4	0.8	20.9
Biomass burning	N_2O	0.0	10.3
Net emissions			**–26,854.5**

Note: Columns may not total due to rounding.

Key categories

Afforestation and reforestation, *Deforestation* and *Forest management* are all included in key categories for New Zealand (*Forest land remaining forest land*, *Land converted to forest land* or *Land converted to grassland*). See table 1.5.1, chapter 1, for more information.

11.1.1 Definitions of forest and any other criteria

New Zealand is using the same *Forest land* definition for the period to 2021 as defined in *New Zealand's Initial Report under the Kyoto Protocol* (Ministry for the Environment, 2006). This definition is consistent with use in the 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 excludes 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 for crops and/or animals.

For reporting under the Kyoto Protocol, New Zealand categorised its forests into four types: pre-1990 natural forest, pre-1990 planted forest, post-1989 planted forest and post-1989 natural forest. These subcategories are also used for inventory reporting on the LULUCF sector under the UNFCCC (see chapter 6).

For all post-1989 forest, emissions and removals from carbon losses and gains due to *Afforestation and reforestation*[77] and *Deforestation* activities are reported under Article 3.3, along with emissions from *Deforestation* activities in pre-1990 natural and pre-1990 planted forest. For all *Forest land* that existed on 31 December 1989, which has been categorised as either pre-1990 natural forest or pre-1990 planted forest, all emissions and removals not associated with *Afforestation and reforestation* or *Deforestation* activities are reported under Article 3.4 – *Forest management*. Emissions and removals from the harvest and conversion of forest plantations and establishment of new forests that satisfy the requirements of Decision 2/CMP.7, Annex para 37 (UNFCCC, 2012), are reported under Article 3.4 – *Forest management* as carbon equivalent forests.

The definition of forest used for reporting to the Food and Agriculture Organization is currently different from that used for reporting under the Convention and the Kyoto Protocol. For reporting to the Food and Agriculture Organization, 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 did not elect to report on any of the voluntary activities under Article 3.4 of the Kyoto Protocol for 2021. This is consistent with the first and second commitment periods.

11.1.3 Election of the natural disturbance provision

Information on how New Zealand calculated the background level for natural disturbance over the Kyoto Protocol reporting period is included in annex 5, section A5.2.

77 Including emissions from harvesting of post-1989 forest.

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 2021, this covered 10,360,974 hectares, or 38.4 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, 2014). 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, and annex 3, section A3.2.2) 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 (see annex 3, section A3.2.2)
- an estimate of total afforestation for planted forest for the period 2017 to 2021 is based on the National Exotic Forest Description (Ministry for Primary Industries, 2021)
- the annual area of afforestation of post-1989 natural forest for 2017 to 2019 is estimated from the Ministry for Primary Industries afforestation scheme data
- the area of post-1989 natural afforestation for 2020 and 2021 is estimated from the Afforestation and Deforestation Intentions Survey for 2020 by taking the total area of 'natural reversion' and 'indigenous tall planted' (Manley, 2022)
- for post-1989 natural forest dominated by wilding exotic conifers, a linear extrapolation of the mapped area of land use change between 2012 and 2016 (for this forest type) was used to estimate afforestation for 2017 to 2020
- deforestation mapping for 2008 to 2019 (Indufor Asia Pacific, 2013, 2016, 2018; Lynker Analytics Consortium, 2020)
- the area of deforestation occurring during 2020 and 2021 has been estimated by extrapolating the rate of deforestation from the mapped years of 2013 to 2019. Further information on the methods used to estimate deforestation are described in annex 3, section A3.2.2.

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, section 6.2, and annex 3, section A3.2.2. Further information on the estimation of the total area of afforested and reforested land occurring between 2008 and 2021 can be found in annex 3, section A3.2.2.

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 these forests are classified correctly. This process is shown in annex 3, section A3.2, figure A3.2.2.

Transitions to deforestation are based on deforestation mapping, as described in annex 3, section A3.2.2.

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, post-1989 planted forest and post-1989 natural forest), survey and scheme data (Manley, 2022; Ministry for Primary Industries, 2021) to determine the forest age, harvest age, and harvest age profile associated with planted forests. Carbon analyses are performed to estimate the carbon stored per hectare per pool and are described in chapter 6, section 6.3.2.

11.3.2 Afforestation and reforestation (CRF 4(KP.A.1))

Between 1990 and 2021, it is estimated that 872,546 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 2021 was 824,073 hectares. Emissions from this land in 2021 were –11,488.3 kt CO_2-e. Of the total area afforested or reforested between 1990 and 2021, an estimated 48,473 hectares were deforested between 1990 and 2021 (table 11.3.1). The emissions for this area are reported under *Deforestation*.

New Zealand's post-1989 forest is described in further detail in chapter 6, section 6.3.

Table 11.3.1 New Zealand's estimated annual area under *Afforestation and reforestation* in 2021

	Annual area of *Afforestation and reforestation* (ha)			
Year	**Afforestation/reforestation+**	**Harvesting**	**Deforestation**	**Net cumulative area**
2021	54,268	18,329	1,512	824,073
Total (1990–2021)	**872,546**	**89,684**	**48,473**	**824,073**

Note: + = gross area. Columns may not total due to rounding. Afforestation differs from that in chapter 6 due to carbon equivalent forests being reported separately.

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 in 2021 for *Forest land remaining forest* *land* under the Convention. This is due to forests reported under land in transition and carbon equivalent forests (CEFs). These tables have been added to address expert review team recommendations KL.5 and KL.8 (FCCC/ARR/2017/NZL, UNFCCC, 2018).

Table 11.3.2 New Zealand's estimated annual area under *Afforestation and reforestation* in 2021

	Cumulative area of *Afforestation and reforestation* of different forest types (ha)		
Year	Planted forest	Natural forest	Net cumulative area
2021	728,910	95,163	**824,073**

Table 11.3.3 New Zealand's *Afforestation and reforestation* reconciliation between Kyoto Protocol and Intergovernmental Panel on Climate Change Convention reporting in 2021

	2021
Forest remaining forest (kha)	9,696.6
Forest management (kha)	9,195.7
Difference (kha)	**501**
New forest planted before 1990 – included in FM (kha)	–
New forest planted after 1990 – included in A&R (kha)	–509.8
Carbon equivalent forests	
CEF – Newly established	4.9
CEF – Harvested and converted	4.0
Total in Forest management but not Forest remaining forest	**–501**

Note: A&R = Afforestation and reforestation; CEF = carbon equivalent forest; FM = Forest management; kha = kilohectare. Columns may not total due to rounding.

The Land Use Carbon Analysis System land use map is used to determine the new planting area activity data from 1990 to 2016. The activity data used to estimate new planting in planted forests between 2017 and 2021 are derived from a combination of land use mapping, national statistics and forestry scheme data (Ministry for Primary Industries, 2021), the NZ ETS scheme for areas subject to the carbon equivalent forest provision, and the Ministry for Primary Industries afforestation scheme data. 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 2017 and 2020. 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 reports on harvested wood products originating from *Afforestation and reforestation* activities. This is described further in section 11.3.6.

New Zealand chose not to apply the provision for the treatment of natural disturbance emissions to its afforestation and reforestation accounting for the period 2013-2020. 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.

Government initiatives and legislation

Since 1993, the New Zealand Government has introduced legislation and government initiatives to encourage forest establishment and discourage deforestation. These measures are summarised below.

- Climate Change Response Act 2002 (amended 8 December 2009 and 22 June 2020)

  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 have been able to voluntarily participate in the NZ ETS and receive emission units (New Zealand Units (NZUs)) for increases in carbon stocks. Recent participants in the NZ ETS may claim units for increases in carbon stocks from the start of the previous emissions reporting period for the NZ ETS, the most recent of which is 2018. Participants can also claim units annually through a voluntary emissions return.

- Erosion Control Funding Programme

  The Erosion Control Funding Programme, formerly the East Coast Forestry Project, is a grant scheme that was established in 1992. It aimed to address soil erosion on the worst eroding land in the Gisborne District through planting trees or encouraging natural reversion to native bush (Ministry for Primary Industries, 2014). To date, 40,342 hectares of forest have been established under the scheme. This programme was discontinued in 2018 and superseded by the One Billion Trees Programme (see below).

- Permanent Forest Sink Initiative

  The Permanent Forest Sink Initiative enables land owners to earn carbon credits through the establishment of permanent forests on land that was not forested before 1990 (Ministry for Primary Industries, 2015b). In total, 15,584 hectares have been registered under this scheme. In 2018 it was announced that the scheme would be discontinued and replaced by a permanent post-1989 forest category from 1 January 2024.

- Hill Country Erosion Programme

  The Hill Country Erosion Programme, like the Erosion Control Funding Programme, is focused on the retiring and afforestation of erosion-prone, hill-country land. This programme focuses on giving councils additional resourcing to build their technical capability, give advice to land owners of erosion-prone land, and supports the planting of trees and establishment of forests. 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, 16,289 hectares of plantings have been established under this scheme, of which 5,882 hectares meet the definition of forest land.

- Afforestation Grant Scheme

  The Afforestation Grant Scheme was first established in 2008 to promote carbon sequestration, reduce soil erosion and improve water quality. The first round of the scheme established 9,343 hectares of new forest between 2008 and 2013. A second afforestation grant scheme was established in 2015, and 7,846 hectares of new forest were established under this scheme (Ministry for Primary Industries, 2015a). The scheme was replaced by the One Billion Trees Programme in 2018.

- One Billion Trees Programme

  The One Billion Trees Programme 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 land owners and organisations to achieve the goal of planting 1 billion trees by 2028 (Te Uru Rākau, 2018). Since the programme was announced, until mid-2022, 472,539,000 trees have been planted.

In addition to government policies and legislation, afforestation and deforestation rates in New Zealand have also been driven by market conditions. For example, new planting rates were high from 1992 to 1998, averaging 60,533 hectares per year. This is attributed to 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. This is likely due to the relative profitability of other forms of land use and high rural land prices. 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).

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 and the increase in profitability of other non-forest land uses. In 2019 and 2020, *Afforestation and reforestation* activities significantly increased again, with 27,070 hectares of new planting occurring in 2019 and 40,887 hectares in 2020. This is likely due to seedlings funded by the One Billion Trees programme being planted and higher carbon prices in the NZ ETS resulting from the announcements leading up to the Climate Change Response (Emissions Trading Reform) Amendment Bill and its passing in June 2020.

11.3.3 Deforestation (CRF 4(KP.A.2))

In 2021, *Deforestation* emissions were 1,391.0 kt CO_2-e. These emissions result from the loss of carbon, which was stored in the biomass before 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, under each land use category.

The estimated area reported under *Deforestation* for 2021 was 2,493 hectares.

Table 11.3.4 shows the areas of *Forest land* subject to *Deforestation* activities in 2021 by forest category.

Table 11.3.4 Area of New Zealand subject to deforestation in 2021

	Annual area of deforestation (ha)				
Year	Pre-1990 natural forest	Pre-1990 planted forest	Post-1989 planted forest	Post-1989 natural forest	Total
2021[P]	596	385	1,447	65	**2,493**

Note: P = provisional figure. Areas as at 31 December 2021. Deforestation differs from that in chapter 6 due to carbon equivalent forests being reported separately.

Further detail on the methods employed for estimating deforestation is provided in annex 3, section A3.2.2.

11.3.4 Forest management CRF 4(KP.B.1))

In this submission, New Zealand reports emissions and removals from *Forest management* in 2021. 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 2021, emissions on this land were –16,757.3 kt CO_2-e. This included emissions of –7,823.3 kt CO_2-e from harvested wood products originating from *Forest management*.

The total area remaining in *Forest management* at the end of 2021 was 9,312,309 hectares; this is a decrease of 21,866 hectares (or 1.0 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 category, *Forest land remaining forest land*, of the inventory.

Where the land reported under *Forest management* has remained in the same land use category 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 subdivision in steady state, specifically to model land-use change 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 organic soil is present on land reported under *Forest management* that is no longer natural forest, the soil organic carbon pool is reported as an ongoing source of emissions. More detail is provided in annex 3, section A3.2.4. This information has been added to address expert review team recommendation KL.4 (FCCC/ARR/2017/NZL, UNFCCC, 2018).

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 kt CO_2-e per year. New Zealand has submitted three previous technical corrections to the 2013 to 2020 FMRL; the 2016 submission, the 2019 submission and the 2021 submission. Because this submission covers the period outside of the FMRL no further technical corrections have been applied. New Zealand is yet to set the FMRL for 2021 onwards.

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 in 2021, are summarised in table 11.3.5.

Table 11.3.5 Carbon equivalent forests (2013 to 2021)

	2021
CEF_{NE} area (ha)	0.0
Net emissions (t CO_2)	–35.7
CEF_{HC} area (ha)	116.6
Net emissions (t CO_2)	105.1
Total (kt CO_2)	**69.4**

Note: CEF_{HC} refers to the existing forest land that is harvested and converted to non-forest land; CEF_{NE} refers to the non-forest land on which a forest is newly established. Columns may not total due to rounding. Disaggregated data on the application of the provision are provided in annex 5, section A5.3.

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, 2014). Misalignments between the domestic and international rule sets 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 carbon stored in 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 Decision 2/CMP.7 and the 2013 supplementary Kyoto Protocol guidelines and reporting under the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines. The carbon equivalent forest provision is not recognised under the UNFCCC and instead 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 has been reporting changes in the harvested wood products pool under the Kyoto Protocol since 2013. For *Afforestation and reforestation* and *Forest management*, estimates were derived from a modified IPCC Convention reporting model. The emissions from *Harvested wood products* originating from *Deforestation* activities are instantly oxidised.

Harvested wood product emissions for 2021 *Afforestation and reforestation* were –4,840.4 kt CO_2-e, and for *Forest management* they were –7,823.3 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 6.9.

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, 2014), 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 6.9.1).

Activity data on roundwood production volume, roundwood export volume, wood product production and export are sourced from the Ministry of Primary Industries (Ministry for Primary Industries, 2022a, 2022b).

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*. Note that New Zealand did not account for the *Harvested wood products* pool in the first commitment period. Also, the *Solid wood* category used for IPCC Convention reporting is disaggregated into *Sawnwood* and *Wood-based panels* for Kyoto Protocol reporting.

Furthermore, in accordance with volume 4, chapter 12, page 12.6 of the 2006 IPCC Guidelines, New Zealand treats CO_2 released from wood burnt for energy as an instant emission. Carbon dioxide emissions from *Harvested wood products* in solid waste disposal sites are also treated as an instant emission. These emissions are accounted for under the *Harvested wood products* category and not in the waste sector and this is described in more detail in Wakelin et al., 2020.

In 2019, a large proportion (nearly 62 per cent) of New Zealand's harvest was exported as raw materials in the form of logs or wood chips (Ministry for Primary Industries, 2022a). The database produced by the Statistics Division of the Food and Agriculture Organization the United Nations (FAOSTAT) 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, India and South Korea). The study found that most New Zealand wood is converted into construction and packaging materials. Therefore, weighted half-lives were found to be 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. More information on this is provided in chapter 6, section 6.9.2, and annex 3, section A3.2.6.

Emissions from the harvest of *Afforestation and reforestation* land are reported for 2021. These lands will provide a growing contribution to *Harvested wood products* as post-1989 planted forest reaches harvest age. Harvested wood products originating from *Afforestation* *and reforestation* land each year are estimated by prorating the above-ground biomass carbon losses from the harvest of these lands to the total above-ground biomass carbon losses from all harvesting and deforestation.

Harvesting is the primary driver of emissions from *Forest management* land, specifically pre-1990 planted forest, for which emissions from harvested wood products were accounted for from 2013-2020 under the Kyoto Protocol. Harvested wood products originating from *Forest management* land each year are estimated by prorating the above-ground biomass carbon losses from the harvest of these lands to the total above-ground biomass carbon losses from all harvesting and deforestation. Accounting of harvested wood products on these lands from 2013-2020 was against New Zealand's projected FMRL and, therefore, emissions from the decay of harvested wood products created before 2013 were 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 roundwood volume originating from *Deforestation* is estimated by comparing the above-ground biomass carbon losses from *Deforestation* with the above-ground biomass carbon losses 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 N_2O emissions from nitrogen fertilisation are reported under the Agriculture sector in 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, 2014).

Methane and nitrous oxide emissions from drained and rewetted organic soils (CRF 4(KP-II)2)

New Zealand reports on N_2O emissions, as a result of oxidation of organic matter, from the drainage of organic soils for *Afforestation and reforestation*, *Deforestation* and *Forest management.* Emissions are estimated following the methodology outlined in the IPCC Guidelines (IPCC, 2006a) and described in chapter 6, section 6.10.2. Total emissions for these three activities are 0.5 kt N_2O. The emissions occurring under each activity are reported in table 11.3.6.

Table 11.3.6 Nitrous oxide emissions from the drainage of organic soils in 2021 by activity

Activity	Emissions (kt N_2O)	Emissions (kt CO_2-e)
Afforestation and reforestation	0.2	61.9
Deforestation	0.1	29.5
Forest management	0.2	62.3
Total	**0.5**	**153.6**

Note: Columns may not total due to rounding.

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. The emissions occurring under each activity are reported in table 11.3.7.

Table 11.3.7 Nitrous oxide emissions from nitrogen mineralisation and immobilisation soils in 2021 by activity

Activity	Emissions (kt N_2O)	Emissions (kt CO_2-e)
Afforestation and reforestation	0.2	49.0
Deforestation	0.0	1.7
Forest management	0.0	0.0
Total	**0.2**	**50.7**

Note: Columns may not total due to rounding.

Emissions associated with *Indirect N_2O emissions from managed soils* are also reported under the Agriculture sector. New Zealand reports IE in the relevant CRF tables.

Biomass burning (CRF 4(KP-II)4)

Afforestation and reforestation

Non-carbon dioxide (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 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 currently assumed that controlled burning of post-harvest residues before 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).

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 6.10.8. Around 1 per cent of wildfire emissions in *Grassland* are estimated to have occurred on deforested land between 2008 and 2021.

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) before the establishment of exotic planted forest (see 'Afforestation and reforestation' above).

The survey also provided data on the burning of post-harvest slash before 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 the 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 6.10.8.

11.4 Other methodological issues

11.4.1 Uncertainty and time-series consistency

The uncertainty in net emissions from *Afforestation and reforestation* is ±35.9 per cent at the 95 per cent confidence interval. This is based on the uncertainty in emissions from post-1989 planted forest, post-1989 natural forest and *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* at the 95 per cent confidence intervals is ±66.6 per cent (table 11.4.2).

The combined uncertainty in emissions from *Forest management* is ±85.9 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 planted forest, post-89 natural forest and *Harvested wood products* is provided in chapter 6, sections 6.3.3 and 6.9.3.

Total uncertainty in New Zealand's estimates of emissions for Article 3.3 and Article 3.4 of the Kyoto Protocol is ±58.7 per cent at a 95 per cent confidence interval.

Table 11.4.1 Uncertainty in New Zealand's estimates for *Afforestation and reforestation*, *Deforestation* and *Forest management* in 2021

	Uncertainty (%) at a 95% confidence interval							
	Afforestation and reforestation		Deforestation				Forest management	
	Post-1989 planted forest	Post-1989 natural forest	Pre-1990 natural forest	Pre-1990 planted forest	Post-1989 planted forest	Post-1989 natural forest	Pre-1990 natural forest	Pre-1990 planted forest
Activity data								
Uncertainty in land area	±8.0	±8.0	±5.0	±5.0	±5.0	±5.0	±5.0	±5.0
Emission factors								
Uncertainty in biomass carbon stocks (losses)	±20.5	–	±27.3	±21.2	±20.5	±27.0	–	±21.2
Uncertainty in biomass carbon change (gains)	±8.9	±44.8	–	–	–	–	±119.6	±11.3
Uncertainty in soil carbon stocks	±10.4	±10.4	±7.9	±12.3	±10.4	±10.4	±7.9	±12.3
Uncertainty in harvested wood products	±68.2		–	–	–		–	±68.2
Uncertainty introduced into emissions for Kyoto Protocol	**±14.3**	**±0.9**	**±0.4**	**±0.5**	**±0.9**	**±0.0**	**±14.7**	**±55.0**

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, post-1989 planted forest or post-1989 natural forest.

Table 11.4.2 Total uncertainty in New Zealand's estimates for *Afforestation and reforestation*, *Deforestation* and *Forest management* in 2021

Variable	Emissions (kt CO_2-e)	Uncertainty in emissions (%) at a 95% confidence interval	Uncertainty introduced to Kyoto Protocol emissions (%)
Afforestation and reforestation uncertainty introduced into emissions for Kyoto Protocol	–11,488.3	35.9	14.7
Deforestation uncertainty introduced into emissions for Kyoto Protocol	1,391.0	66.6	4.0
Forest management uncertainty introduced into emissions for Kyoto Protocol	–16,757.25	85.9	56.9
Total uncertainty for Kyoto Protocol	**–26,854.5**	**58.7**	

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 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 6.3.4.

11.4.3 Recalculations

New Zealand's greenhouse gas estimates for activities under Article 3.3 of the Kyoto Protocol have not been recalculated since the previous submission as the previous commitment period concluded at the end of 2020. Comparisons with recalculated 2020 values are therefore not provided.

11.4.4 Planned improvements

With no further commitments under the Kyoto Protocol, all relevant planned improvements are covered within the LULUCF sector. Improvements for the LULUCF sector are described under each specific land use category in chapter 6.

11.5 Demonstration that activities apply

11.5.1 Year of the onset of an activity

The *Afforestation* occurring in each year is estimated from the Land Use Carbon Analysis System land use map, as described in section 11.3.2, and the National Exotic Forest Description survey, which captures information from the Ministry for Primary Industries schemes and programmes described in section 11.3.2 (Ministry for Primary Industries, 2021). This information ensures that the activity is attributed to the correct year of onset.

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 completed for activity occurring in the 2020 to 2021 period, the total deforestation area for these years has been estimated as described in annex 3, section A.3.2.2.

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 land owner does not replant trees immediately but leaves the land fallow for a 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).

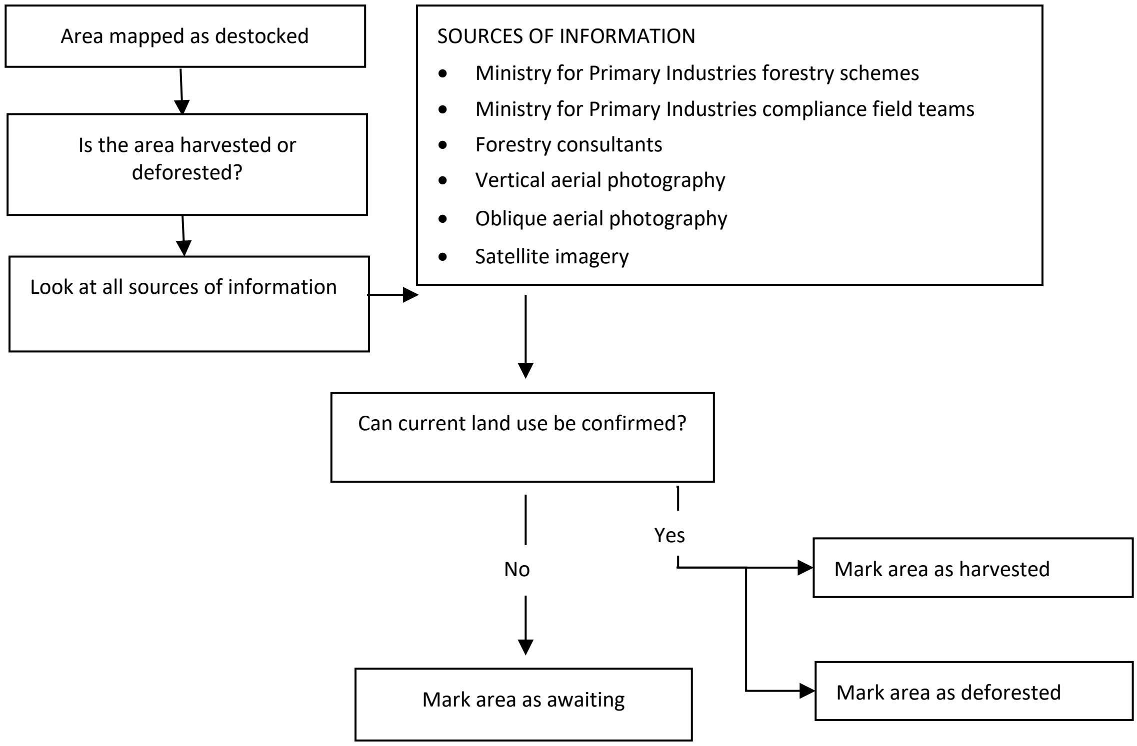
In New Zealand, temporarily unstocked or cleared areas of forest (e.g., harvested areas and areas subject to disturbances) remain designated as *Forest land* unless a change in land use is confirmed or if, after four years, no reforestation (replanting or regeneration) has occurred. This follows the 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, 2014). New Zealand has defined the expected period between the removal of tree cover and successful natural regeneration or planting as four years. In New Zealand, the tree grower and land owner are often different people. Forest land can be temporarily unstocked for several years while land owners 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). A data-sharing agreement is in place 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 is determined using a range of ancillary data including:

- 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 – a range of environmental conditions 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 livestock exclusion, such as a fence line or a change to steep terrain (gully or hill), which provides a natural barrier to livestock.

The evidence that the afforestation is human induced includes data from the following.

- 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 the land owner has entered the area in the NZ ETS (with associated application costs) is considered strong evidence of their intention to grow a forest.

- Aerial imagery – showing fence lines, spot spraying or regular planting patterns consistent with the establishment of indigenous forest cover.

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 destocked land

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, 2014), 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.

All areas of awaiting land that was destocked before 2017 have now been reclassified as either harvested or deforested based on field verification.

The total area of unclassified land for 2017 to 2019 is shown in table 11.5.1.

Table 11.5.1 Area of land destocked in New Zealand in 2017 to 2019 that has not yet been classified

Year of destocking	Pre-1990 natural forest (ha)	Pre-1990 planted forest (ha)	Post-1989 forest (ha)	Total (ha)
2017	4	231	200	435
2018	192	1,619	1,895	3,705
2019	76	940	1,045	2,061

Note: Rows may not total due to rounding.

No estimates of awaiting land for 2020 and 2021 have been made because land use mapping has not been completed for these years. The *Deforestation* areas reported for 2021 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, because these emissions are reported under 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 before 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 for by comparing greenhouse gas emissions and removals during the commitment period with a benchmark business as usual scenario, the FMRL.

11.6.3 Key category analysis for Article 3.3 and Article 3.4 activities (CRF NIR-3)

Afforestation and reforestation, Deforestation and *Forest management* are all included in key categories for New Zealand (*Forest land remaining forest land*, *Land converted to forest land* or *Land converted to grassland*).

11.7 Information relating to Article 6

New Zealand is not involved in any LULUCF activities under Article 6 of the Kyoto Protocol.

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Chapter 12: Information on accounting of the Kyoto Protocol units

12.1 Background information

Assigned amount and commitment period reserve

In January 2008, New Zealand's national registry was issued with New Zealand's assigned amount of 309,564,733 metric tonnes of carbon dioxide equivalent (CO_2-e) for the first commitment period (CP1).

The commitment period reserve for the CP1 of 278,608,260 metric tonnes of 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.

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 (environment.govt.nz/facts-and-science/climate-change/measuring-greenhouse-gas-emissions/about-new-zealands-greenhouse-gas-inventory). Information on New Zealand's submission of the standard electronic format is included in table 12.2.1.

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 2022, 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. The number and mix of units held at the end of 2022 were the same as at the beginning of 2022, because no international transactions occurred during this period and this value includes the units retired to meet CP1 obligations. No second commitment period (CP2) units were held by New Zealand in 2022.

At the end of 2022, 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 2022.

The transactions made to New Zealand's national registry during 2022 are summarised below.

- No external transfers of Kyoto units occurred. A total of 24,507 AAUs were subtracted internally through voluntary cancellation.
- There were no conversions to ERUs. No CP2 Kyoto units were held by New Zealand during the 2022 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 2022 first and second commitment period units have not 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 (see table 12.3.1).

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 2022.
15/CMP.1 annex I.E, paragraph 13 & 14: List of CDM notifications	No CDM notifications occurred in 2022.
15/CMP.1 annex I.E, paragraph 1 15: List of non-replacements	No non-replacements occurred in 2022.
15/CMP.1 annex I.E, paragraph 1 15: List of invalid units	No invalid units exist as at 31 December 2022.
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, through the 'Public information and reports' link. A list of publicly accessible information is provided in table 12.4.1.

Table 12.4.1 List of the publicly accessible information in New Zealand's national registry

Type of information to be made public pursuant to part E of the annex to 13/CMP.1, paragraphs 44 to 48	Publicly available on New Zealand's national registry website (refer www.emissionsregister. govt.nz; Public information and reports) (yes/no/partial)	Timing of information to be made available under New Zealand's Climate Change Response Act 2002	Relevant reference to New Zealand's Climate Change Response Act 2002 where information is not publicly available in accordance with paragraphs 44 to 48
44. Each national registry shall make non-confidential information publicly available and provide a publicly accessible user interface through the Internet that allows interested persons to query and view it.	Details of information availability are provided below.		
45. The information referred to in paragraph 44 above shall include up-to-date information for each account number in that registry on the following:			
(a) Account name: the holder of the account.	Yes (refer Public information and reports: Accounts).	Up to date (note, refreshed daily)	NA
(b) Account type: the type of account (holding, cancellation or retirement).	Yes (refer Public information and reports: Accounts).	Up to date (note, refreshed daily)	NA
(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)	NA
(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.	NA	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 holders' 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	NA
(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	NA

Type of information to be made public pursuant to part E of the annex to 13/CMP.1, paragraphs 44 to 48	Publicly available on New Zealand's national registry website (refer www.emissionsregister. govt.nz; Public information and reports) (yes/no/partial)	Timing of information to be made available under New Zealand's Climate Change Response Act 2002	Relevant reference to New Zealand's Climate Change Response Act 2002 where information is not publicly available in accordance with paragraphs 44 to 48
(c) Years of ERU issuance: the years when ERUs have been issued as a result of the Article 6 project.	Yes (refer Public information and reports: Ministers' directions, which lists directions relating to the transfer of emission reduction units to individual JI projects. The New Zealand Emission Trading Register Unit Holding and Transaction Summary Report shows in aggregate the total ERUs converted from AAUs by year).	Joint implementation projects annually by 31 January for the previous calendar year Ministers' directions – up to date (note, refreshed daily)	NA
(d) Reports: downloadable electronic versions of all publicly available documentation relating to the project, including proposals, monitoring, verification and issuance of ERUs, where relevant, subject to the confidentiality provisions in decision 9/CMP.1.	Partial – some of this information is published on the UNFCCC's website for JI projects at https://ji.unfccc.int/JI_Parties/DB/E48QQ342M7VSOFWEI6MTBKVVF9NFAM/viewDFP This provides a link to the project documentation on the UNFCCC site and is not replicated on the New Zealand's national registry website. 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.	NA
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, 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.
(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	NA

Type of information to be made public pursuant to part E of the annex to 13/CMP.1, paragraphs 44 to 48	Publicly available on New Zealand's national registry website (refer www.emissionsregister. govt.nz; Public information and reports) (yes/no/partial)	Timing of information to be made available under New Zealand's Climate Change Response Act 2002	Relevant reference to New Zealand's Climate Change Response Act 2002 where information is not publicly available in accordance with paragraphs 44 to 48
(c) 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	NA
(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	NA 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	NA
(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	NA 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	NA
(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	NA

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
(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	NA
(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	NA
(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	NA
(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, 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.
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)	NA

Note: NA = not applicable.

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 2022 is:

Commitment period reserve (CPR) limit:	278,608,260
Units held:	402,074,068
CPR level:	402,098,575
CPR level = (% of assigned amount):	144.32%
CPR level comprises the following units:	
AAUs	208,331,536
ERUs (converted from AAUs)	97,027,042
CERs	16,117,338
RMUs	80,598,152
Total units	402,074,068

Chapter 12: Reference

Ministry for the Environment. 2006. *New Zealand's Initial Report under the Kyoto Protocol.* Wellington: Ministry for the Environment. Retrieved from unfccc.int/files/national_reports/application/pdf/new_zealands_initial_report_under_the_kyoto_protocol.pdf (30 March 2023).

Chapter 13: Information on changes to the national inventory system

No changes have been made in the legal or institutional arrangements in the national inventory system since the 2022 inventory submission.

Although no major changes were made in the structure of the national inventory system, several programme and operational improvements were implemented, to increase the quality and efficiency of the inventory production. These include:

- continuing to develop automated methods for the National Inventory Report production, especially where large quantities of data reported are within several different source documents
- continuing to develop the expertise of inventory contributors through coaching and structured training courses
- continuing to resource project management and quality control within the central inventory agency (the Ministry for the Environment).

The improvements are expected to enhance the functioning of the national system and, in doing so, ensure continuous improvement of national inventory submissions into the future.

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 2022 submission are included in table 14.1.

No recommendations were made in the review of New Zealand's 2022 submission by the expert review team (see table 14.2).

The contact details for the national registry are provided in table 14.3.

Table 14.1 Changes made to New Zealand's national registry

Section subheading	New Zealand's response
15/CMP.1 Annex II.E, paragraph 32.(a): Change in the name or contact for the national registry	The contact details for the national registry have not been changed during the reporting period.
15/CMP.1 Annex II.E, paragraph 32.(b): Change in cooperation arrangement	No change of cooperation arrangement occurred during the reported period.
1/CMP.1 Annex II.E, paragraph 32.(c): Change to the database or the capacity of the national registry	No change to the database or the capacity of the national registry occurred during the reporting period.
15/CMP.1 Annex II.E, paragraph 32.(d): Change in the conformance to technical standards	No change in the conformance to technical standards occurred during the reporting period.
15/CMP.1 Annex II.E, paragraph 32.(e): Change in the discrepancy procedures	No change of discrepancies procedures occurred during the reporting period.
15/CMP.1 Annex II.E, paragraph 32.(f): Change in security	No change in security occurred during the reporting period.
15/CMP.1 Annex II.E, paragraph 32.(g): Change in the list of publicly available information	No 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 ETS Manager 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	Dave Stuart Team Leader, ETS Operations Environmental Protection Authority Private Bag 63002, Wellington 6140, New Zealand Phone: +64 4 474 5750 Fax: +64 4 978 3661 Email: dave.stuart@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.

Until 2022 this reporting has been a requirement under Article 3.14 of the Kyoto Protocol, from 2024 this will be a requirement under the new Paris Agreement reporting. In the interim year (2023), for transparency, accountability and consistency, New Zealand has decided to continue to report on the minimisation of adverse impacts of response measures.

15.1 Overview

New Zealand is undertaking several mitigation actions and policies to reduce emissions to meet its Paris Agreement (2015) commitments, as well as prioritising adaptation and resilience in the Pacific. These measures include:

- implementing New Zealand's updated Nationally Determined Contribution
- developing an economy-wide, sector-specific and cross-cutting emissions reduction plan mandated to meet New Zealand's legislated emission budgets (published in May 2022)
- developing a methane emissions reduction plan across the Agriculture, Waste, Industry and Energy sectors to contribute to 30 per cent global reduction in methane emissions by 2030 (published in December 2022)
- improving New Zealand's emissions trading scheme, including by being one of the first countries in the world to put a price on agricultural emissions
- legislating a mandatory climate-related financial disclosures regime
- improving energy efficiency initiatives
- investing in public transport, electric and low-emission light vehicles
- supporting afforestation
- undertaking research, technology development and sharing of technical expertise, most notably in the agricultural sector
- achieving 100 per cent of electricity produced from renewable energy sources by 2035
- establishing the Carbon Neutral Government Programme
- strengthening international cooperation by joining several initiatives that commit countries to effective and ambitious climate action, including playing a leading role in the Friends of Fossil Fuel Subsidy Reform (FFSR), the Global Research Alliance on Agricultural Greenhouse Gases, the Carbon Neutrality Coalition, the Agreement on Climate Change, Trade and Sustainability negotiations and helping to found the inclusive Coalition of Trade Ministers on Climate
- sharing New Zealand's long-standing expertise in renewable energy development internationally
- increasing climate-related support four-fold, to be delivered by New Zealand's International Development Cooperation (IDC) Programme (see www.mfat.govt.nz/en/environment/climate-change/supporting-our-region).

Further information on actions and policies is included in *New Zealand's Fifth Biennial Report*, published in December 2022 (Ministry for the Environment, 2022).

New Zealand recognises the potential for its climate policies to have consequences for its Pacific neighbours, particularly in relation to supply chains. In the development of major policy initiatives related to these mitigation measures, an analysis of impacts of the proposed policy is undertaken. 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, opportunities are available for concerns to be raised about the possible or actual adverse impacts of New Zealand policies and to have them resolved within the bilateral relationship. An opportunity is also available for people and/or organisations to raise concerns and highlight issues about new policies during the public consultation phase. To date, no specific concerns about any negative impacts of New Zealand's climate change response policies on non-Annex I Parties have been raised. No changes have been made compared with the information reported in the previous National Inventory Report. New Zealand officials regularly participate in negotiation sessions on response measures under the United Nations Framework Convention on Climate Change (UNFCCC): seeking to minimise the negative and maximise the positive impacts of the implementation of mitigation policies. This multilateral setting is another forum to raise any concerns, come to decisions on technical areas, such as just transition, and facilitate information sharing between Parties.

New Zealand is meeting its climate finance commitments under the Paris Agreement by progressively scaling up finance for developing countries to transition to low emission economies. New Zealand delivers its climate finance commitment through the IDC Programme managed by the Ministry of Foreign Affairs and Trade. New Zealand works closely with the partner country to agree priorities for the particular country's international development cooperation. Doing so helps ensure New Zealand's IDC Programme is aligned to the priorities and needs of the partner country, while also reflecting New Zealand values. Practice standards for IDC activities, funded by the New Zealand IDC 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).

Regular consultations, held between New Zealand and partner countries to discuss the delivery of IDC activities, provide another opportunity for partner countries to raise concerns about impacts, and for both partners to work collaboratively to address those concerns. This partnership approach is also taken with New Zealand's Pacific regional and multi-country climate change activities.

New Zealand is committed to the Sustainable Development Goals (SDGs), adopted by the international community in 2015. New Zealand implements the SDGs through the IDC Programme by supporting areas such as climate change adaptation, disaster risk reduction and humanitarian response to natural disasters.

New Zealand is also supporting countries to undertake analysis to transition to low emission, climate-resilient economies, particularly in sectors such as energy and transport. As a critical element of long-term sustainable development efforts, Small Island Developing States (SIDS) continue to increase their uptake of renewable energy. The New Zealand IDC Programme supports a major push to increase this uptake in the Pacific and reduce the region's reliance on imported diesel. This includes support to develop energy roadmaps, as well as installation and upgrades to renewable energy systems, and investigation into opportunities for energy efficiency and transport energy projects.

Compared with information reported in the previous National Inventory Report, additional initiatives include opportunities for new energy efficiency and transport energy projects. Scoping and design for these activities was initiated in 2019, with implementation beginning in Nauru (energy efficiency) in 2021 and the Marshall Islands (transport) in 2022.

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.

Trade is a critical part of New Zealand's economy. Through the Inclusive Trade Action Group, New Zealand and likeminded countries are driving a more inclusive and sustainable trade agenda. New Zealand maintains a liberalised and open trading environment, consistent with the principles of free trade and investment, ensuring both developed and developing countries can maximise opportunities in New Zealand's market regardless of the response measures undertaken.

15.3 Removal of inefficient fossil fuel 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 is a leading advocate for the reduction and, ultimately, elimination of fossil fuel subsidies internationally. Fossil fuel subsidies work against international efforts to limit climate change, and reform of inefficient fossil fuel subsidies would also release government funds that can instead be allocated towards a green and climate-resilient COVID-19 recovery.

New Zealand is a founding member of the 'Friends' of FFSR. The Friends is an informal collection of non-Group of Twenty (G20) economies that aims to build international political consensus on the importance of FFSR. The support of the Friends for reform is based on the essential notion that it is illogical to continue subsidising the costs of emissions from fossil fuels while, at the same time, making concerted efforts to mitigate those emissions through actions elsewhere. As a member of the Friends, New Zealand has been working 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.

The World Trade Organization (WTO) has a central role in disciplining trade-distorting subsidies, and New Zealand works to advance fossil fuel subsidy reform internationally through this platform. In December 2021, and at Twelfth Ministerial Conference in June 2022, New Zealand led the relaunch of the Joint Ministerial Statement on Fossil Fuel Subsidy Reform at the WTO, which built on prior efforts in 2017.[78] In the new statement, ministers seek the

[78] In December 2017, New Zealand delivered the Joint Ministerial Statement to the World Trade Organization (WTO), encouraging Members to address the global harm being caused by inefficient fossil fuel subsidies. Endorsed by 12 WTO Members, the Joint Ministerial 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.

rationalisation and phase out of inefficient fossil fuel subsidies that encourage wasteful consumption along a clear timeline. Notably, the statement's 47 co-sponsors agreed an accompanying work plan and to develop concrete options to address fossil fuel subsidies within the binding and enforceable WTO frameworks.

New Zealand is also active with the Friends group through the UNFCCC. At the 27th Conference of Parties in 2022 (COP27), the Friends launched a new statement to keep the topic of phasing out fossil fuel subsidies on the agenda, after parties the previous year pledged to accelerate efforts towards the phase-down of inefficient fossil fuel subsidies, and held two events with the International Institute of Sustainable Development. Previously, at COP24 New Zealand helped to launch a 'Friends Network', to broaden understanding of the need for reform and practical ways to achieve it. The Friends Network held a series of five virtual interactive roundtables in 2019, which were attended by representatives from about 20 economies from around the world. New Zealand has also hosted a side-event on FFSR at the United Nations High-Level Political Forum in July 2018, which focused on improving energy access and responding to the SDGs through the phase out of fossil fuel subsidies.

The Asia-Pacific Economic Cooperation is another platform in which New Zealand advances fossil fuel subsidy reform. New Zealand used its APEC 2021 host year to drive regional trade and environment outcomes to support its multilateral ambitions. New Zealand led APEC to achieve consensus on work towards operationalising a voluntary standstill on inefficient fossil fuel subsidies from the end of 2022.

In negotiating trade deals, New Zealand advocates for increased transparency and commitment to take steps to reform (such as New Zealand's free trade deals with the European Union and United Kingdom). New Zealand is also leading negotiations on the Agreement on Climate Change, Trade and Sustainability trade initiative, which was launched in 2019, in a group of six like-minded countries including Costa Rica, Fiji, Iceland, Norway and Switzerland. It seeks to develop legally binding rules to eliminate harmful fossil fuel subsidies. It is expected the Agreement will expand into an open plurilateral initiative, open to WTO Members that meet the established standard, with the view to building towards a multilateral outcome over time.

Transparency is an important element of subsidy reform. New Zealand participates in reporting through APEC (participating in a voluntary peer review in 2015 and voluntary self-reporting in 2022) and the Organisation for Economic Co-operation and Development (OECD; participating in a voluntary peer review in 2018 and in regular reporting). The peer review found that New Zealand does not have any inefficient fossil fuel subsidies that encourage wasteful consumption. However, the OECD review found that New Zealand had nine remaining indirect support measures that could support the use of fossil fuels. Three of these measures have now been terminated. New Zealand committed to evaluate the remaining indirect support measures in 2019, and not to introduce any new fossil fuel subsidies. The evaluation found that New Zealand does not have any support measures that could directly or indirectly support the wasteful consumption of fossil fuels.

In response to several crises – including the global energy crisis, the cost of living crisis and efforts to recover from the COVID-19 pandemic – in 2022, New Zealand implemented a range of temporary support measures. These included a 25 cent cut to fuel excise tax and a reduction in road user charges. To mitigate the impacts of these and incentivise mode shift, the cost of all public transport was also halved. These temporary measures will be phased out in time.

New Zealand has the third highest share of renewable electricity generation in the OECD and is working towards 100 per cent renewable electricity generation by 2030. Prices for energy products and services are set freely by the market. New Zealand is a member of the Powering Past Coal Alliance and became an associate member of the Beyond Oil and Gas Alliance in 2021.

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 yet participated actively in activities of this nature.

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. This can be achieved by improving the efficiency in upstream and downstream activities related to fossil fuels and taking into consideration the need to improve the environmental efficiency of these activities.

The New Zealand IDC Programme maintains a focus on renewable energy and energy efficiency and the transition away from fossil fuel dependency to affordable, reliable and clean energy sources. This continues to support partner countries, with a focus on the Pacific, to reduce their carbon emissions through a transition from fossil fuels to renewable energy sources and improved energy efficiency. For example, New Zealand is supporting Nauru to implement a suite of end-use energy efficiency measures, expected to save 6 per cent of its fossil fuel imports.

New Zealand continues championing development partner coordination, particularly in the Pacific region, where New Zealand is an acknowledged leader in the energy sector. New Zealand is a major funder and member of the Pacific Regional Infrastructure Facility (PRIF) that coordinates the Pacific efforts of eight large development partners. The PRIF has an active and effective energy sector working group, where these development partners coordinate and share opportunities for partnering in the energy sector. Sharing a coordinated, regional approach to renewable energy and energy efficiency projects undertaken by PRIF partners will accelerate progress towards achieving countries' renewable energy targets, which form an important part of their Nationally Determined Contributions submitted under the Paris Agreement.

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 served on the IRENA Council in 2020 and is involved with several of IRENA's work programmes in the Pacific and further afield, using its strong credentials in the IRENA Assemblies and council meetings to support Pacific SIDS. 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 IDC Programme provides support to several non-Annex I Parties for purposes of economic diversification (refer to section 15.6). The Pacific region is a priority for New Zealand's IDC Programme, and the main recipient of assistance in the Energy sector. South East Asia is the second region receiving the most support, followed by Africa and the Caribbean, where the focus is on developing their geothermal energy resources.

The Pacific is the most petroleum dependent region in the world, with countries heavily reliant on imported petroleum products for electricity and transport. Energy systems are vulnerable to the impacts of climate change, affecting the resilience of the essential services, communities and economies. New Zealand supports the transition towards renewable energy systems in the region, by investing in climate-resilient renewable energy systems. For example, New Zealand is supporting Vanuatu to develop its rural electrification masterplan and its strategy to replace diesel with coconut oil for electricity generation. Other ongoing activities include a programme of support under the Papua New Guinea Electrification Partnership and support for the expansion and renewal of Tokelau's renewable energy systems.

Beyond the Pacific, New Zealand supports growing local capacity and capability for increasing access to renewable electricity. This includes leveraging New Zealand's geothermal expertise to support the development of geothermal energy resources and, more recently, supporting countries in South East Asia to improve their policy and regulatory frameworks to enable further investment in renewable energy.

New Zealand is committed to providing long-term assistance to non-Annex I Parties in achieving economic diversification that is independent of fossil fuels.

15.8 New Zealand's IDC climate commitment

In August 2022, New Zealand announced its *International Climate Finance Strategy – Tuia te Waka a Kiwa* (see www.mfat.govt.nz/assets/Aid/Climate-finance/International-Climate-Finance-Strategy-FINAL-16Aug22-low-res.pdf), which will guide the delivery of New Zealand's NZD$1.3 billion international climate finance commitment. At least 50 per cent of the commitment will support Pacific Island countries and another 50 per cent will target adaptation. The strategy works towards four main goals:

1. to enhance resilience and adaptation
2. promote quicker action on mitigation
3. improve information to allow evidence-based decisions
4. leverage New Zealand's investments to make greater impact.

New Zealand is committed to being guided by Pacific partner government priorities when delivering this commitment especially those described in Nationally Determined Contributions and National Adaptation Plans.

More broadly, New Zealand remains committed to the global goal of jointly mobilising USD$100 billion per year from a variety of sources through to 2025. This is in the context of meaningful mitigation actions by developing countries and for transparency on implementation.

Chapter 15: References

Ministry for the Environment. 2022. *Te Rīpoata Taurua Tuarima o Aotearoa: New Zealand's Fifth Biennial Report under the United Nations Framework Convention on Climate Change*. Wellington: Ministry for the Environment.

Ministry of Foreign Affairs and Trade. 2022. *International Climate Finance Strategy – Tuia te Waka a Kiwa*. Wellington: Ministry of Foreign Affairs and Trade. Retrieved from www.mfat.govt.nz/assets/Aid/Climate-finance/International-Climate-Finance-Strategy-At-a-glance-FINAL.pdf (28 February 2023).