NATIONAL GREENHOUSE GAS INVENTORY DOCUMENT SINGAPORE

2024

UNDER THE UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE

National Environment Agency
Safeguard · Nurture · Cherish

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Ministry of Transport
National Climate Change Secretariat

NOTES ON USING THIS DOCUMENT

As a developing country Party to the United Nations Framework Convention on Climate Change (UNFCCC), Singapore is obliged to submit our Biennial Transparency Report (BTR) every two years, with the first submission to the UNFCCC by 31 December 2024. In accordance with Article 13. 7(a) of the Paris Agreement, all Parties must submit a GHG inventory as part of the BTR.

This document was prepared as a stand-alone report in accordance with the UNFCCC modalities, procedures, and guidelines (MPGs) for the Enhanced Transparency Framework (annex to decision 18/CMA.1). The National Inventory Report (NIR) consists of a national inventory document (NID) and the common reporting tables[1] where the common reporting tables is reported electronically. The NID 2024 presents Singapore's Greenhouse Gas (GHG) Inventory from 2000 to 2022, providing anthropogenic emissions by sources and removals by sinks of GHGs, in accordance with the MPGs contained in chapter II.

[1] The outline for reporting the GHG inventory information may be found in annex V to decision 5/CMA.3.

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LIST OF COMMON ABBREVIATIONS AND UNITS

AD	Activity Data
AFOLU	Agriculture, Forestry and Other Land Use
AGB	Above-ground biomass
AHTN	ASEAN Harmonised Tariff Nomenclature
AR5	Fifth Assessment Report
BTR	Biennial Transparency Report
BUR	Biennial Update Report
CDM	Clean Development Mechanism
CEMS	Continuous Emissions Monitoring System
CFC	Chlorofluorocarbons
CH_4	Methane
CHP	Combined Heat and Power Generation
CMA	Conference of the Parties serving as the meeting of the Parties to the Paris Agreement
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
CO_2 eq	Carbon Dioxide Equivalent
CO	Carbon Monoxide
CPA	Carbon Pricing Act
COD	Chemical Oxygen Demand
CVD	Chemical vapour deposition
DBH	Diameter at breast height
DBOO	Design, Build, Own and Operate
DOC	Degradable Organic Carbon
DOS	Department of Statistics
DTSS	Deep Tunnel Sewerage System
ECA	Energy Conservation Act
EDMA	Emissions Data Monitoring and Analysis
EF	Emission factor
EMA	Energy Market Authority
EOL	end-of-life
EPHA	Environmental Public Health Act
EPMA	Environmental Protection and Management Act
ER	Emissions Report
ETF	Enhanced Transparency Framework
FAO	Food and Agriculture Organisation
FC	Fluorinated compound
GCB	Gas Circuit Breakers
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIL	Gas Insulated Lines
GIS	Gas Insulated Switchgear and Substations
GWP	Global Warming Potential
GIS	Gas Insulated Switchgear and Substations
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbons

HFO	Hydrofluoro-olefins
HS	Harmonised System
IAWG	Inter-agency Working Group
ICA	International Consultation and Analysis
ICAO	International Civil Aviation Organization
IE	Included elsewhere
IMCCC	Inter-Ministerial Committee on Climate Change
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Processes and Product Use
ISIC	International Standard Industrial Classification
KCA	Key Category Analysis
KSTP	Seghers Tuas Waste-To-Energy Plant
LAC	Low Activity Clay
LCD	Liquid Crystal Display
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
LTA	Land Transport Authority
LUC	Land-use change
LULUCF	Land Use, Land-Use Change and Forestry
MCF	Methane Correction Factor
MCS	Monte Carlo Simulation
MDIs	Metered dosed inhalers
MINDEF	Ministry of Defence
MMS	Manure Management Systems
MRV	Measurement, Reporting and Verification
MP	Monitoring Plan
MPGs	Modalities, Procedures and Guidelines
MRV-TF	MRV Taskforce
MSS	Meteorological Service Singapore
MSW	Municipal Solid Waste
$MtCO_2$ eq	Million Tonnes of Carbon Dioxide Equivalent
NA	Not applicable
N_2O	Nitrous Oxide
NCCS	National Climate Change Secretariat
NE	Not estimated
NEA	National Environment Agency
NID	National Inventory Document
NMVOCs	Non-Methane Volatile Organic Compounds
NO	Not occurring
NOx	Nitrogen Oxides
NParks	National Parks Board
PEMS	Periodic Emissions Monitoring System
PFCs	Perfluorocarbons
PMO	Prime Minister's Office
PUB	PUB, Singapore's National Water Agency
PV	Photovoltaic
QA	Quality Assurance

QC	Quality Control
RAC	Refrigeration and air-conditioning
SCDF	Singapore Civil Defence Force
SES	Singapore Energy Statistics
SF_6	Sulphur Hexafluoride
SITC	Standard International Trade Classification
SLA	Singapore Land Authority
SSEA	Survey on Sales of Electrical Appliances
SO_2	Sulphur Dioxide
SOC	Soil organic carbon
SOx	Sulphur oxide
SWDS	Solid Waste Disposal Site
SWTE	Senoko Waste-To-Energy Plant
T1	Tier 1 approach
T2	Tier 2 approach
T3	Tier 3 approach
TACCC	Transparency, Accuracy, Completeness, Consistency and Comparability
tCO_2 eq	Tonne of Carbon Dioxide Equivalent
TFT-FPD	Thin-film-transistor flat panel display
TIW	Toxic Industrial Waste
TIWC	Toxic Industrial Waste Collector
TTE	Team of Technical Experts
TER	Technical Expert Review
TASR	Technical Analysis Summary Report
TSIP	Tuas South Incineration Plant
TWTE	TuasOne Waste-To-Energy Plant
UNFCCC	United Nations Framework Convention on Climate Change
WCO	World Customs Organisation
WtE	Waste-to-Energy

Units

g	gram
Gg	gigagram
Gt	gigatonne
ha	hectare
kg	kilogram
kha	kilohectare
km	kilometre
kt	kilotonne
m	metre
Mha	million hectares
Mt	megatonne
MW	megawatt
TJ	terajoule
t	tonne

EXECUTIVE SUMMARY

ES.1. Background Information on GHG Inventories and Climate Change

Singapore reports the Greenhouse Gas (GHG) Inventory as part of the Biennial Transparency Report (BTR) as outlined in the modalities, procedures and guidelines (MPGs) (annex to decision 18/CMA.1). Under the Enhanced Transparency Framework (ETF) of the Paris Agreement, Parties must submit BTR every two years, with the first BTR to be submitted by 31 December 2024.

The GHG inventory is compiled and prepared based on the reporting guidance provided in the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National GHG Inventories (hereinafter referred to as 2006 IPCC Guidelines), the 2000 IPCC Good Practice Guidance and Uncertainty Management in National GHG Inventories (hereinafter referred to as 2000 GPG) and the 2013 Supplement to the 2006 IPCC Guidelines for National GHG Inventories Wetlands (hereinafter referred to as 2013 Supplement).

For small island-states like Singapore, climate change poses an asymmetrical challenge. While our impact on global emissions is small, the impact of climate change on us is disproportionately large. Despite the unique challenges and constraints we faced as a dense built-up city-state with no hinterland and limited resources, Singapore is committed to doing our part in the global fight against climate change.

ES.2. Summary of Trends Related to National Emissions and Removals

The total GHG emissions in 2022 is 58.59 Mt CO_2 eq, including Land Use, Land-use Change and Forestry (LULUCF). As shown in Table 2, this is an increase of 47% as compared to the emissions in 2000. In 2020, the emission trend shows a dip in GHG emissions. The dip in emissions is mainly attributed to the global COVID-19 pandemic, which led to a significant slowdown in economic activities, including manufacturing, construction and transportation.

The majority of Singapore's emissions is attributed to CO_2, accounting for around 86% of the total national emissions or 50 Mt CO_2 eq in 2022 as shown in Figure 2 and Table 2. It is followed by hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) where the combined emissions make up approximately 11% of the total national emissions or 6.7 Mt CO_2 eq in 2022. The HFC and PFC emissions are attributed mostly to the electronics and semiconductor manufacturing industry and higher demands for cooling and air conditioning, particularly due to Singapore's tropical climate and high levels of urbanisation.

Figure 1: Total GHG emissions from 2000 to 2022 (Mt CO_2 eq)

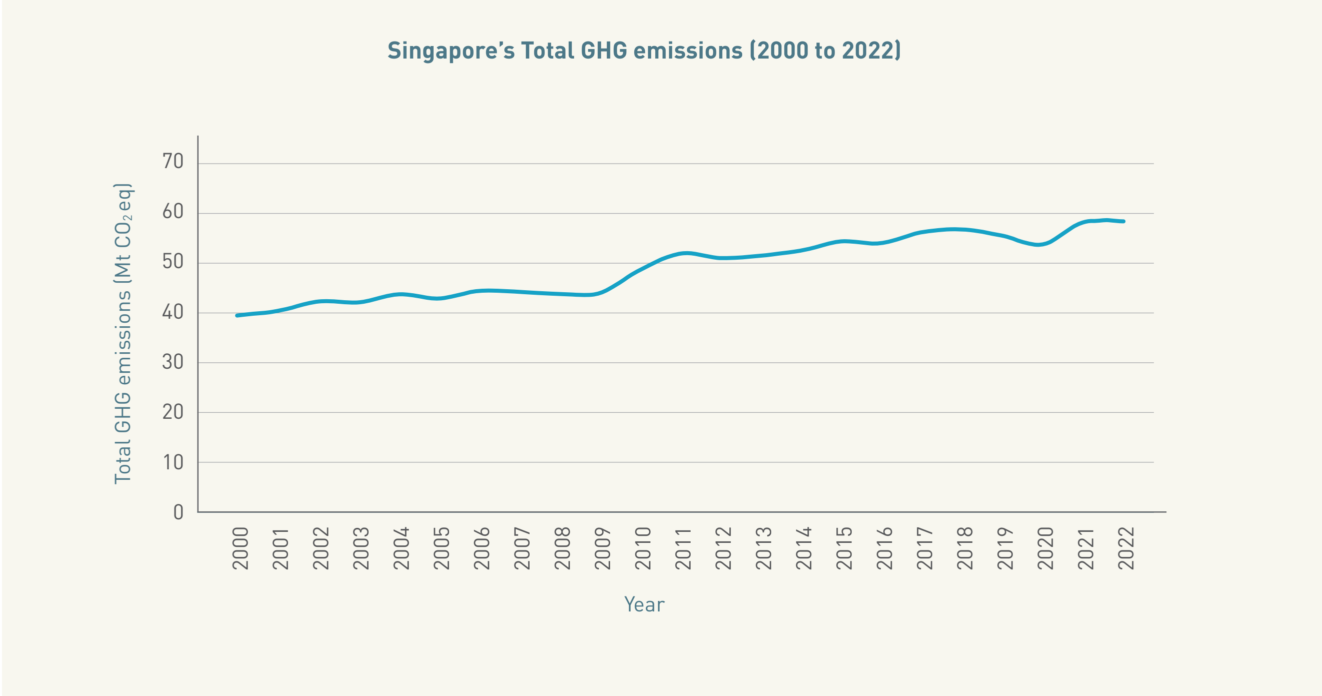


Table 1: Total GHG emissions from 2000 to 2022 (Mt CO_2 eq)

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Total GHG Emissions (Mt CO_2 eq)	39.69	40.58	42.34	42.32	43.89	43.11	44.63	44.47	44.07	44.24	48.90	52.10

Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Total GHG Emissions (Mt CO_2 eq)	51.26	51.59	52.61	54.41	54.14	56.06	56.84	55.58	53.87	58.28	58.59

Figure 2: Total GHG emissions by GHG type (Gg CO_2 eq)

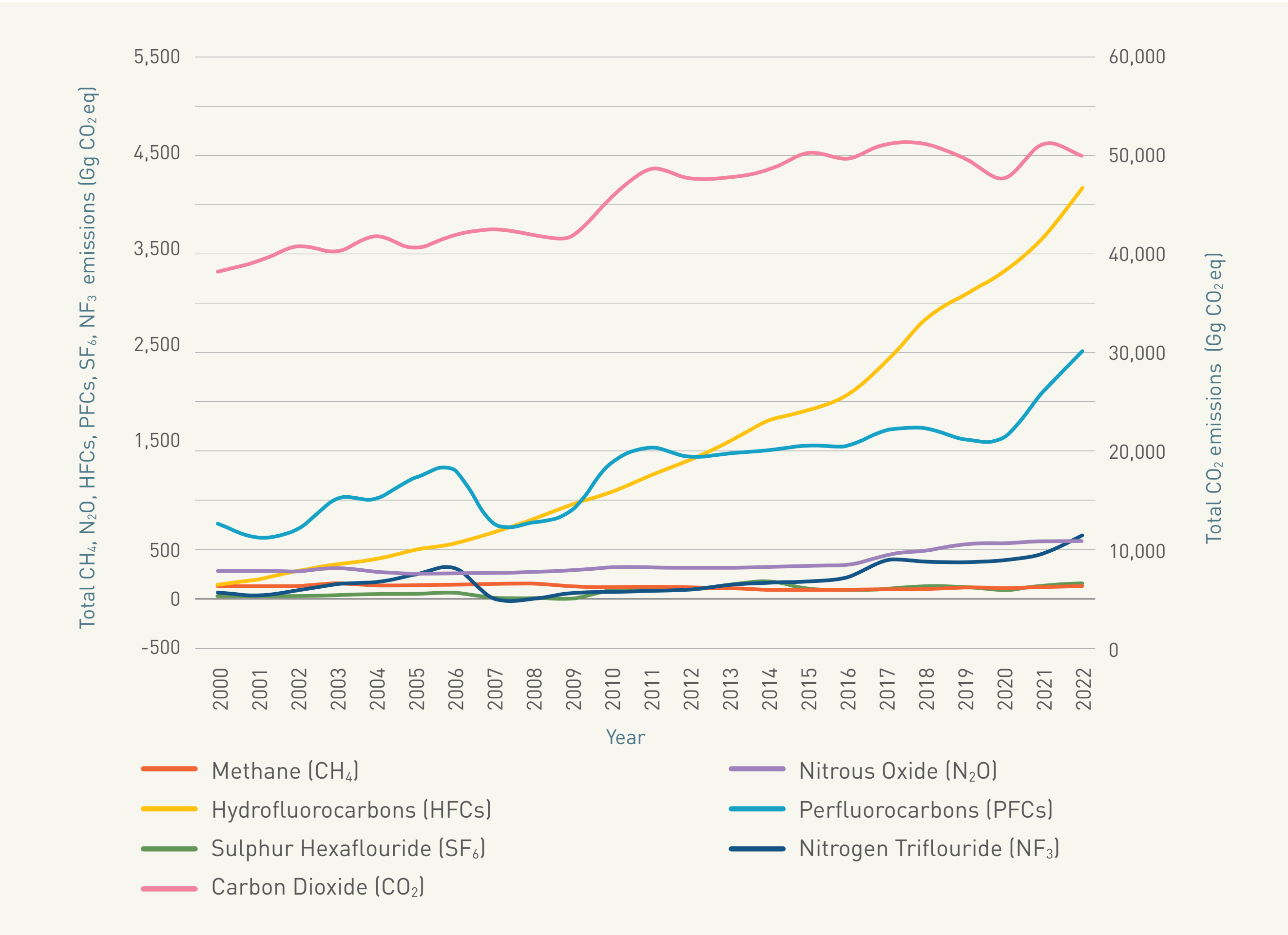


Table 2: Total GHG emissions by GHG type (Gg CO_2 eq)

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Carbon Dioxide (CO_2)	38,260	39,255	40,802	40,280	41,816	40,679	41,964	42,572	42,034	41,876	45,821
Methane (CH_4)	137	137	138	163	146	147	153	158	163	133	126
Nitrous Oxide (N_2O)	287	297	290	324	285	259	262	268	272	304	320
Hydrofluorocarbons (HFCs)	147	197	285	350	403	493	564	676	806	958	1,084
Perfluorocarbons (PFCs)	764	624	704	1,014	1,021	1,227	1,308	771	777	904	1,383
Sulphur Hexafluoride (SF_6)	32	30	29	38	49	52	59	18	15	5	87
Nitrogen Trifluoride (NF_3)	68	40	87	151	173	250	315	5	5	60	74

Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Carbon Dioxide (CO_2)	48,689	47,771	47,801	48,525	50,229	49,763	50,898	51,171	49,703	47,732	51,199	50,375
Methane (CH_4)	129	122	111	88.28	88.20	93.81	100	101	117	118	124	129
Nitrous Oxide (N_2O)	321	324	325	333	343	348	448	497	562	574	596	597
Hydrofluorocarbons (HFCs)	1,252	1,410	1,596	1,811	1,913	2,067	2,409	2,837	3,088	3,321	3,665	4,168
Perfluorocarbons (PFCs)	1,531	1,441	1,478	1,509	1,556	1,556	1,709	1,729	1,618	1,640	2,105	2,519
Sulphur Hexafluoride (SF_6)	95	95	139	180	104	95	101	128	120	91	132	155
Nitrogen Trifluoride (NF_3)	82	97	142	165	180	221	391	381	374	397	464	645

ES.3.
Overview of Source and Sink Category Emission Estimates and Trends

The GHG emissions in the Energy sector show the highest emissions, attributing to 84% of the total national emissions in 2022 as shown in Figure 3. With the inclusion of HFC emissions from the refrigeration and air-conditioning (RAC) sector, the emissions from Industrial Processes and Product Use (IPPU) increased from 8% to 16% of the total national emissions. The sectors with lowest emissions (~0.1% of total national emissions) are from the Agriculture, Forestry and Other Land Use (AFOLU) sector due to small geographic size and high urban development which limit the extent of agricultural and forestry activities, resulting in lower emissions from this sector.

Figure 3: Total GHG emissions by IPCC sectors (Gg CO_2 eq)

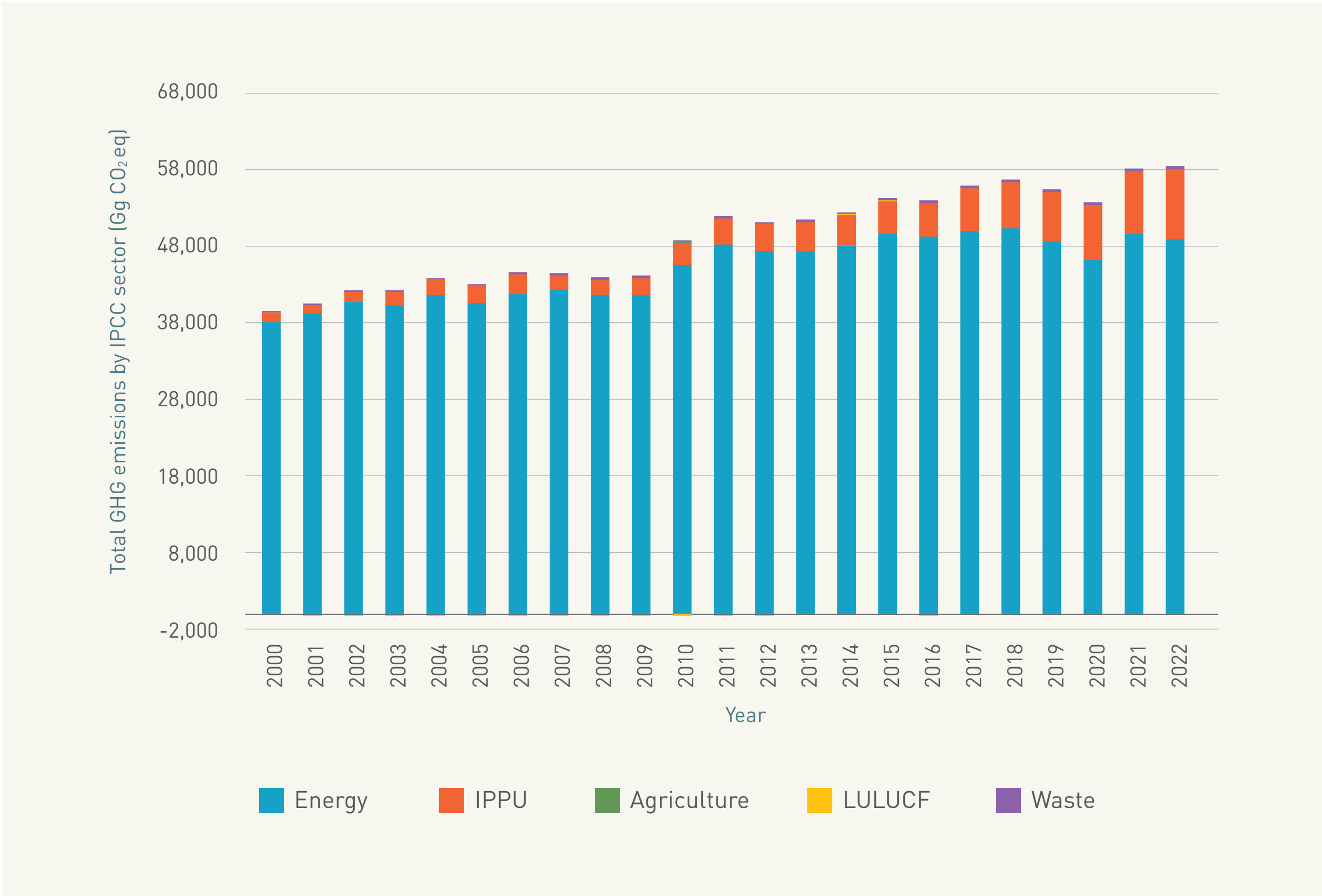


Table 3: Total GHG emissions by IPCC sectors (Gg CO_2 eq)

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Energy[2]	38,273	39,365	40,859	40,386	41,812	40,634	41,801	42,390	41,735	41,778	45,640
IPPU	1,199	1,055	1,272	1,747	1,899	2,366	2,635	1,877	2,091	2,234	3,004
Agriculture	7	7	7	6	6	6	6	6	6	6	6
LULUCF	2	-73	-30	-55	-65	-120	-82	-77	-43	-41	-63
Waste	214	225	228	234	240	222	265	273	282	263	309

Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Energy[2]	48,362	47,514	47,514	48,154	49,759	49,435	50,242	50,507	48,686	46,398	49,762	49,068
IPPU	3,434	3,524	3,797	4,149	4,279	4,394	5,441	6,013	6,569	7,135	8,153	9,088
Agriculture	7	7	8	7	7	7	7	7	8	8	8	8
LULUCF	-37	-63	1	17	85	-34	5	10	16	24	31	38
Waste	334	278	272	284	282	341	360	306	304	306	330	384

[2] Emissions from incineration of Municipal Solid Waste (MSW) and sludge have been included under the Energy sector.

ES.4. Other Information

Emissions of precursors such as carbon monoxide (CO), nitrogen oxides (NOx), non-methane volatile organic compounds (NMVOCs) and other gases such as sulphur dioxide (SO_2) are not included in the inventory. The levels of these gases in the air are currently monitored by a network of ambient air quality monitoring stations. CO, NOx and SO_2 are considered air pollutants and are regulated under the Environmental Protection and Management Act (EPMA) which stipulates emission standards for these pollutants. Strict enforcement programmes and air quality monitoring have helped to ensure that the emissions of all these precursors are minimised and that air quality remains good.

ES.5. Key Category Analysis

A key category analysis (KCA) is conducted for the GHG inventory to identify major sources of GHG emissions; so that the resources available for inventory preparation are prioritised to improve GHG emissions estimates for those major sources.

The KCA is performed for emission sources, in terms of CO_2 equivalent (CO_2 eq) emissions. Key categories are identified using the Approach 1 level assessment and trend assessment from the 2006 IPCC Guidelines, whose emissions when summed in descending order of magnitude add up to 95% of the total GHG emissions.

In 2022, 13 sources were identified as key categories under the level assessment and eight sources were identified as key categories under the trend assessment.

The categories with the greatest influence at the national level are:

- Fuel combustion - Energy Industries - Gaseous Fuels, CO_2
- Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels, CO_2
- Road Transportation - Liquid Fuels, CO_2
- Fuel combustion - Manufacturing Industries and Construction - Gaseous Fuels, CO_2
- Refrigeration and Air conditioning, HFCs

The categories with the greatest influence on the national trend are:

- Fuel combustion - Energy Industries - Liquid Fuels, CO_2
- Fuel combustion - Energy Industries - Gaseous Fuels, CO_2
- RAC - HFCs
- Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels, CO_2
- Road Transportation - Liquid Fuels, CO_2

Details and full results of the key category assessments can be found in Section 1.4. Brief description of key categories and Annex I.

ES.6. Improvements Introduced

In support of continual improvement in reporting and transparency, a national inventory improvement plan (NIIP) was implemented in 2023 in consultation with government agencies, stemming from an in-country Quality Assurance (QA) workshop conducted jointly with the UNFCCC Transparency Division in the same year. The NIIP includes the following sections:

i) Institutional arrangement
ii) Cross-cutting
iii) Energy
iv) IPPU
v) Agriculture
vi) LULUCF
vii) Waste

Each identified area of improvement has been allocated to the responsible agency and prioritised according to low, medium and high. For areas identified as a high priority, these are areas essential for the next NID reporting. Of medium priority are areas useful for the next NID reporting while low priority are areas not required for the next NID reporting.

A summary of the number of areas of improvement required can be found in Table 4 below and further details of the NIIP can be found in Section 8.4. Areas of improvement and/or capacity-building in response to the review process.

Table 4: Areas of improvement identified and prioritised

Area of improvement	Priority level			Total
	High	Medium	Low	
Institutional arrangement	1	6	2	9
Cross-cutting	28	8	7	43
Energy	21	22	23	66
IPPU	13	6	11	30
Agriculture	34	0	8	42
LULUCF	23	0	129	152
Waste	14	6	3	23

Chapter 1

NATIONAL CIRCUMSTANCES, INSTITUTIONAL ARRANGEMENTS AND CROSS-CUTTING INFORMATION

1.1. Background Information on GHG Inventories and Climate Change

This NID details Singapore's GHG Inventory, containing information on anthropogenic emissions and removals by sinks of GHGs from year 2000 to 2022 in accordance with the modalities, procedures and guidelines (MPGs) included in the annex to decision 18/CMA.1 under the ETF referred to in Article 13 of the Paris Agreement.

Methodology Used

Singapore estimated its emissions based on the 2006 IPCC Guidelines for National GHG Inventories, primarily using Tier 1 methodology. Higher tier methodologies and country/plant-specific emission factors were used for specific categories. The LULUCF sector emissions were obtained using Tier 2 and Tier 3 methodologies. With the 2006 IPCC Guidelines applied, it improves the transparency, accuracy, completeness, consistency and comparability (TACCC) of the national GHG inventory.

Global Warming Potential (GWP)

The estimated CH_4, N_2O, HFCs, PFCs, SF_6 and NF_3 emissions were converted to CO_2 eq using the 100-year time-horizon GWP values from the IPCC 5th Assessment Report (AR5), as presented in Table 5.

Table 5: 100-year time-horizon GWP values from the IPCC AR5

Greenhouse Gas	Chemical Formula	GWP
Carbon dioxide	CO_2	1
Methane	CH_4	28
Nitrous oxide	N_2O	265
HFC-125	CHF_2CF_3	3,170
HFC-134	CHF_2CHF_2	1,120
HFC-134a	CH_2FCF_3	1,300
HFC-143a	CH_3CF_3	4,800
HFC-152a	CH_3CHF_2	138
HFC-227ea	CF_3CHFCF_3	3,350
HFC-23	CHF_3	12,400
HFC-236ea	CHF_2CHFCF_3	1,330
HFC-236fa	$CF_3CH_2CF_3$	8,060
HFC-245fa	$CHF_2CH_2CF_3$	858
HFC-32	CH_2F_2	677
HFC-365mfc	$CH_3CF_2CH_2CF_3$	804
HFC-41	CH_3F	116
HFC-43-10mee	$CF_3CHFCHFCF_2CF_3$	1,650
PFC-116	C_2F_6	11,100
PFC-14	CF_4	6,630
PFC-218	C_3F_8	8,900
PFC-318	c-C_4F_8	9,540
Sulphur hexafluoride	SF_6	23,500
Nitrogen trifluoride	NF_3	16,100

Singapore's Actions to Fight Climate Change

Singapore has taken several actions to address climate change. Some of these actions include:

1. Mitigation Efforts
Singapore has since committed, as our NDC, to reduce emissions to around 60 Mt CO2 eq in 2030 after peaking emissions earlier. Singapore also raised our national climate target to achieve net zero emissions by 2050 as part of our Long-Term Low-Emissions Development Strategy (LEDS). This involves implementing measures to improve energy efficiency, increase the adoption of renewable energy sources and promote sustainable transportation.

2. Climate Resilience
The country has been enhancing its infrastructure to be more resilient to the impacts of climate change, such as rising sea levels and extreme weather events. This includes measures like coastal protection, drainage improvements and the development of climate-resilient buildings.

3. International Collaboration
Singapore actively participates in international climate change negotiations and agreements, including the Paris Agreement. Furthermore, Singapore engages in discussions on global climate action and contributes to the international effort to address climate change.

4. Research and Innovation
Singapore invests in research and development of clean energy technologies, sustainable urban solutions and climate adaptation strategies. This includes initiatives to promote green buildings, sustainable water management and the development of low-carbon technologies.

5. Public Awareness and Education
The government has been actively raising public awareness about climate change and promoting sustainable practices among its citizens. This includes educational campaigns, community outreach programmes and initiatives to encourage sustainable living.

These are just a few examples of Singapore's actions to address climate change, and Singapore continues to explore new strategies and initiatives to mitigate and adapt to the impacts of climate change.

1.2.

A Description of National Circumstances and Institutional Arrangements

Historically, our strategic geographical position along the East-West trade routes made Singapore a natural location for regional trade. Today, building on our position as a key regional port, much international trade takes place here and we continue to supply critical products from oil refining and petrochemical plants to the world. While the sector is a large source of our carbon emissions, it also employs a sizeable workforce. As such we are carefully managing the sector's transition. We have started work on improving energy efficiency across the sector and will continue to push for further reductions in the sector's emissions.

Singapore is committed to doing our part in the global fight against climate change. We will continue to build on a long-standing and comprehensive national approach that seeks to achieve sustainable growth alongside environmental protection. As we work towards a low-carbon future, the extent of emissions reduction from our climate strategy will depend on our national circumstances, past mitigation efforts and geographical constraints which limit our access to renewable energy at scale.

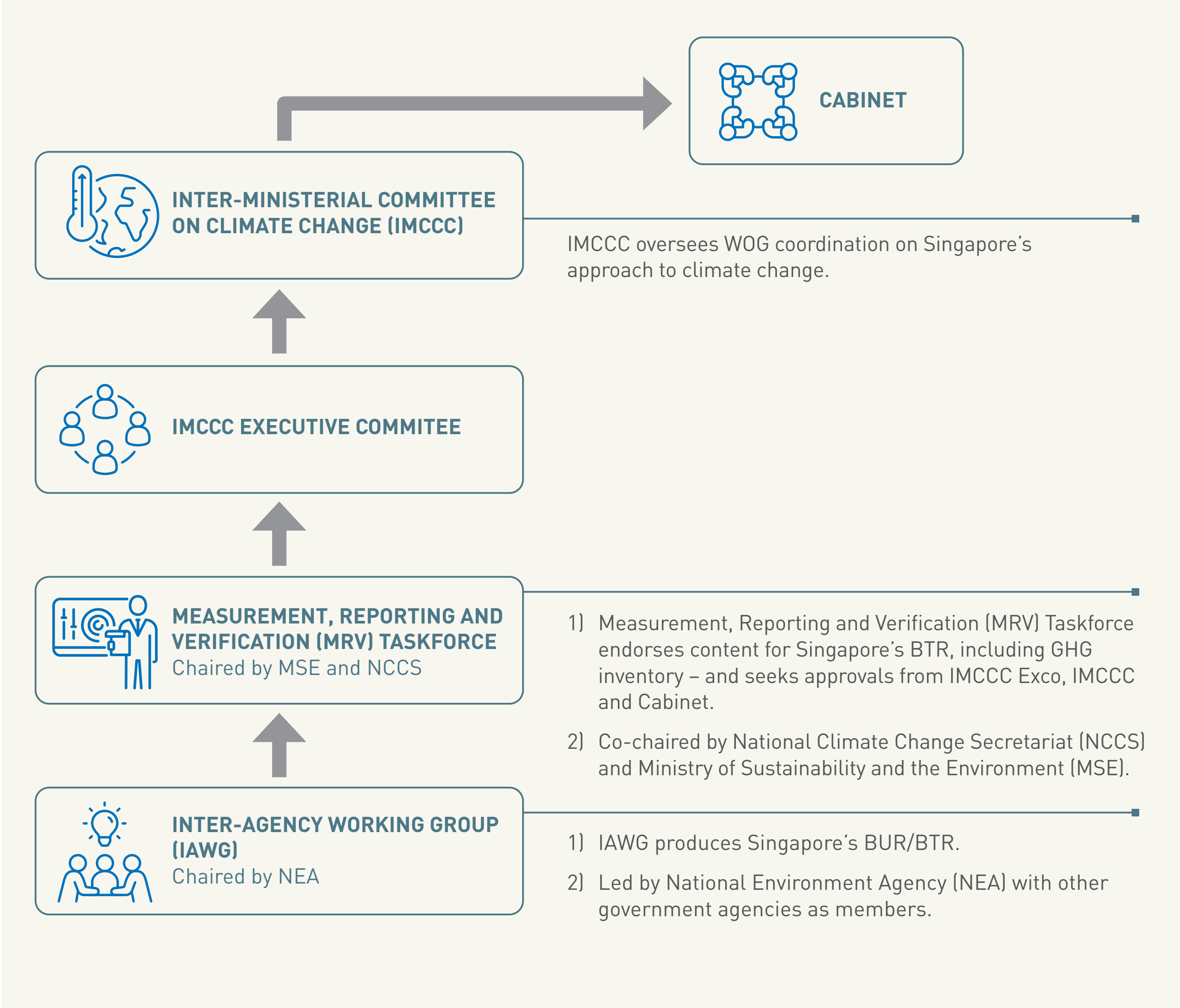
1.2.1. National Entity or National Focal Point

The Inter-Ministerial Committee on Climate Change (IMCCC) oversees the Whole-Of-Government (WOG) coordination on climate change policies to ensure that Singapore is prepared to address climate change. Established in 2007, the IMCCC is chaired by Mr Teo Chee Hean, Senior Minister and Coordinating Minister for National Security, and includes the Ministers from the following Ministries: Sustainability and the Environment, Finance, Foreign Affairs, National Development, Trade and Industry as well as Transport.

To ensure the effective coordination of Singapore's domestic and international policies, plans and actions on climate change, the National Climate Change Secretariat (NCCS) was established as a dedicated unit in July 2010 under the Prime Minister's Office (PMO). NCCS is part of the Strategy Group which supports the Prime Minister and his Cabinet to establish priorities and strengthen strategic alignment across the Government. The positioning of NCCS underscores the importance that Singapore places on climate change.

The preparation of the national GHG inventory is a multi-agency effort led by the NEA, which also chairs the inter-agency working group (IAWG) that produces the BTR, NC and NID. The IAWG submits the finalised BTR and NID to the MRV Taskforce (MRV-TF) Co-Chairs for approval. MRV-TF would then seek approval from the IMCCC Executive Committee before tabling at the Cabinet as shown in Figure 4 below. The approved report would then be submitted to the UNFCCC Secretariat.

Figure 4: BTR/NID preparation process



1.2.2. Inventory Preparation Process

In a typical inventory preparation process, the key steps are to:

i) Define the scope and boundaries of the GHG inventory, including the sectors, gases and sources to be included and the government agencies that are responsible for each source. This involves establishing the inventory year, geographical coverage and the level of detail for the inventory which is based on the 2006 IPCC Guidelines.

ii) Identify the areas for improvement in the inventory preparation process through the QA/QC process or the technical expert review (TER). Thereafter, to incorporate it as part of the work plan such as in the NIIP. In an effort to continuously improve the inventory preparation process, Singapore also actively participates in capacity-building activities.

i) Gather relevant activity data on energy, industrial processes, agriculture, LULUCF and waste sector through legislation and surveys conducted by the respective government agencies. This involves collaborating with various stakeholders, including government agencies, industries and research institutions.

ii) Identify and select appropriate emission factors for different sources of GHG emissions. Emission factors are used to convert activity data into emissions estimates. If country-specific or plant-specific emission factors are not available, default emission factors from 2006 IPCC Guidelines or other international guidelines will be used.

i) Compile the calculated GHG emissions data into the national GHG inventory report. The report includes detailed information on the methodology, assumptions and uncertainties associated with the emissions estimates, following the reporting guidelines provided by the UNFCCC.

ii) Implement QA process by personnel who are not directly engaged in the compilation or development of the inventory after the implementation of QC procedures on a completed inventory to ensure that the inventory reflects accurate estimates of emissions and removals and to validate the effectiveness of the QC process.

iii) Endorse the national GHG inventory prior to submission to UNFCCC.

i) Use the collected data and emission factors to calculate and estimate GHG emissions for each relevant emission source. This involves using specific calculation methodologies and tools recommended by IPCC guidelines or other international standards if it is not available in the IPCC Guidelines. Recalculation is conducted to ensure time series consistency.

ii) Assess and uphold the quality of a GHG inventory through the QC process. QC is carried out by the personnel responsible for compiling the emissions stream during its compilation by conducting regular checks and identifying errors and omissions in the inventory to ensure the accuracy and completeness of data.

These steps are essential for the development of a robust and reliable GHG inventory, providing a foundation for informed decision-making and effective climate action in line with international standards and commitments.

1.2.3. Archiving of Information

An Emissions Data Monitoring and Analysis (EDMA) system has been designed for efficient electronic data management and archival of all data used in the estimation of emissions to ensure the continuity and security of the national GHG inventory. The data management functions of the system include archival and storage of past activity data and emission factors, archival and storage of data source descriptions, methodology descriptions and reference materials and one-stop integrated access to the documentation of data sources, methodology descriptions and reference materials.

Data documentation is a crucial process in maintaining the longevity of the GHG preparation as it provides a starting point for subsequent inventory compilation by future officers. In addition to ensuring proper data management in the system, digital copies of data and information used for the compilation of Singapore's GHG inventory are also timestamped and properly documented into their respective prescribed folders with each file named according to the inventory year. Email exchanges to obtain and clarify information are periodically saved and archived in electronic media such as a hard disk for ease of future reference.

Printed versions of historical datasets where digital copies were not available in the earlier years are filed in a physical storage location.

1.2.4. Processes for Official Consideration and Approval of Inventory

As part of our institutional arrangements, the national GHG inventory compiled by the NEA (with inputs from respective agencies) and the quality control and quality assurance (QC / QA) procedures conducted by agencies will be reviewed by officers from the MRV-TF for endorsement.

1.3. Brief General Description of Methodologies (Including Tiers Used) and Data Sources Used

2006 IPCC Guidelines

Singapore's emissions were estimated according to the 2006 IPCC Guidelines for National GHG Inventories. Emissions estimates were based on the sectoral approach. Most emissions estimates were derived using the Tier 1 methodology provided in the 2006 IPCC Guidelines. Where default conversion and emission factors were used, they were taken from the 2006 IPCC Guidelines as well, unless otherwise stated.

Higher tier methodology was used where data were available. Specifically, higher tiers and country/plant-specific emission factors were used for estimating fugitive emissions from oil and natural gas, emissions from some categories of IPPU, CH_4 emissions from solid waste disposal and CO_2 emissions from the incineration of solid waste.

Emissions from the LULUCF sector were also obtained mainly from using Tier 2 and Tier 3 methodologies based on the 2006 IPCC Guidelines and the 2013 Supplement to the 2006 IPCC Guidelines: Wetlands (Wetlands Supplement), where applicable.

IPCC Good Practice Guidance

The CO_2 emissions from hazardous waste incineration were estimated using Tier 1 methodology from the 2006 IPCC Guidelines, with default emission factors from the IPCC Good Practice Guidance due to unavailable factors in the 2006 IPCC Guidelines.

In addition, the IPCC Good Practice Guidance and Uncertainty Management in National GHG Inventories were applied to improve the TACCC in the national GHG inventory of emissions estimates.

The methods applied and emission factors used for each category can be found in the relevant sections of the chapters while the overview can be found in Annex V.

Table 6 below shows the roles and responsibilities of each entity in the inventory preparation process.

Table 6: Data Sources and Data Owners for the GHG Inventory

SOURCE OF DATA FOR GHG INVENTORY		
IPCC Sector	**Type of GHG**	**Data Owner**
1 - ENERGY		
1.A. - Fuel Combustion Activities		
1.A.1. Energy industries	CO_2, CH_4, N_2O	Energy Market Authority National Environment Agency PUB, Singapore's National Water Agency
1.A.2. Manufacturing industries and construction		National Environment Agency Energy Market Authority
1.A.3. Transport		Civil Aviation Authority of Singapore National Environment Agency Energy Market Authority Maritime and Port Authority of Singapore
1.A.4. Other sectors		Energy Market Authority Department of Statistics
1.A.5. Other (Not specified elsewhere)		Ministry of Defence
1.B. - Oil, natural gas and other emissions from energy production	CO_2, CH_4, N_2O	National Environment Agency
2 - INDUSTRIAL PROCESSES AND PRODUCT USE		
2.B. Chemical industry	CO_2, CH_4, N_2O	National Environment Agency
2.C. Metal industry	CO_2, CH_4	National Environment Agency
2.D. Non-energy products from fuels and solvent use	CO_2, CH_4, N_2O	National Environment Agency
2.E. Electronics industry	CO_2, N_2O, CH_4, HFCs, PFCs, SF_6, NF_3	National Environment Agency
2.F. Product uses as substitutes for ODS		
2.F.1. Refrigeration and air-conditioning	HFCs	National Environment Agency Department of Statistics Land Transport Authority
2.F.2. Foam blowing agents		National Environment Agency
2.F.3. Fire protection		National Environment Agency Singapore Civil Defence Force
2.F.4. Aerosols		National Environment Agency Health Sciences Authority
2.F.5. Solvents		National Environment Agency
2.G. Other product manufacture and use	SF_6	National Environment Agency
2.H. Other	CO_2, CH_4, N_2O	National Environment Agency
3 - AGRICULTURE	CO_2, CH_4, N_2O	Singapore Food Agency
4 - LAND USE, LAND-USE CHANGE AND FORESTRY	CO_2, N_2O	National Parks Board
5 - WASTE		
5.A. Solid waste disposal	CH_4	PUB, Singapore's National Water Agency
5.C. Incineration and open burning of waste	CO_2, CH_4, N_2O	National Environment Agency
5.D. Wastewater treatment and discharge	CH_4, N_2O	PUB, Singapore's National Water Agency

1.4. Brief Description of Key Categories

A key category is an emission stream that is prioritised within the national inventory system because its estimate has a significant influence on a country's total GHG inventory. There are three important aspects where special consideration for key categories should be taken into account.

1. Identification of key categories allows limited resources available for inventory preparation to be prioritised, that is, to improve data and methods for these key categories.
2. Derivation of higher tier (Tier 2 and 3) methods. In cases where data for Tier 2 and 3 are not available, Tier 1 approach can be used and should be clearly documented in the methodological choice.
3. Additional attention could be given to QA/QC process for key categories.

There are two approaches to identify key categories, that is, Approach 1 and Approach 2. In Approach 1, key categories are identified using pre-determined cumulative emissions threshold[3]. In Approach 2, categories are sorted according to their contribution to uncertainty and the results of Approach 2 are additional to Approach 1. It is encouraged to use Approach 2 in addition to Approach 1 for further insights into reasons why particular categories are key and to prioritise activities to improve inventory quality and reduce overall uncertainty. Both approaches used level and trend assessment to identify the key categories. While level assessment identifies the top 95% of categories by its emissions, trend assessment identifies categories whose trend is significantly different from the trend of the overall inventory which may not be identified by level assessment. Currently, Singapore uses Approach 1 for both level and trend assessment to identify the key categories for the starting year and latest reporting year, that is, year 2000 and 2022 by implementing a KCA consistent with 2006 IPCC Guidelines. The key categories identified in Table 7 to 12 are performed with and without LULUCF for Year 2000 and 2022 using Approach 1 level and trend assessment. For key categories that had been identified and Tier 1 methods had been used, efforts to use higher tier will be prioritised.

Level Assessment

In 2000, there were five key categories identified and the number of key categories increased to 13 in 2022, for both level assessment with and without LULUCF. All key categories identified were from the Energy and IPPU sector. Of the 13 key categories identified in 2022, eight key categories originate from fuel combustion activities which primarily produce CO_2 emissions. The main contributor to Singapore's 2022 GHG inventory is CO_2 emissions from the combustion of gaseous fuels (30.6% with LULUCF) from energy industries. The other five key categories identified are HFCs, PFCs and NF_3 from the RAC and Electronics Industry category.

[3] Key categories are those that, when summed together in descending order of magnitude, add up to 95 percent of the total level.

Table 7: Level Assessment with LULUCF (Year 2000)

IPCC Code	IPCC Category	Greenhouse Gas	Emissions (Gg CO_2 eq)	Percentage Contribution	Cumulative Total
1.A.1.	Fuel combustion - Energy Industries - Liquid Fuels	CO_2	17,178	43.06%	43.06%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	CO_2	10,397	26.06%	69.13%
1.A.3.b.	Road Transportation	CO_2	5,628	14.11%	83.23%
1.A.2.	Fuel combustion - Energy Industries - Gaseous Fuels	CO_2	2,767	6.94%	90.17%
1.A.1.	Fuel combustion - Energy Industries - Other Fossil Fuels	CO_2	849	2.13%	92.30%
2.E.	Electronics Industry	PFCs	764	1.92%	94.21%
1.A.4.	Other Sectors - Liquid Fuels	CO_2	367	0.92%	95.13%

Table 8: Level Assessment without LULUCF (Year 2000)

IPCC Code	IPCC Category	Greenhouse Gas	Emissions (Gg CO_2 eq)	Percentage Contribution	Cumulative Total
1.A.1.	Fuel combustion - Energy Industries - Liquid Fuels	CO_2	17,178	43.32%	43.32%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	CO_2	10,397	26.22%	69.53%
1.A.3.b.	Road Transportation	CO_2	5,628	14.19%	83.72%
1.A.2.	Fuel combustion - Energy Industries - Gaseous Fuels	CO_2	2,767	6.98%	90.70%
1.A.1.	Fuel combustion - Energy Industries - Other Fossil Fuels	CO_2	849	2.14%	92.84%
2.E.	Electronics Industry	PFCs	764	1.93%	94.77%
1.A.4.	Other Sectors - Liquid Fuels	CO_2	367	0.93%	95.69%

Table 9: Level Assessment with LULUCF (Year 2022)

IPCC Code	IPCC Category	Greenhouse Gas	Emissions (Gg CO_2 eq)	Percentage Contribution	Cumulative Total
1.A.1.	Fuel combustion - Energy Industries - Gaseous Fuels	CO_2	17,995	30.64%	30.64%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	CO_2	12,695	21.61%	52.25%
1.A.3.b.	Road Transportation	CO_2	6,426	10.94%	63.19%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Gaseous Fuels	CO_2	6,129	10.43%	73.62%
2.F.1.	Refrigeration and air-conditioning	HFCs	3,973	6.76%	80.39%
2.E.	Electronics Industry	PFCs	2,519	4.29%	84.67%
1.A.1.	Fuel combustion - Energy Industries - Liquid Fuels	CO_2	1,732	2.95%	87.62%
1.A.1.	Fuel combustion - Energy Industries - Other Fossil Fuels	CO_2	1,609	2.74%	90.36%
2.B.10.	Other (Total chemical production)	CO_2	815	1.39%	91.75%
2.E.	Electronics Industry	NF_3	645	1.10%	92.85%
1.B.2.c.	Fugitive Emissions from Fuels - Venting and flaring	CO_2	565	0.96%	93.81%
2.B.8.	Petrochemical and Carbon Black Production	CO_2	473	0.81%	94.61%
1.A.3.d.	Domestic Navigation - Liquid Fuels	CO_2	431	0.73%	95.35%

Table 10: Level Assessment without LULUCF (Year 2022)

IPCC Code	IPCC Category	Greenhouse Gas	Emissions (Gg CO_2 eq)	Percentage Contribution	Cumulative Total
1.A.1.	Fuel combustion - Energy Industries - Gaseous Fuels	CO_2	17,995	30.74%	30.74%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	CO_2	12,695	21.68%	52.42%
1.A.3.b.	Road Transportation	CO_2	6,426	10.98%	63.39%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Gaseous Fuels	CO_2	6,129	10.47%	73.86%
2.F.1.	Refrigeration and air-conditioning	HFCs	3,973	6.79%	80.65%
2.E.	Electronics Industry	PFCs	2,519	4.30%	84.95%
1.A.1.	Fuel combustion - Energy Industries - Liquid Fuels	CO_2	1,732	2.96%	87.91%
1.A.1.	Fuel combustion - Energy Industries - Other Fossil Fuels	CO_2	1,609	2.75%	90.66%
2.B.10.	Other (Total chemical production)	CO_2	815	1.39%	92.05%
2.E.	Electronics Industry	NF_3	645	1.10%	93.15%
1.B.2.c.	Fugitive Emissions from Fuels - Venting and flaring	CO_2	565	0.96%	94.11%
2.B.8.	Petrochemical and Carbon Black Production	CO_2	473	0.81%	94.92%
1.A.3.d.	Domestic Navigation - Liquid Fuels	CO_2	431	0.74%	95.66%

Trend Assessment

There are eight key categories identified in the trend assessment with the highest percentage contributing to the increase in 1.A.1. Fuel combustion of liquid fuels in energy industries (46.2% with LULUCF), followed by the increase in fuel combustion of gaseous fuels from energy industries (27.3% with LULUCF). While this category was not identified in the level assessment, it had been identified as a key category in trend assessment due to its high percentage contribution. All key categories identified were from the Energy and IPPU sector. With the inclusion of HFC emissions from RAC following the completion of the study, the contribution to the increase to trend assessment (with LULUCF) rose from 0.7% in year 2018 to 7.4% in year 2022.

Table 11: Trend Assessment with LULUCF

IPCC Code	IPCC Category	Greenhouse Gas	Y2000 Emissions (Gg CO_2 eq)	Y2022 Emissions (Gg CO_2 eq)	Trend Assessment	Percentage contribution to trend assessment	Cumulative Total
1.A.1.	Fuel combustion - Energy Industries - Liquid Fuels	CO_2	17,178	1,732	0.59	46.22%	46.22%
1.A.1.	Fuel combustion - Energy Industries - Gaseous Fuels	CO_2	2,767	17,995	0.35	27.31%	73.53%
2.F.1.	Refrigeration and air-conditioning	HFCs	137	3,973	0.09	7.40%	80.93%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	CO_2	10,397	12,695	0.07	5.13%	86.06%
1.A.3.b.	Road Transportation	CO_2	5,628	6,426	0.05	3.65%	89.71%
2.E.	Electronics Industry	PFCs	764	2,519	0.03	2.73%	92.45%
2.B.10.	Other (Total chemical production)	CO_2	8.39	815	0.02	1.57%	94.02%
2.E.	Electronics Industry	NF_3	67.57	645	0.01	1.07%	95.09%

Table 12: Trend Assessment without LULUCF

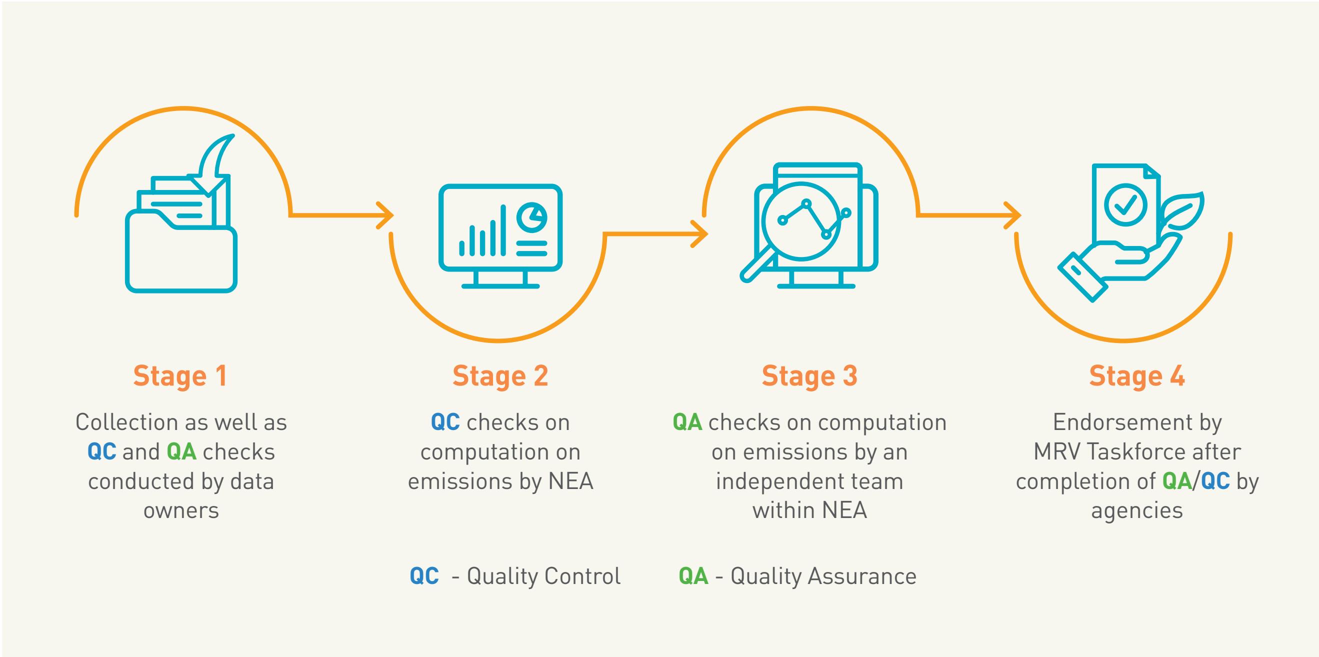
IPCC Code	IPCC Category	Greenhouse Gas	Y2000 Emissions (Gg CO_2 eq)	Y2022 Emissions (Gg CO_2 eq)	Trend Assessment	Percentage contribution to trend assessment	Cumulative Total
1.A.1.	Fuel combustion - Energy Industries - Liquid Fuels	CO_2	17,178	1,732	0.60	46.42%	46.42%
1.A.1.	Fuel combustion - Energy Industries - Gaseous Fuels	CO_2	2,767	17,995	0.35	27.33%	73.75%
2.F.1.	Refrigeration and air-conditioning	HFCs	137	3,973	0.10	7.41%	81.16%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	CO_2	10,397	12,695	0.07	5.22%	86.37%
1.A.3.b.	Road Transportation	CO_2	5,628	6,426	0.05	3.70%	90.07%
2.E.	Electronics Industry	PFCs	764	2,519	0.04	2.73%	92.80%
2.B.10.	Other (Total chemical production)	CO_2	8.39	815	0.02	1.58%	94.38%
2.E.	Electronics Industry	NF_3	67.57	645	0.01	1.07%	95.45%

1.5. Brief General Description of QA/QC Plan and Implementation

Quality control and quality assurance checks for the compilation of data and computation of GHG emissions were developed based on the 2006 IPCC Guidelines for National GHG Inventories. The EDMA system was developed to facilitate the inventory compilation process. The system was designed to receive input and activity data from different data sources, generate emissions estimates, facilitate quality control checks and provide the relevant government agencies with secure access to the emissions database.

An overview of the four-stage QA/QC process for the GHG inventory preparation is shown in Figure 5 below.

Figure 5: Quality Control and Quality Assurance of the national GHG inventory



1 - Quality Control and Quality Assurance for the Collection/Compilation of Data

Data required for the national GHG inventory are collected/compiled through legislation and surveys administered by the various government agencies (data owners).

QC for Data

The quality control checks conducted by the data owners are summarised in Table 13 below.

Table 13: QC Activity by Data Owners

	QC Activity	Actions by Data Owner
Units	Check that parameter units are correctly recorded and that appropriate conversion factors are used.	Analysed and verified data trends for potential unit or conversion errors.
Database	Check that parameter units are correctly recorded and that appropriate conversion factors are used.	Analysed data trends. Highlighted deviations and outliers and verified them for potential data input errors and reference coding errors.
	Check the integrity of database files.	Verified data processed in the database against original data files to ensure consistency and data integrity.
	Check for consistency in data between source categories.	Verified the data mapping tables and files used to ensure that mapping and data consistencies between different source categories are maintained. Data mapping tables adopt Singapore's classification.
	Undertake completeness checks.	Streamlined and aligned data sources used. Included new data streams where applicable.
	Check methodological and data changes resulting in recalculations.	Re-processed updated data in the system and recompiled sub-totals and totals from the updated data. Analysed time series of totals to ensure data quality standards are achieved. Adopted appropriate splicing techniques to ensure a consistent time series.
Compilation	Check that the movement of inventory data among processing steps is correct.	Verified and checked sub-totals against totals when computing aggregated figures.
	Internal documentation.	Conducted regular data compilation reviews and documented these processes. Archived and stored the data in the EDMA system periodically.
Comparison	Compare estimates to previous estimates.	Analysed time series of totals to ensure data quality standards are achieved.

QA for Data

Data collected are verified by an independent team within each agency, which is not involved in the data collection and compilation process. After these QA checks, agencies will submit their QC and QA documentation together with their data to NEA for computation/conversion to GHG emissions.

For facilities that are taxable under the Carbon Pricing Act (CPA), the Emission Report submitted under the Act would have to be verified by an accredited third-party verification company prior to the submission. Detailed information that identifies and describes the facility's GHG emission sources and streams, emissions quantification methods and quality management procedures would be documented in the Monitoring Plan (MP) validated by NEA.

2 - Quality Control for the Computation of Emissions

GHG emissions are computed by the GHG inventory team within NEA based on the activity data provided by agencies. The quality control checks on emissions computed from source data are verified by persons who are not involved in the emissions computation. These procedures help to minimise human errors during inventory compilation and ensure the production of complete, accurate and consistent inventories. The quality control procedures conducted by the GHG inventory team within NEA are summarised in Table 13.

Quality control checks have also been incorporated into the EDMA system. These include checks on the acceptable range of data input and factors, as well as percentage differences compared to emissions from previous years.

3 - Quality Assurance for Computation of Emissions

The QA procedures involve checking of transcription of data between databases, verification of data, emission factors, conversion factors and equations, including checking of congruence of totals and sub-totals.

The computed emissions are verified by an independent NEA team that is not involved in the computation of the GHG emissions. This QA team conducts a review of the inventory compilation process. The review involves the verification of methods, data, processes and assumptions for the preparation of the inventory, and recommendation of areas for improvement as necessary. During the review, needs for institutional strengthening and capacity-building are identified and planned to improve future work on the national GHG inventory. Training is essential for new and existing officers involved in the preparation of the national GHG inventory to attend training programs regularly to continually enhance the national GHG inventory.

4 - Endorsement

An inter-agency working committee (MRV Taskforce) will review the QC and QA procedures conducted by agencies and endorse the national GHG inventory.

1.6. General Uncertainty Assessment, Including Data Pertaining to The Overall Uncertainty of Inventory Totals

Uncertainty Analysis

While Singapore's national GHG inventories are computed in accordance with the TACCC principles, estimates and calculations inevitably carry some uncertainty. Uncertainties in the estimates may stem from systematic and/or random uncertainties arising from the input parameters or estimation modelling. Computing and reducing uncertainties are done through in-depth reviews of estimation models, and improvements to the activity data collection and calculation methods of emission factors and other model variables. According to the 2006 IPCC Guidelines, it is important to note that the main objective of computing and presenting quantitative uncertainty information is to set priorities to facilitate the improvement of inventories and provide a guide on the compilation methods to use. Hence, a quantitative uncertainty analysis of the national GHG inventory was developed based on the 2006 IPCC Guidelines and 2019 Refinement to the 2006 IPCC Guidelines (hereinafter referred to as 2019 Refinement) to prioritise national efforts to reduce inventory uncertainties and guide decisions on methodological choice.

For most CRT sectors of this inventory submission and the aggregation of overall uncertainties, Error Propagation (Approach 1) was implemented using Table 3.2 in the 2006 IPCC Guidelines and the tool provided together with the 2019 Refinement. Monte Carlo Simulation (MCS) (Approach 2) was used for specific CRT sectors of the Inventory, namely Product uses as substitutes for Ozone Depleting Substances (ODS) (Sector 2.F.) and LULUCF (CRT Sector 4). As a developing state with a small land space, LULUCF does not account for a significant portion of the inventory. Therefore, a single uncertainty analysis is provided within this report under Section 6.1.4 Uncertainty Assessment.

Based on the 2006 IPCC Guidelines, uncertainty of the activity data and emission factor inputs are typically represented by a 95 percent confidence interval expressed as a percentage of the point estimate of the input. In this report, when the probability distribution is known to be asymmetrical, the interval is replaced by a symmetrical interval built using the magnitude of the larger of the two percentage uncertainties. The Approach 1 analysis estimates uncertainty by first combining uncertainty from emission factors, activity data and other estimation parameters by category and type of GHG. The combined uncertainty factors are then weighted against the total inventory emissions and the contribution to the overall uncertainty of each sector is quantified and assessed.

The aggregation of overall uncertainties using Approach 1 is estimated using the formula below (IPCC, 2006):

Approach 1 - Error Propagation - Multiplication

$$U_{total} = \sqrt{U_1^2 + \cdots + U_i^2 + \cdots + U_n^2}$$

Where:
U_{total} = the percentage uncertainty in the product of the quantities (half the 95 percent confidence interval divided by the total as a percentage

U_i = the percentage uncertainties associated with each of the quantities and parameters

Approach 1 – Addition and Subtraction

$$U_{total} = \frac{\sqrt{(U_1 + x_1)^2 + (U_2 + x_2)^2 + \cdots + (U_n + x_n)^2}}{|x_1 + x_2 + \cdots + x_n|}$$

Where:

U_{total} = the percentage uncertainty in the product of the quantities (half the 95 percent confidence interval divided by the total as a percentage)

x_i and U_i = the uncertain quantities and the percentage uncertainties associated with them, respectively

Approach 2 – Error Propagation through Monte Carlo Simulation

MCS, or Approach 2, is a numerical simulation method which simulates the behaviour of a random static system where input parameters are defined by a known probability density function. This methodology of estimating uncertainty is catered to the more intricate assessment of uncertainty, especially when the uncertainties are large, follow a non-normal distribution, the algorithms are complex functions and/or the activity data and emission factors are not mutually exclusive. Similarly, the uncertainty is defined as the 95% confidence interval of the probability distribution function.

Unlike Approach 1 where a normal distribution curve is assumed, MCS may require the probability distribution function to be established first before the simulation of the data inputs and parameters. While it may be obtained through different methods including statistical analysis of the data and expert elicitation, for the probability distribution functions used in the MCS to estimate uncertainty in this NID, expert advice was consulted and implemented.

As Approach 2 is only used for a small subset of reporting categories, namely Category 2.F. Product uses as substitutes for ODS and the LULUCF sector, the uncertainty that has been estimated using MCS are combined with the rest of the uncertainty values of the remaining CRT sectors using Approach 1 – Error Propagation (formula as seen above) to develop the overall uncertainty estimate for the national GHG inventory.

Trend Uncertainty

In addition to overall uncertainty stemming from uncertainty from activity data collection and emission factors, uncertainty introduced into the trend in total national emissions is also documented in this report. According to the 2006 IPCC Guidelines, the uncertainty in the trend will be a function of the uncertainties of the emissions in both the base year and current year. As a result, the uncertainty of the trend will be a function of the uncertainties of the activity data and emission factors from the respective years. The trend uncertainty in this report adheres to Approach 1 – Error Propagation. Full correlation between emission factors in the base year and the current year, as well as independence between activity data from the base year and the current year, is assumed to facilitate computation of trend uncertainty.

The trend uncertainty in total emissions in Singapore is estimated using the below formula (IPCC, 2006):

Approach 1 - Trend Uncertainty

$$U_T = \sqrt{\sum_i (U_{Te,i}^2 + U_{Ta,i}^2)}$$

Where:

U_T = uncertainty in the trend in total emissions in Singapore

$U_{Te,i}$ = trend uncertainty introduced by the uncertainty associated with the emission factor of the category/gas i

$U_{Ta,i}$ = trend uncertainty introduced by the uncertainty associated with the activity data of the category/gas i

Uncertainties for the GHG inventory is summarised in the table below, with the detailed uncertainty analysis being presented in Annex II.

Table 14: Summary of uncertainties for GHG inventory by IPCC sectors

Inventory sector	Base year, 2000 emissions/removals (Gg CO_2 eq)	Year t, 2022 emissions/ removals (Gg CO_2 eq)	Contribution to variance by category in year t (%)	Uncertainty introduced into the trend in total national emissions (%)
Energy	38,272.76	49,068.42	6.04	90.09
IPPU	1,199.09	9,088.05	22.15	0.43
Agriculture	7.01	8.04	0.00	0.00
LULUCF	1.97	38.12	0.01	9.29
Waste	213.78	384.19	71.80	0.20
Total	39,694.62	58,586.82	100.00	100.00
			6.89	5.38

1.7. General assessment of completeness

All sources and sinks listed in the common reporting tables as per 2006 IPCC Guidelines have been included in the national GHG inventory. Where data are not available, notation keys such as "NO", "NE", "NA", "IE" and "C" have been used as defined in UNFCCC reporting guidelines (decision 18/CMA.1, annex, paragraph 31). The definition of each notation keys used is as shown below.

(a) "NO" (not occurring) for categories or processes, including recovery, under a particular source or sink category that do not occur within a Party;

(b) "NE"[4] (not estimated) for activity data and/or emissions by sources and removals by sinks of GHGs that have not been estimated but for which a corresponding activity may occur within a Party;

(c) "NA" (not applicable) for activities under a given source/sink category that do occur within the Party but do not result in emissions or removals of a specific gas;

(d) "IE" (included elsewhere) for emissions by sources and removals by sinks of GHGs estimated but included elsewhere in the inventory instead of under the expected source/sink category;

(e) "C" (confidential) for emissions by sources and removals by sinks of GHGs where the reporting would involve the disclosure of confidential information.

For categories reported as NE, these are for activity data and emissions that have not been estimated. As part of the improvement plans, continuous efforts are made particularly to identify activity data and emission factors that are used for computation of emissions for categories that are NE. These details can be found in the individual sector chapters in Chapter 3 to 7 or in CRT Table 9 specifically for NE and IE. NE notation key is also used in the reporting of agriculture sector when the emissions from a category is either below 0.05% of the national GHG emissions, excluding LULUCF, or 500 kt CO_2 eq, whichever is lower.

1.8. Metrics

Singapore is using the 100-year time-horizon GWP values from the IPCC Fifth Assessment Report for the NID as agreed upon by the CMA, and reports aggregate emissions and removals of GHGs expressed in units of CO_2 eq.

1.9. Summary of any Flexibility Applied

In accordance with the UNFCCC MPGs for the ETF (Annex to decision 18/CMA.1), a consistent annual time series starting from 1990 shall be reported. Upon consulting with various stakeholders on the availability of historical data, more time would be required to acquire more data and to assess the appropriate methodology to conduct projection if needed. Hence, the starting year for the time series that is reported in the NID 2024 is from year 2000 to 2022. Efforts were undertaken to enhance the completeness of GHG inventory reporting in this inventory submission for year 2000 to 2022 and we will continue to ensure time series consistency when the inventory time series starting from year 1990 is included in future reports.

[4] As per paragraph 32 of the MPG, "NE" could also be used when emissions from a category should only be considered insignificant if the likely level of emissions is below 0.05 per cent of the national total GHG emissions, excluding LULUCF, or 500 kt CO_2 eq, whichever is lower.

Chapter 2

TRENDS IN GREENHOUSE GAS EMISSIONS AND REMOVALS

2.1. Description of Emissions and Removal Trends for Aggregated GHG Emissions and Removals

The total GHG emissions in 2022 was 58,587 Gg CO_2 eq, an increase of 47% from year 2000 to 2022 as shown in Figure 6. This increase can mainly be attributed to economic growth, leading to increased industrial activities, energy consumption and transportation demands. In particular, Singapore saw significant growth in economic activities in manufacturing, petrochemicals and refining, which contributed to the high percentage of Energy and IPPU sectors in Singapore. The increase in population by 40% from year 2000 to 2022 has also led to a higher demand for goods and services and transportation activities, resulting in higher emissions.

Emissions from the agriculture and LULUCF sectors in Singapore are relatively insignificant since Singapore has limited agricultural land due to its small geographic size and high level of urbanisation. Within the LULUCF sector, the largest source of emissions is from Settlements while the largest sink is from Forest Land.

Waste emissions in comparison is small compared to the emissions in the energy sector. This is mainly due to Waste-to-Energy (WtE) incineration, which limits the release of GHGs from waste disposal, contributing to lower emissions from the waste sector. Furthermore, Singapore currently only has one active landfill containing only non-incinerable wastes and ash, which does not contribute to the landfill emissions in the waste sector.

Figure 6: Total GHG emissions by IPCC sectors (Gg CO_2 eq)

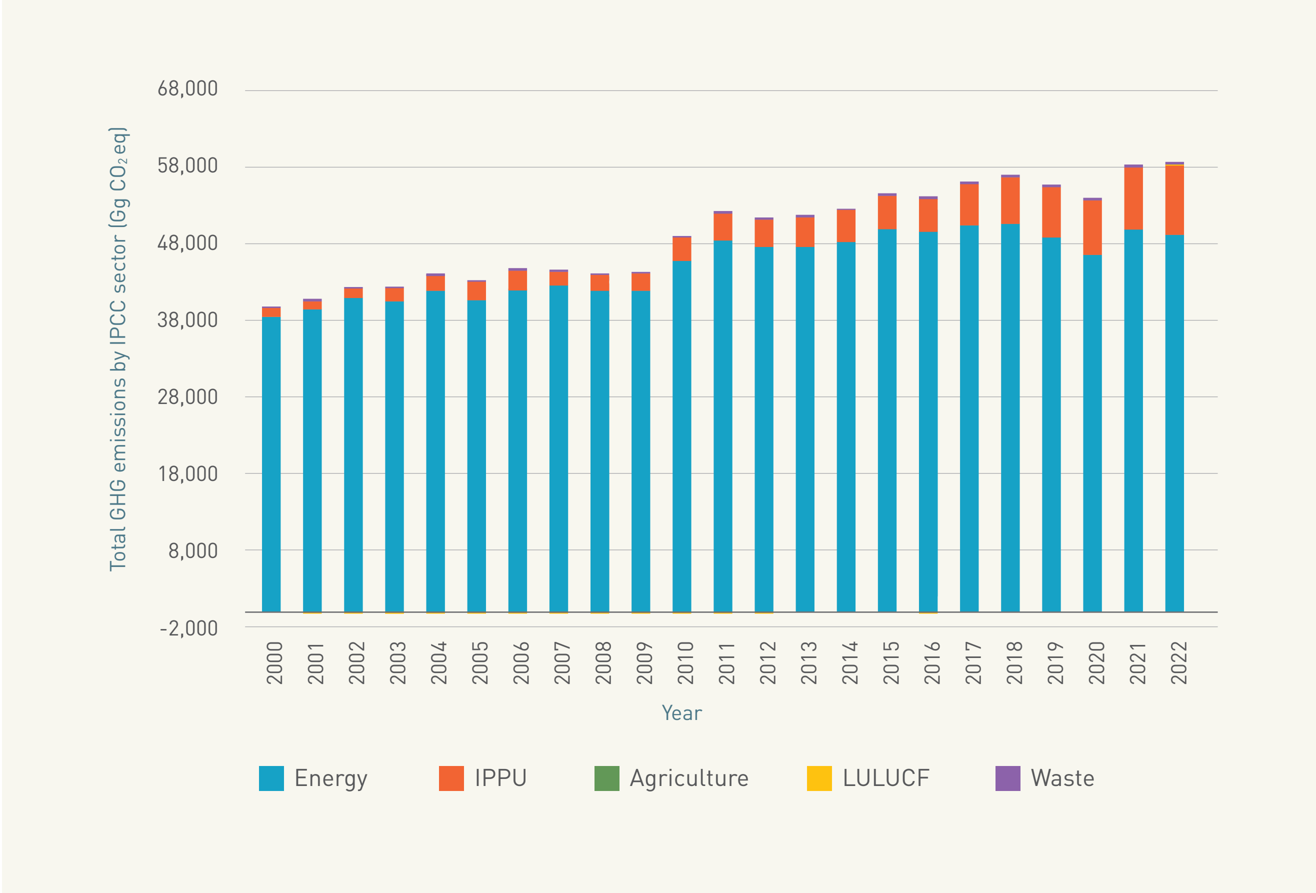


Table 15: Total GHG emissions and emissions by IPCC sectors (Gg CO_2 eq)

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Total with LULUCF (Gg CO_2 eq)	39,695	40,579	42,336	42,319	43,893	43,107	44,625	44,469	44,071	44,240	48,896
Energy[5]	38,273	39,365	40,859	40,386	41,812	40,634	41,801	42,390	41,735	41,778	45,640
IPPU	1,199	1,055	1,272	1,747	1,899	2,366	2,635	1,877	2,091	2,234	3,004
Agriculture	7	7	7	6	6	6	6	6	6	6	6
LULUCF	2	-73	-30	-55	-65	-120	-82	-77	-43	-41	-63
Waste	214	225	228	234	240	222	265	273	282	263	309

Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Total with LULUCF (Gg CO_2 eq)	52,100	51,260	51,592	52,611	54,412	54,143	56,056	56,843	55,583	53,872	58,285	58,587
Energy[5]	48,362	47,514	47,514	48,154	49,759	49,435	50,242	50,507	48,686	46,398	49,762	49,068
IPPU	3,434	3,524	3,797	4,149	4,279	4,394	5,441	6,013	6,569	7,135	8,153	9,088
Agriculture	7	7	8	7	7	7	7	7	8	8	8	8
LULUCF	-37	-63	1	17	85	-34	5	10	16	24	31	38
Waste	334	278	272	284	282	341	360	306	304	306	330	384

[5] Emissions from incineration of waste and incineration of sludge have been included.

2.2.

Description of Emissions and Removal Trends by Sector and by Gas

Emissions Trends by Sectors

Energy Sector

There was a drop in emissions from 48,686 Gg CO_2 eq in 2019 to 46,398 Gg CO_2 eq in 2020, mainly due to the impact of COVID-19 pandemic which led to a significant slowdown in economic activities, reduced industrial production, and decreased energy demand. Thereafter, emissions returned to around pre-pandemic levels driven by increased energy demand from the recovery of economic and industrial activities.

Figure 7: Total GHG emissions from Energy sector (Gg CO_2 eq)

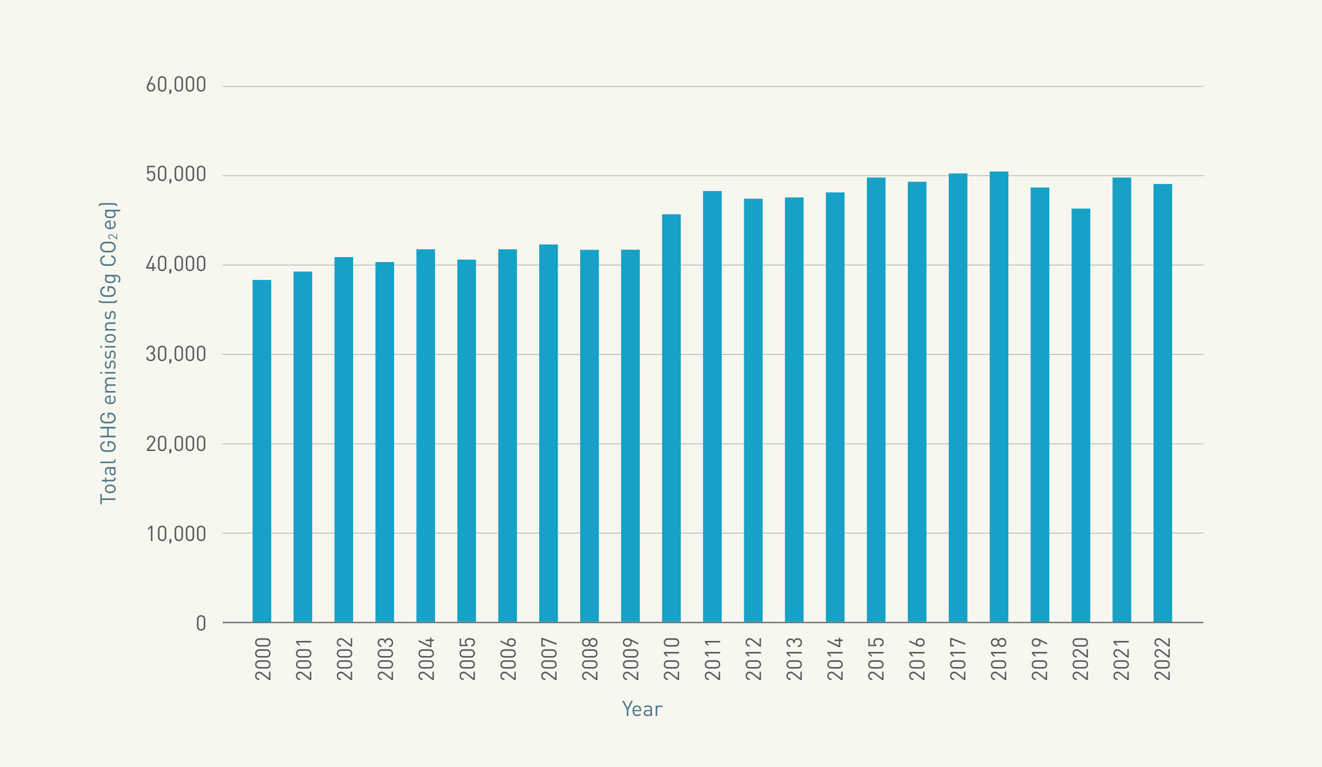


Table 16: Total GHG emissions from Energy sector (Gg CO_2 eq)

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Energy[6]	38,273	39,365	40,859	40,386	41,812	40,634	41,801	42,390	41,735	41,778	45,640

Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Energy[6]	48,362	47,514	47,514	48,154	49,759	49,435	50,242	50,507	48,686	46,398	49,762	49,068

[6] Emissions from incineration of MSW and sludge have been included in the Energy Sector.

IPPU Sector

Data from IPPU sector were only available under the Energy Conservation Act (ECA) from 2013 onwards and from Carbon Pricing Act (CPA) from 2019 onwards. Voluntary surveys were conducted prior to the implementation of the regulations. Hence, the emissions trend prior to 2013 may be vastly different. It would be more representative to compare the trend from 2013 to 2022 instead which shows a significant increase of 139% in emissions from 3,797 Gg CO_2 eq in 2013 to 9,088 Gg CO_2 eq in 2022 in Figure 8 below. The significant increase in emissions from IPPU sector from 2017 to 2022 is mainly due to the increase in emissions from RAC sector and Electronics industry.

Figure 8: Total GHG emissions from IPPU sector (Gg CO_2 eq)

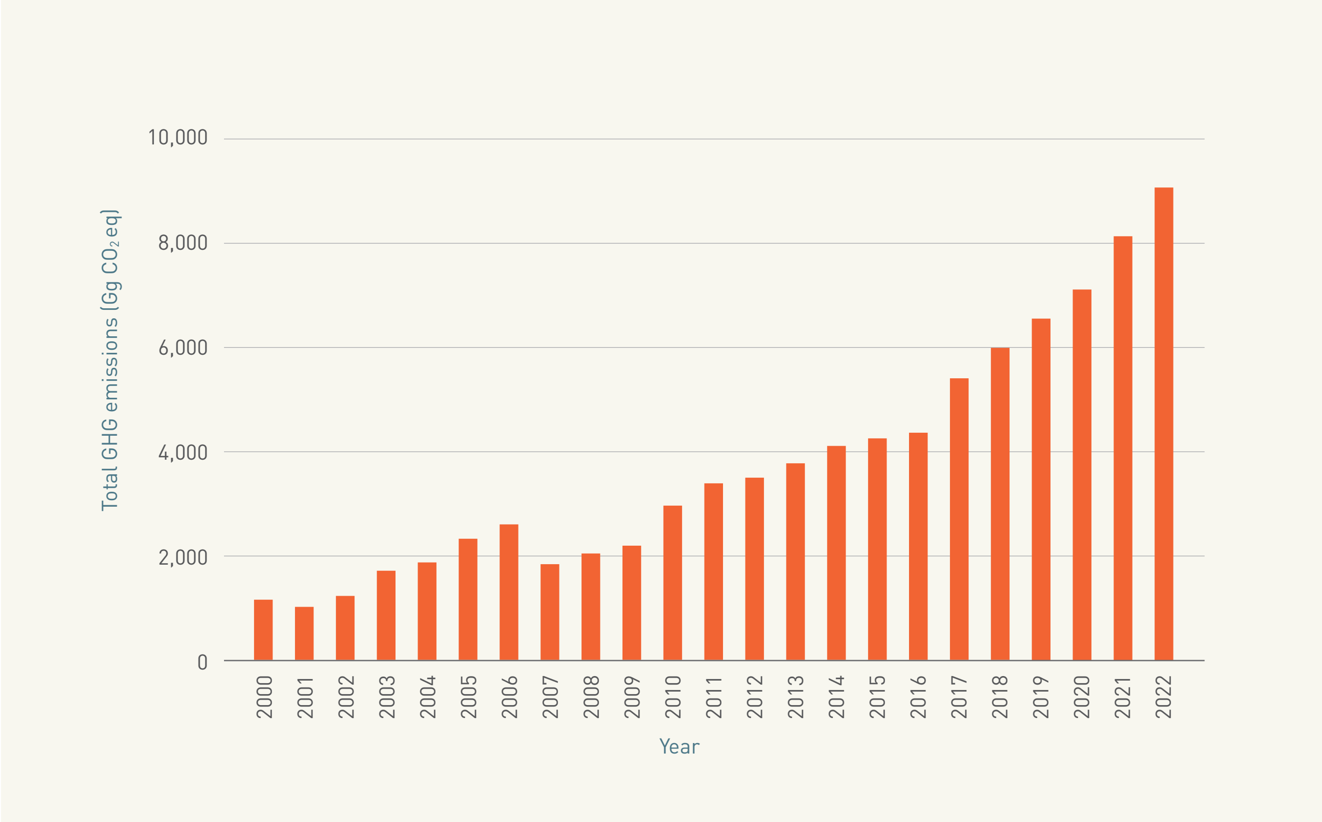


Table 17: Total GHG emissions from IPPU sector (Gg CO_2 eq)

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
IPPU	1,199	1,055	1,272	1,747	1,899	2,366	2,635	1,877	2,091	2,234	3,004

Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
IPPU	3,434	3,524	3,797	4,149	4,279	4,394	5,441	6,013	6,569	7,135	8,153	9,088

Agriculture

Agriculture GHG emissions have remained roughly constant across the time series.

Figure 9: Total GHG emissions from Agriculture sector (Gg CO_2 eq)

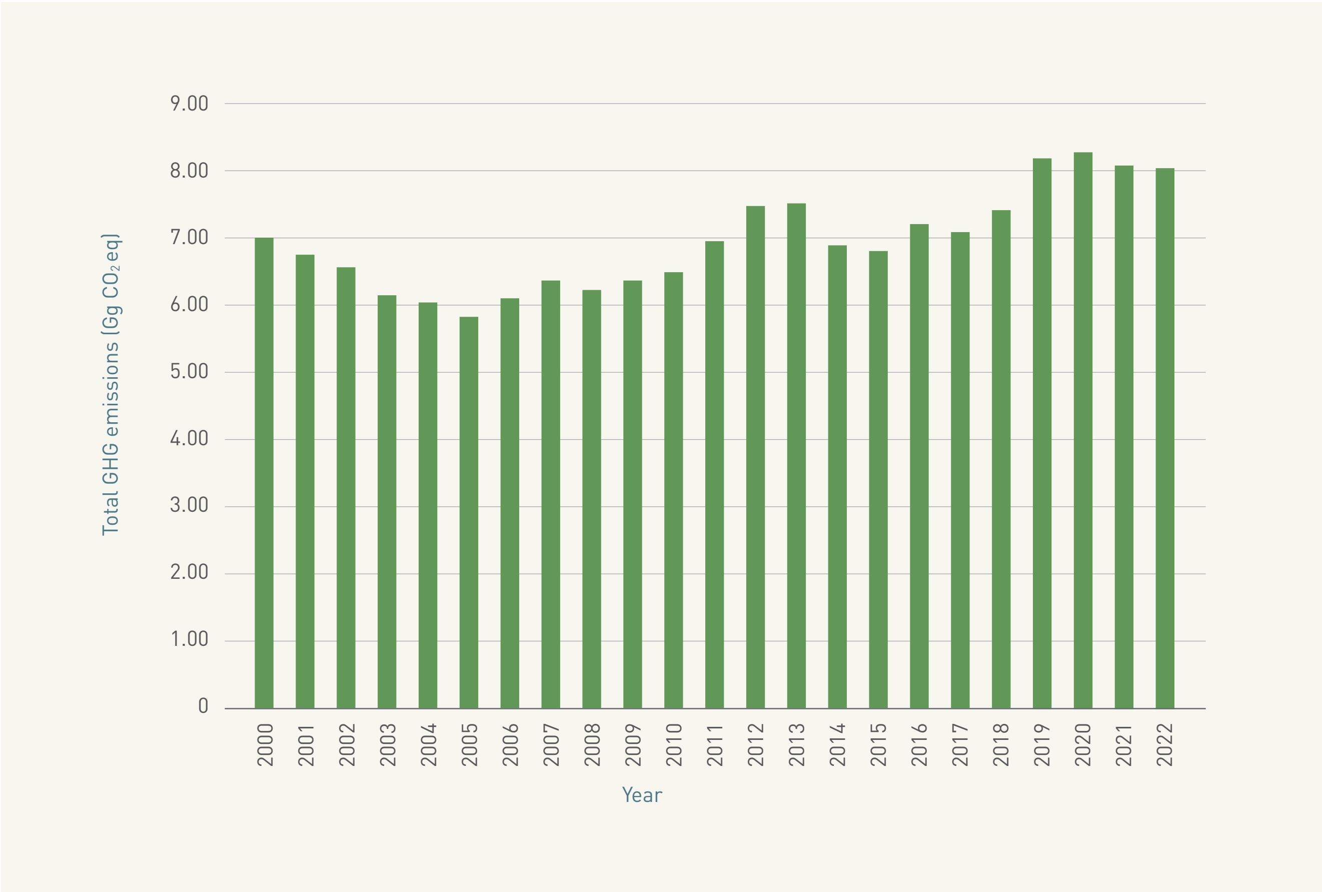


Table 18: Total GHG emissions from Agriculture sector (Gg CO_2 eq)

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Agriculture	7.01	6.75	6.55	6.15	6.04	5.83	6.10	6.37	6.21	6.36	6.50

Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Agriculture	6.95	7.47	7.50	6.89	6.81	7.21	7.07	7.41	8.18	8.27	8.08	8.04

LULUCF

The trend of the LULUCF sector shows strong variations in the time series. These figures reflect the dynamics of the land-use sector in Singapore, which is mainly driven by land-use conversions and related net losses of biomass within the *Settlements* subcategories, as well as land-use changes between *Forest Land* and *Settlements* due to infrastructure construction. The *Forest Land* category represents a sink across the time series. In the last few years, the sector has been a net source mainly due to higher conversions from *Forest Land* to *Settlements* and higher net losses of tree crown cover within the *Settlements* category.

Figure 10: Total GHG emissions from LULUCF sector (Gg CO_2 eq)

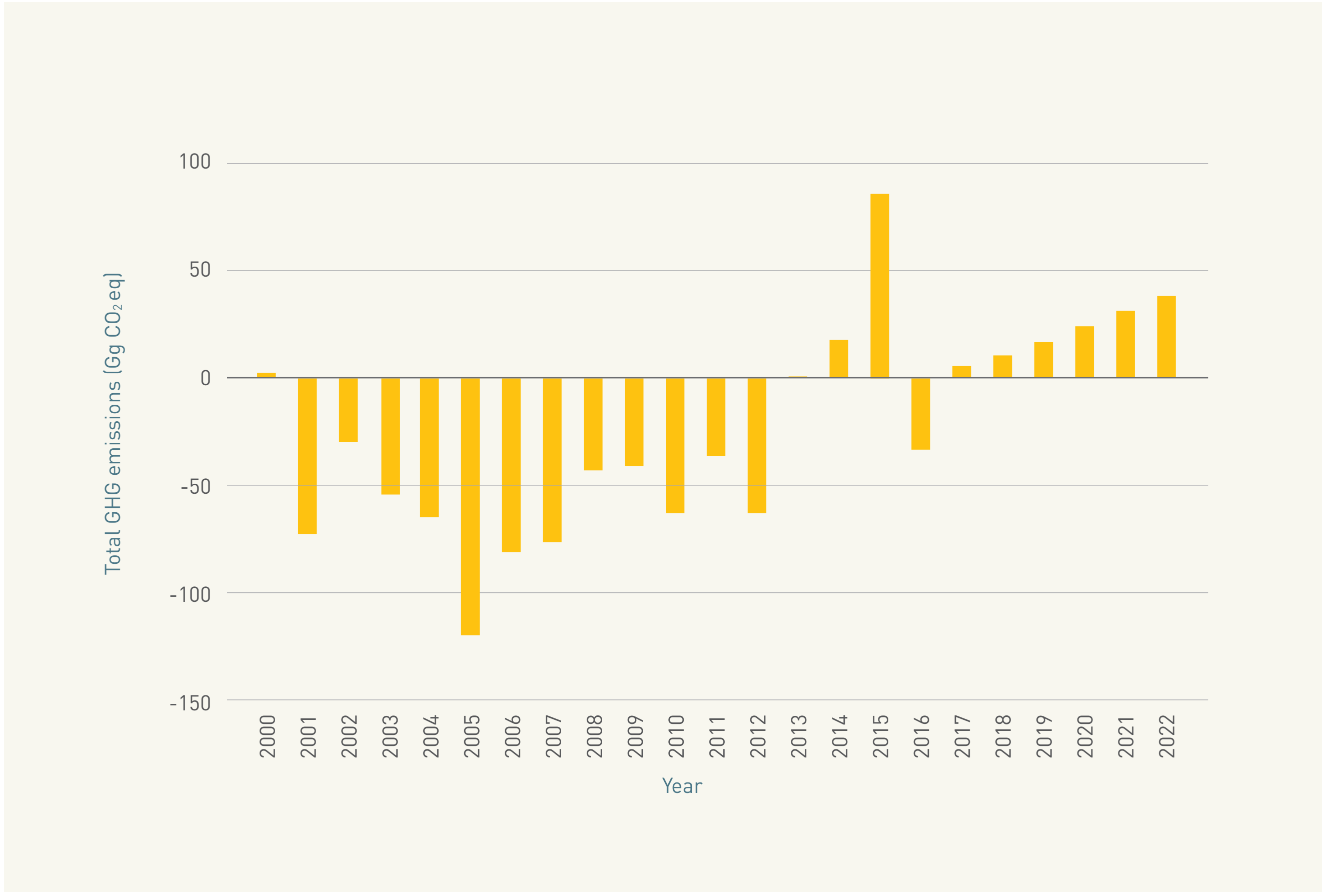


Table 19: Total GHG emissions from LULUCF sector (Gg CO_2 eq)

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
LULUCF	1.97	-72.81	-29.88	-54.53	-64.67	-120.49	-81.72	-76.81	-43.22	-41.35	-63.25

Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
LULUCF	-36.80	-62.83	0.56	17.39	85.32	-33.80	5.40	10.29	16.42	23.59	31.28	38.12

Waste

The waste sector saw an 80% increase in emissions from 2000 to 2022. This increase could be attributed to the economic and population growth of the country.

Figure 11: Total GHG emissions from Waste sector (Gg CO_2 eq)

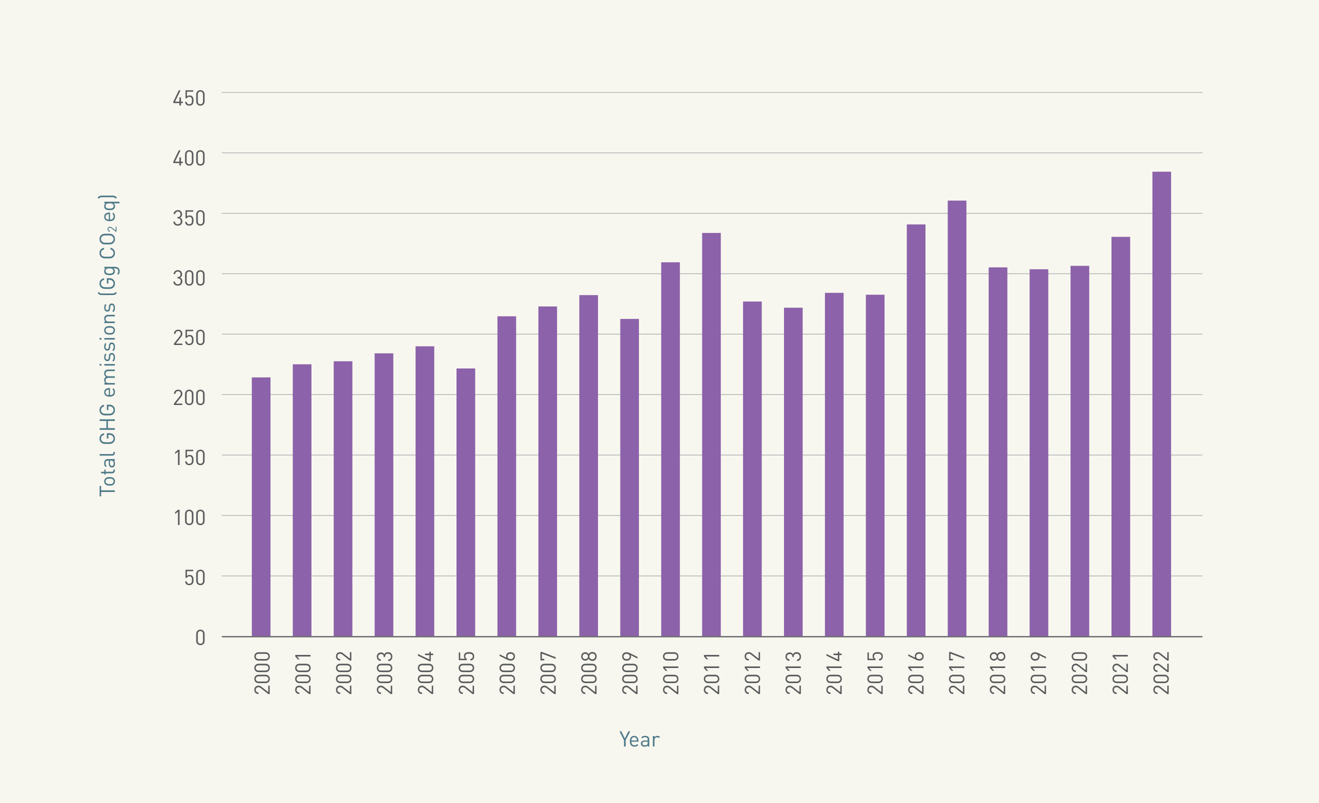


Table 20: Total GHG emissions from Waste sector (Gg CO_2 eq)

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Waste	214	225	228	234	240	222	265	273	282	263	309

Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Waste	334	278	272	284	282	341	360	306	304	306	330	384

Emissions Trends by Gases

CO_2

CO_2 emissions is the largest contributor in the energy sector with approximately 83% of the total national GHG emissions or 48,729 Gg CO_2 eq in 2022 with most of the emissions contributed by the Energy industries and Manufacturing industries. The drop in emissions in 2020 by 4.7% is mainly attributed to the economic slowdown due to the COVID-19 pandemic. For IPPU sector, there is a steep increase from 2019 onwards of about 48%. This increase was mainly contributed by the petrochemical and chemical industries.

Figure 12: Total CO_2 emissions by IPCC sectors (Gg CO_2 eq)

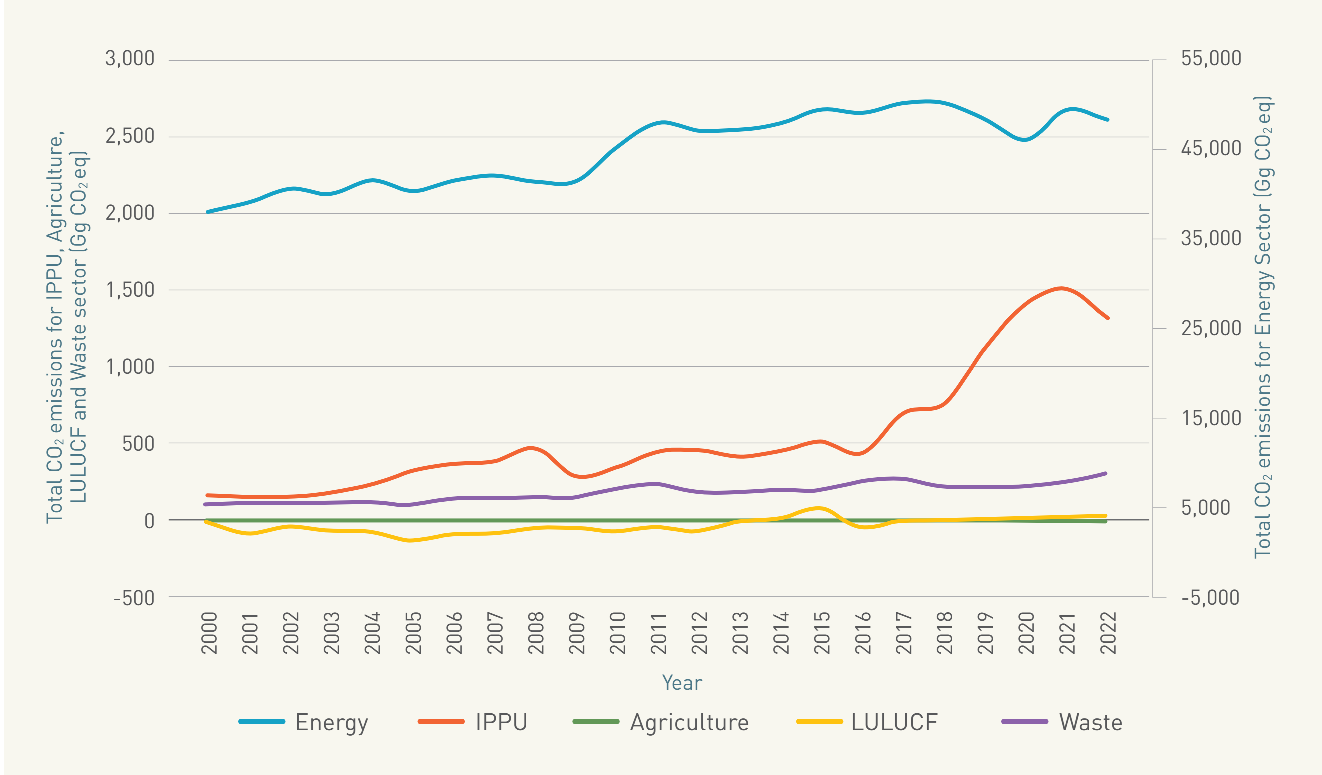


Table 21: Total CO_2 emissions by IPCC sectors (Gg CO_2 eq)

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Energy	38,007.65	39,083.74	40,586.44	40,056.79	41,544.31	40,393.15	41,552.87	42,136.51	41,471.96	41,494.62	45,345.37
IPPU	155.20	140.42	142.56	170.69	224.35	312.39	357.77	375.57	458.58	278.16	337.10
Agriculture	0.11	0.10	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.10	0.10
LULUCF	-6.87	-81.16	-37.87	-62.07	-71.76	-127.04	-87.82	-82.49	-48.57	-46.35	-68.11
Waste	103.85	111.96	110.94	114.67	119.22	100.72	140.63	142.76	151.45	149.23	206.82

Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Energy	48,056.13	47,208.28	47,216.20	47,870.92	49,450.57	49,117.27	49,927.56	50,192.63	48,361.54	46,086.79	49,423.71	48,729.46
IPPU	437.33	445.74	406.46	444.98	501.45	429.46	697.23	753.20	1,111.66	1,403.42	1,498.63	1,310.38
Agriculture	0.10	0.09	0.09	0.08	0.10	0.09	0.09	0.09	0.09	0.09	0.09	0.07
LULUCF	-41.76	-67.65	-4.24	12.59	80.29	-38.94	-0.15	4.47	10.20	17.05	24.29	30.80
Waste	236.87	184.75	182.10	196.53	196.36	254.95	273.01	220.27	219.86	224.55	252.43	304.14

CH_4

Amongst the seven types of reportable GHG, CH_4 emissions is the smallest contributor (~0.2%) to the national totals with the highest emissions (86.4%) in the energy sector. The main contributor to the CH_4 emissions in energy sector was from the venting, flaring and fugitive emissions in 1.B.2. Oil, natural gas and other emissions from energy production category. The CH_4 emissions had also decreased from 64.87 Gg CO_2 eq in 2000 to 1.8 Gg CO_2 eq in 2022 in the waste sector mainly due to a significant reduction of sewage sludge from wastewater treatment plants through sludge incineration from 2009 onwards.

Figure 13: Total CH_4 emissions by IPCC sectors (Gg CO_2 eq)

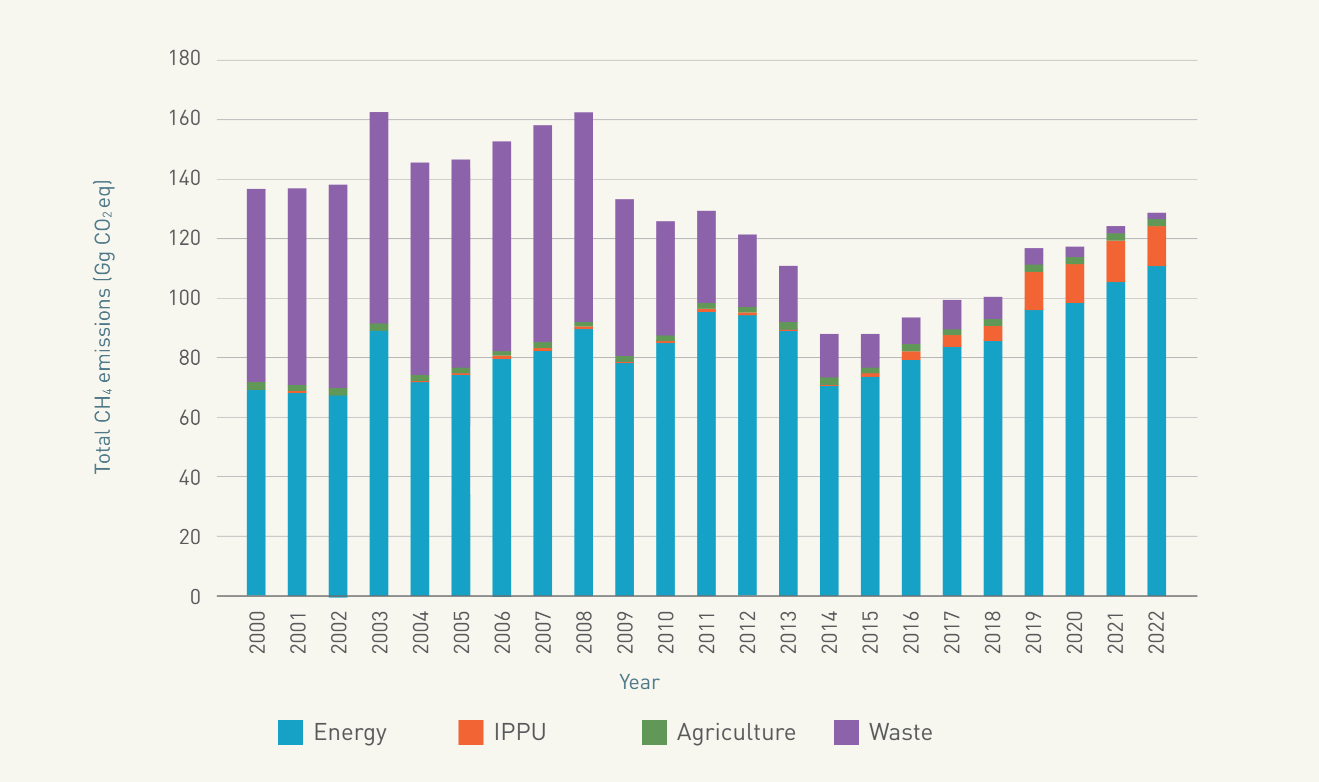


Table 22: Total CH_4 emissions by IPCC sectors (Gg CO_2 eq)

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Energy	69.18	68.53	67.31	89.16	71.98	74.45	79.88	82.32	89.61	78.57	85.20
IPPU	0.31	0.28	0.28	0.34	0.45	0.64	0.73	0.76	0.95	0.56	0.67
Agriculture	2.31	2.27	2.24	2.00	1.98	1.90	1.94	1.98	1.88	1.91	1.98
LULUCF	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Waste	64.87	65.98	68.58	71.42	71.48	69.68	70.32	73.32	70.50	52.40	37.98

Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Energy	95.62	94.19	89.05	70.72	74.06	79.50	83.75	85.89	96.32	98.88	105.75	111.64
IPPU	0.88	0.90	0.81	0.50	0.55	2.92	3.68	4.93	12.82	12.66	13.62	13.00
Agriculture	2.05	2.21	2.21	2.19	2.09	2.27	2.19	2.25	2.56	2.66	2.53	2.70
LULUCF	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Waste	30.71	24.29	19.12	14.87	11.50	9.12	9.99	7.74	5.29	3.55	2.38	1.80

Notation keys:
NA - Not applicable

N_2O

N_2O emissions contributes to 1% of the national totals, 597 Gg CO_2 eq in 2022. Most of the emissions are from Energy and IPPU sector where IPPU sector observed a notable increase in N_2O emissions from 2018 onwards. This increase is mainly due to an increase in N_2O emissions from the Integrated circuit or semiconductor category.

Figure 14: Total N_2O emissions by IPCC sectors (Gg CO_2 eq)

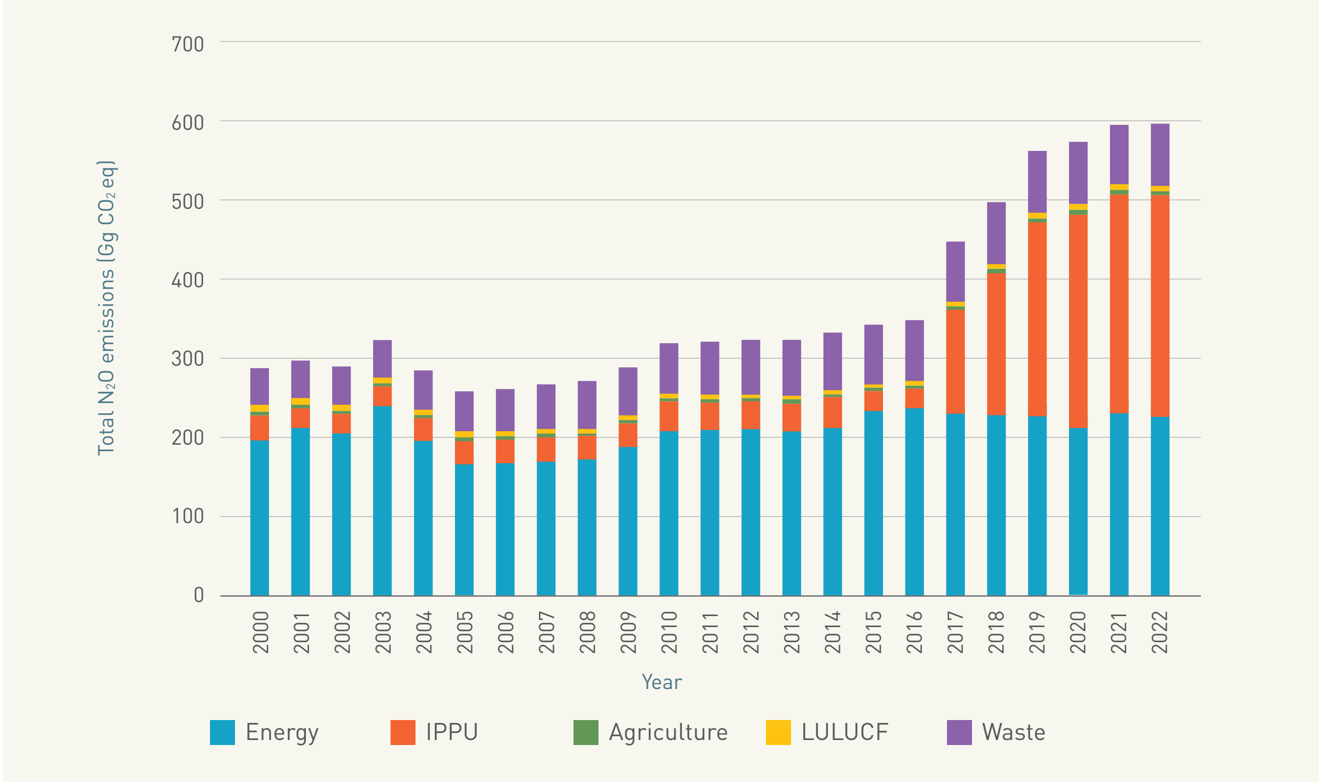


Table 23: Total N_2O emissions by IPCC sectors (Gg CO_2 eq)

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Energy	195.93	212.91	205.49	239.89	196.16	166.82	168.19	171.06	173.33	204.67	209.11
IPPU	32.66	24.51	24.34	24.22	28.26	30.51	29.57	30.23	28.82	29.13	37.39
Agriculture	4.60	4.38	4.22	4.06	3.97	3.83	4.07	4.31	4.24	4.35	4.42
LULUCF	8.85	8.35	7.98	7.54	7.09	6.55	6.10	5.68	5.35	5.00	4.86
Waste	45.07	47.14	48.23	48.20	49.37	51.11	53.74	56.49	60.24	61.29	64.12

Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Energy	209.82	211.52	209.05	212.54	233.91	238.08	230.99	228.74	227.66	212.41	232.29	227.31
IPPU	34.95	33.93	34.77	38.26	24.58	23.69	129.51	179.60	244.48	270.95	275.58	278.82
Agriculture	4.80	5.17	5.21	4.62	4.62	4.84	4.79	5.08	5.53	5.52	5.46	5.27
LULUCF	4.96	4.82	4.80	4.80	5.03	5.15	5.55	5.82	6.22	6.54	6.99	7.31
Waste	66.76	68.60	70.77	72.68	74.50	76.47	77.25	77.59	78.45	78.26	75.38	78.26

HFCs

A steady increase in HFC emissions was also observed from year 2000 to 2022, with the vast majority of increase arising from the category Refrigeration and Air-conditioning. Further details can be found in Section 4.7., 2.F. Product uses as substitutes for ODS.

Figure 15: Total HFC emissions in IPPU sector (Gg CO_2 eq)

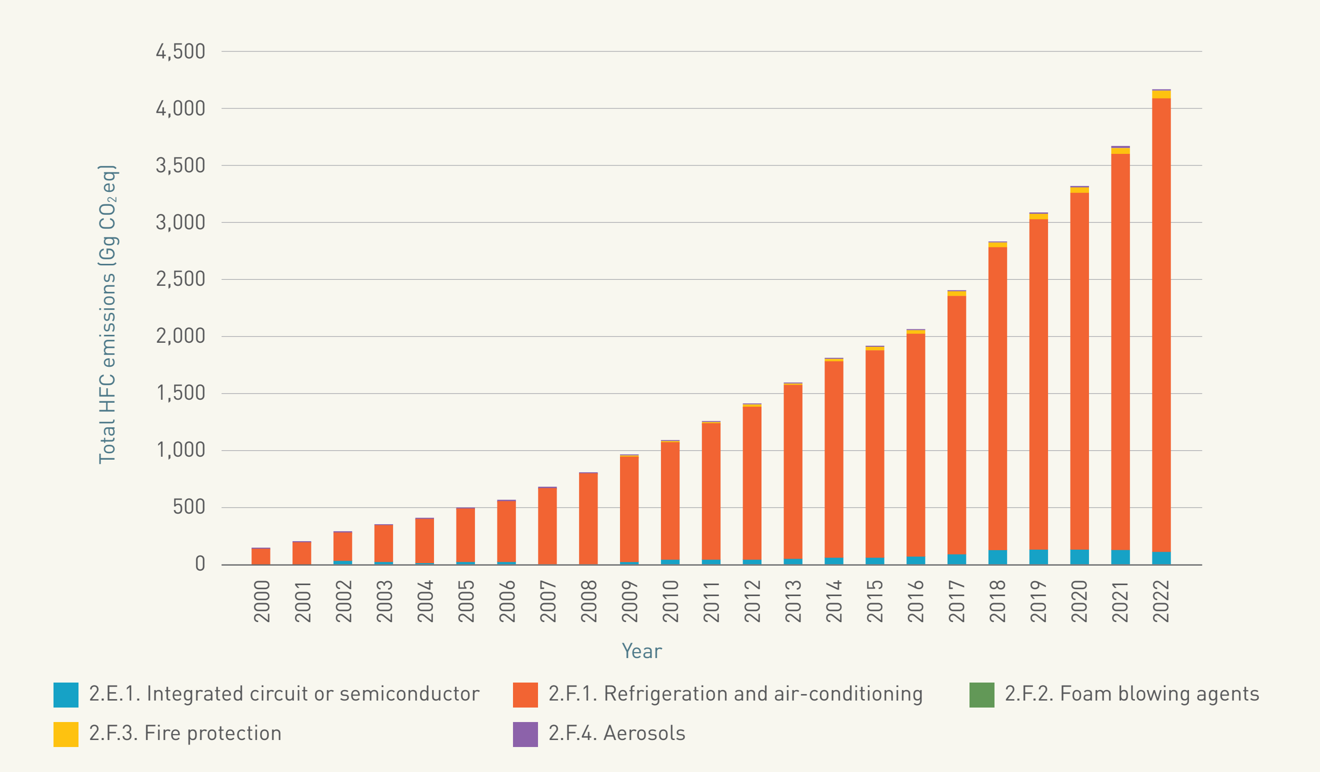


Table 24: Total HFC emissions in IPPU sector (Gg CO_2 eq)

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
2.E.1. Integrated circuit or semiconductor	9.50	7.83	31.91	27.80	18.18	24.03	31.10	8.11	8.92	24.39	42.32
2.F.1. Refrigeration and air-conditioning	137.16	188.71	252.60	321.23	384.07	467.92	531.87	666.04	794.01	926.69	1,031.99
2.F.2. Foam blowing agents	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.F.3. Fire protection	0.12	0.22	0.34	0.41	0.56	0.82	0.92	1.38	2.34	6.02	8.78
2.F.4. Aerosols	0.18	0.21	0.20	0.24	0.41	0.53	0.55	0.61	0.67	0.67	1.11

Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
2.E.1. Integrated circuit or semiconductor	45.70	45.85	55.29	60.77	65.23	72.16	95.31	131.65	133.53	136.28	133.91	117.45
2.F.1. Refrigeration and air-conditioning	1,190.70	1,344.71	1,520.59	1,728.06	1,815.24	1,950.78	2,264.37	2,649.39	2,891.80	3,125.90	3,462.23	3,973.37
2.F.2. Foam blowing agents	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01
2.F.3. Fire protection	13.61	16.45	17.29	19.38	26.47	34.50	39.36	44.28	49.26	45.29	55.28	63.89
2.F.4. Aerosols	2.28	2.78	2.93	3.19	5.72	9.36	10.40	11.76	13.33	13.63	13.41	13.06

PFCs

PFC emissions accounts for 4.3% of the national totals, 2,519 Gg CO_2 eq in 2022 where it is used mainly in the Integrated circuit or semiconductor industry. The rise in PFC emissions from 2021 to 2022 is likely due to an increase in demand for computer and electronics as observed in the rise of the total manufacturing output of computer, electronics and optical products.

Figure 16: Total PFC emissions in Electronics industry (Gg CO_2 eq)

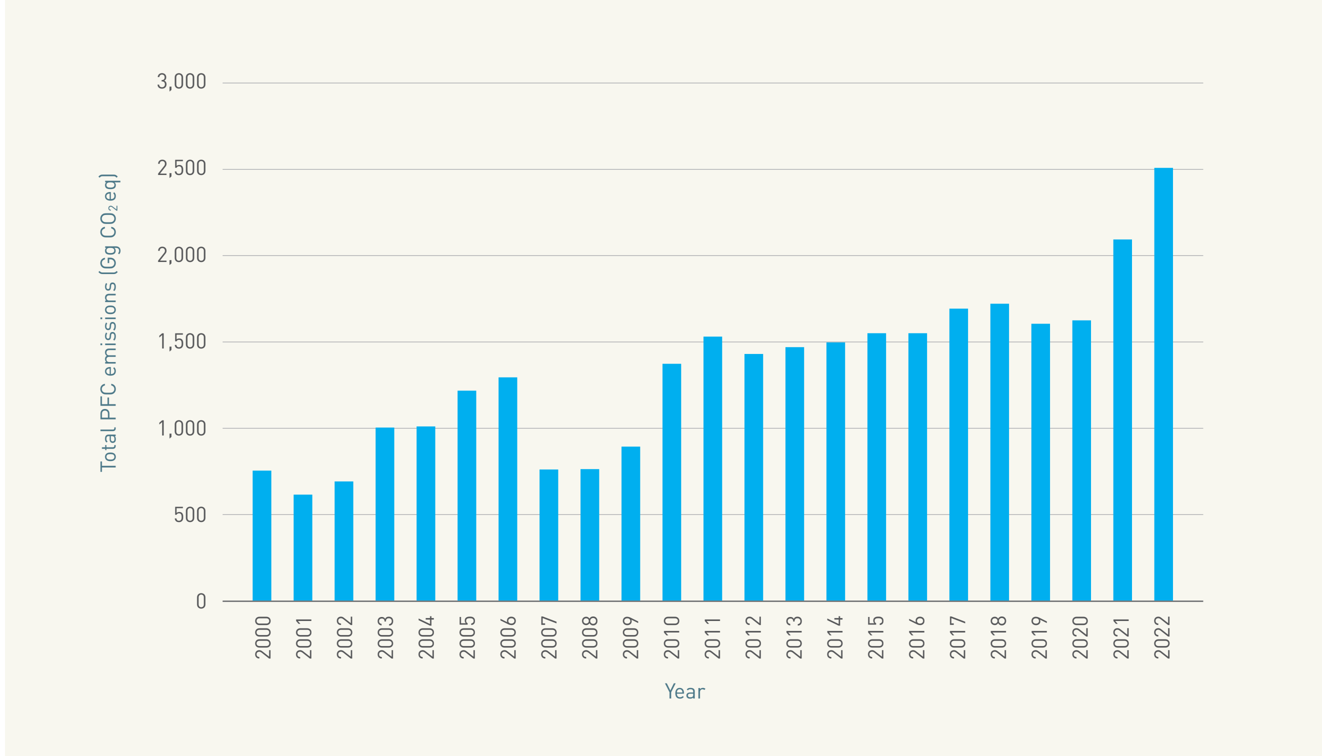


Table 25: Total PFC emissions in Electronics industry (Gg CO_2 eq)

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
2.E.1. Integrated circuit or semiconductor	764	624	704	1,014	1,021	1,227	1,308	771	777	904	1,383

Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
2.E.1. Integrated circuit or semiconductor	1,531	1,441	1,478	1,509	1,556	1,556	1,709	1,729	1,618	1,640	2,105	2,519

SF_6

SF_6 emissions is the second lowest emission contributor to the national totals at 0.26% or 155 Gg CO_2 eq. Similar to PFCs, it is also used mainly in 2.E.1. Integrated circuit or semiconductor industry covering 83% of PFC emissions whereas the SF_6 emissions from electrical equipment covers the remaining 17% of PFC emissions in 2022. The drop in SF_6 emissions in 2007 to 2008 was likely due to the global financial crisis in 2007-2008 which affected the integrated circuit and semiconductor industry.

Figure 17: Total SF_6 emissions in IPPU sector (Gg CO_2 eq)

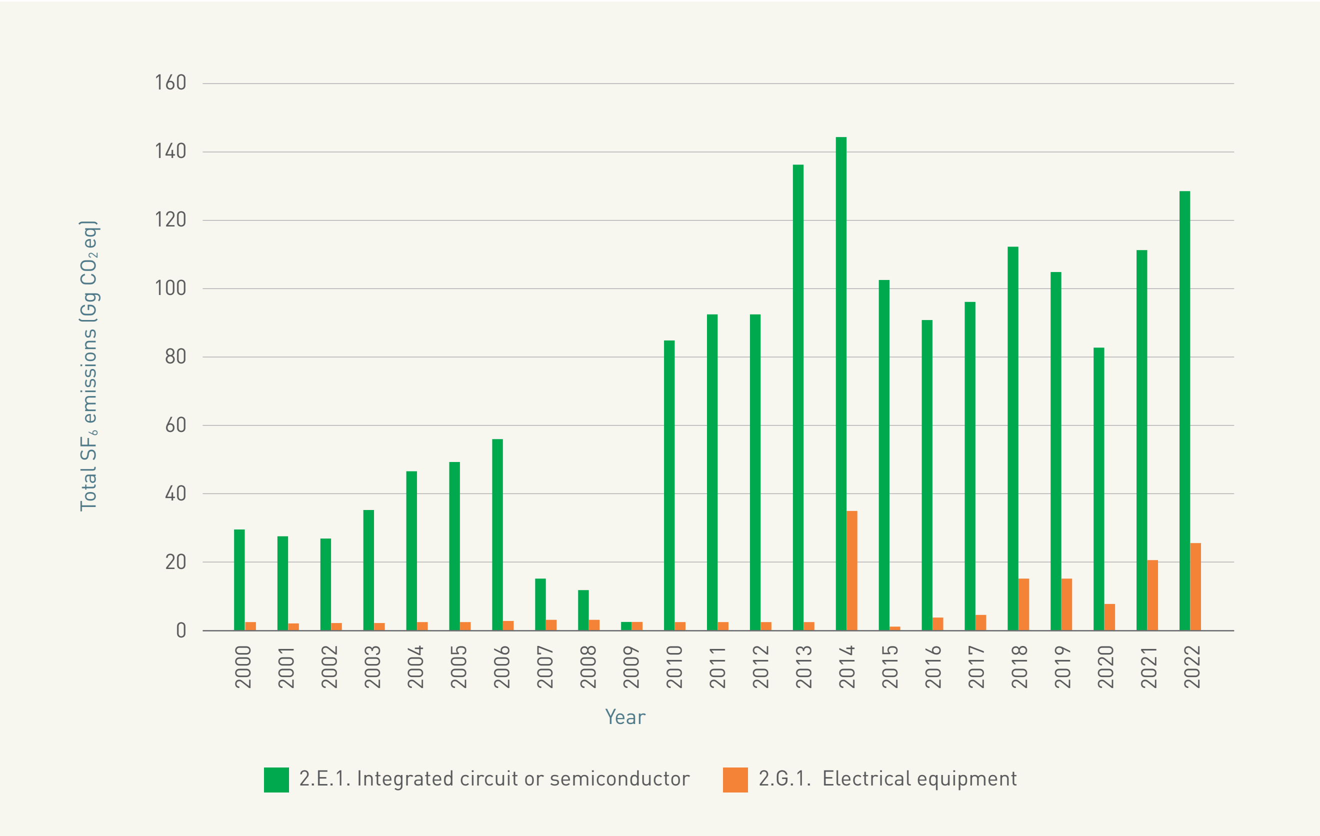


Table 26: Total SF_6 emissions in IPPU sector (Gg CO_2 eq)

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
2.E.1. Integrated circuit or semiconductor	29.75	27.56	27.12	35.41	46.77	49.42	56.20	15.12	11.89	2.61	84.81
2.G.1. Electrical equipment	2.57	2.29	2.20	2.15	2.48	2.58	2.87	3.05	3.14	2.63	2.50

Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
2.E.1. Integrated circuit or semiconductor	92.65	92.54	136.40	144.69	102.64	90.90	96.46	112.39	105.04	82.85	111.23	128.84
2.G.1. Electrical equipment	2.51	2.61	2.61	34.92	1.06	3.74	4.37	15.37	15.37	7.79	20.57	25.74

NF_3

Similar to PFCs, NF_3 is solely used by the Integrated circuit or semiconductor industry where NF_3 contributes to 1.1% of the national totals in 2022. Overall, there has been an increase of NF_3 from 65.57 Gg CO_2 eq in year 2000 to 645 Gg CO_2 eq 2022. The drop in NF_3 emissions in 2007 to 2008 was likely due to the global financial crisis in 2007-2008 which affected the integrated circuit and semiconductor industry.

Figure 18: Total NF_3 emissions by IPCC sectors (Gg CO_2 eq)

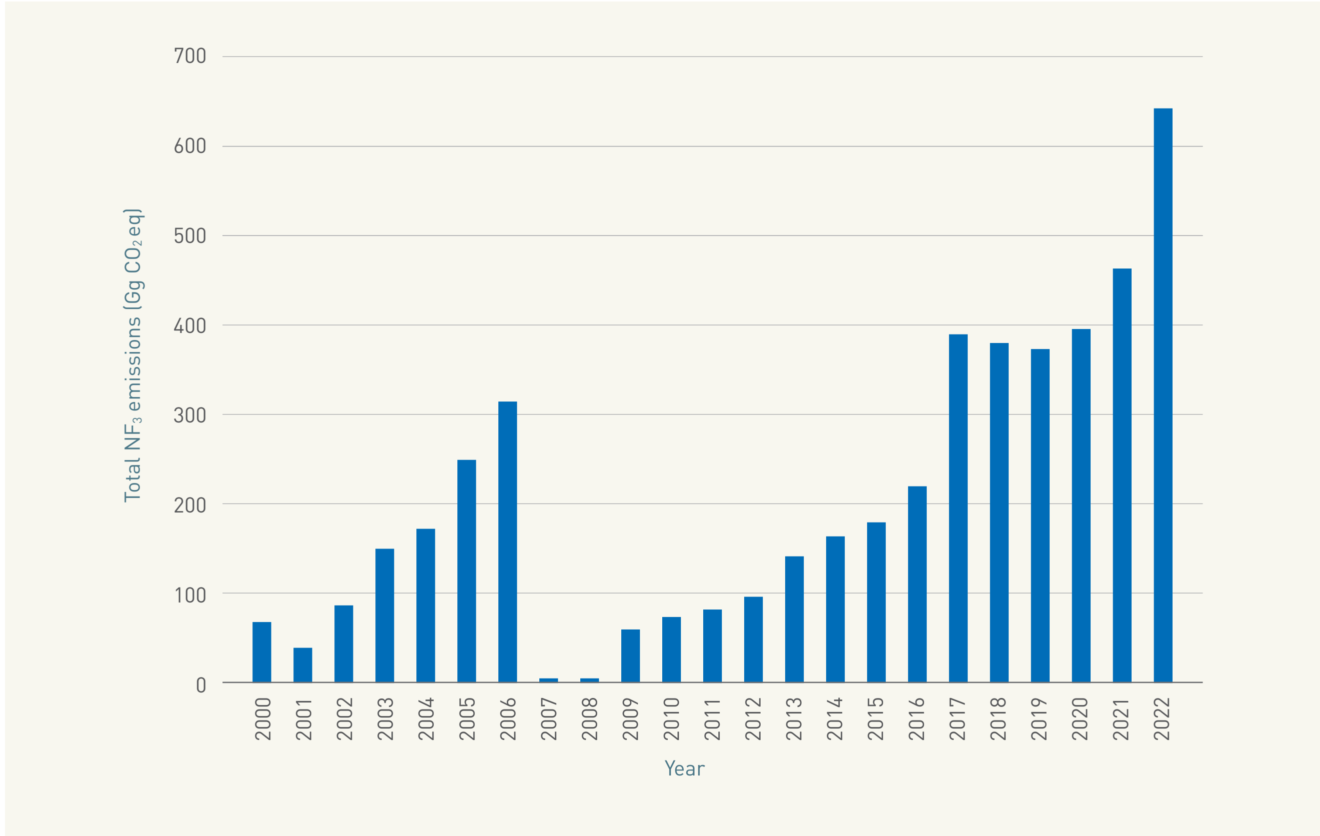


Table 27: Total NF_3 emissions by IPCC sectors (Gg CO_2 eq)

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
2.E.1. Integrated circuit or semiconductor	67.57	39.62	86.92	150.52	172.63	249.56	315.21	5.17	5.06	59.71	73.99

Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
2.E.1. Integrated circuit or semiconductor	81.84	96.97	141.87	164.58	180.12	220.51	391.28	381.25	373.62	397.08	464.31	644.77

Chapter 3

ENERGY (CRT SECTOR 1)

3.1.

Overview of the Sector and Background Information

Energy

The combustion of fossil fuels to generate energy is the major source of GHG emissions in Singapore. The energy sector accounted for 49,068 kt CO_2 eq (83.8%) of Singapore's total GHG emissions in 2022. The energy sector includes GHG emissions from stationary fuel combustion activities and fugitive emissions associated with energy production and consumption.

Fugitive emissions are intentional (e.g. venting, flaring) or unintentional (e.g. leaks) releases of GHGs throughout the fossil fuel value chain of production, processing, transmission and storage. According to the 2006 IPCC Guidelines, 1.B. Fugitive Emissions includes GHG emissions from flaring activities by the oil and gas industry since there is no production of useful heat or energy or generation of mechanical work.

As heat from the incineration of MSW is recovered to produce electricity in Singapore, CO_2, CH_4 and N_2O emissions from WtE incineration plants are reported under the energy sector. According to the 2006 IPCC Guidelines, CO_2 emissions from waste incineration are estimated from the portion of the waste that is fossil-based, and emissions from non-fossil-based fraction are excluded from inventory reporting. Heat from the incineration of sludge used in wastewater treatment processes is also recovered in Singapore, hence CH_4 and N_2O emissions from sludge incineration are reported in the energy sector.

Figure 19: Total GHG emissions by Fuel Combustion activities (2000 to 2022)

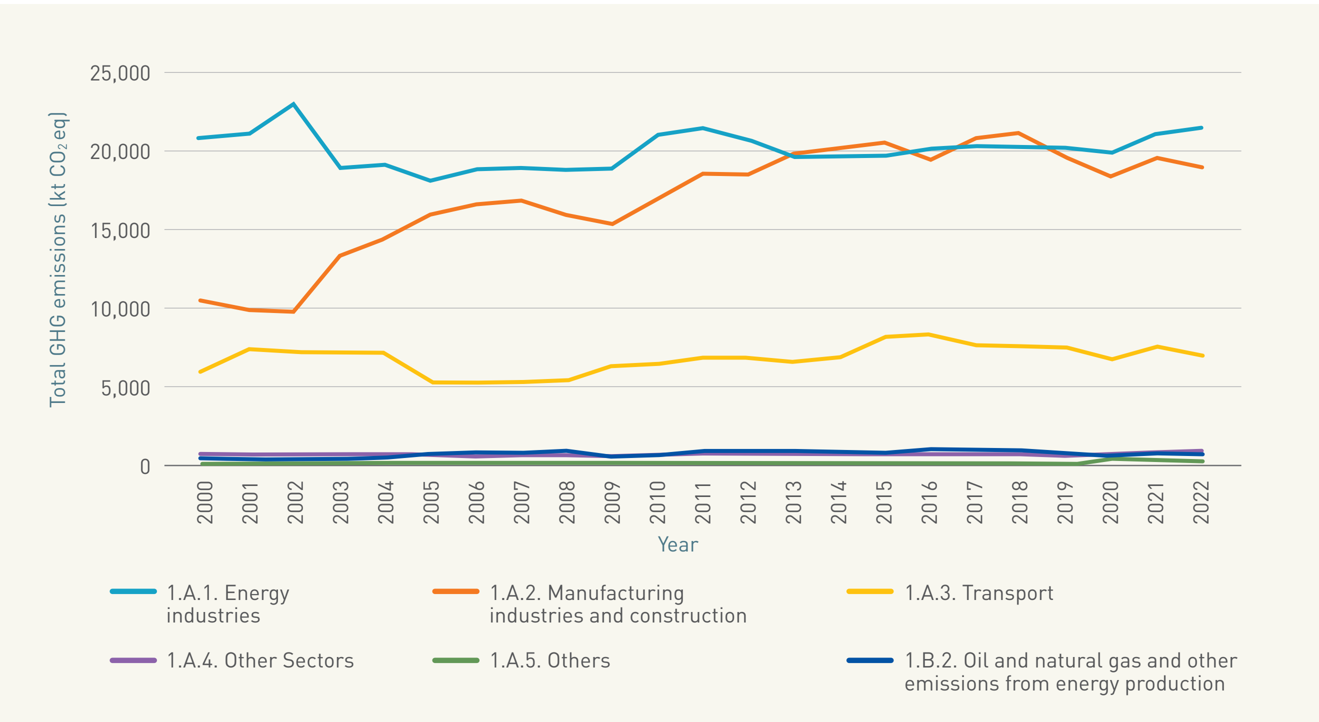


Table 28: Total GHG emissions by Fuel Combustion activities (2000 to 2022)

Greenhouse Gas Category	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
	GHG Emissions (kt CO_2 eq)										
1.A. Fuel combustion activities	37,957	39,079	40,574	40,044	41,362	39,990	41,064	41,619	40,775	41,214	44,964
1.A.1. Energy industries	20,880	21,136	22,948	18,877	19,125	18,117	18,764	18,885	18,789	18,894	20,979
1.A.2. Manufacturing industries and construction	10,452	9,933	9,766	13,294	14,463	15,899	16,556	16,862	15,918	15,357	16,888
1.A.3. Transport	5,982	7,383	7,265	7,240	7,140	5,374	5,177	5,267	5,463	6,321	6,437
1.A.4. Other Sectors	642	627	595	632	633	599	567	606	605	641	661
1.A.5. Others	0	0	0	0	0	0	0	0	0	0	0
1.B. Fugitive emissions from fuels	316	286	285	342	451	645	736	771	960	564	675
1.B.1. Solid fuels	NO	NO	NO	NO	NO	IE	IE	IE	IE	IE	IE
1.B.2. Oil and natural gas and other emissions from energy production	316	286	285	342	451	645	736	771	960	564	675

Greenhouse Gas Category	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
	GHG Emissions (kt CO_2 eq)											
1.A. Fuel combustion activities	47,466	46,598	46,701	47,341	49,009	48,508	49,363	49,600	47,964	45,864	49,110	48,455
1.A.1. Energy industries	21,388	20,660	19,624	19,677	19,688	20,125	20,262	20,303	20,224	19,831	21,066	21,421
1.A.2. Manufacturing industries and construction	18,583	18,445	19,781	20,189	20,536	19,442	20,793	21,092	19,661	18,387	19,527	18,980
1.A.3. Transport	6,848	6,846	6,617	6,836	8,130	8,283	7,663	7,558	7,449	6,730	7,565	7,036
1.A.4. Other Sectors	646	646	679	640	655	659	646	647	630	627	705	765
1.A.5. Others	0	0	0	0	0	0	0	0	0	290	247	252
1.B. Fugitive emissions from fuels	896	916	813	813	750	926	879	907	721	534	652	614
1.B.1. Solid fuels	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1.B.2. Oil and natural gas and other emissions from energy production	896	916	813	813	750	926	879	907	721	534	652	614

Notation keys:
NO - Not occurring, IE - Included elsewhere

Table 29:Total GHG emissions by type of GHG from energy sector (2000 to 2022)

Greenhouse Gas Category	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
	GHG Emissions (kt CO_2 eq)											
Total Energy	38,273	39,365	40,859	40,386	41,812	40,634	41,801	42,390	41,735	41,778	45,640	48,362
CO_2	38,008	39,084	40,586	40,057	41,544	40,393	41,553	42,137	41,472	41,495	45,345	48,056
CH_4	69	69	67	89	72	74	80	82	90	79	85	96
N_2O	196	213	205	240	196	167	168	171	173	205	209	210

Greenhouse Gas Category	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
	GHG Emissions (kt CO_2 eq)										
Total Energy	47,514	47,514	48,154	49,759	49,435	50,242	50,507	48,686	46,398	49,762	49,068
CO_2	47,208	47,216	47,871	49,451	49,117	49,928	50,193	48,362	46,087	49,424	48,729
CH_4	94	89	71	74	79	84	86	96	99	106	112
N_2O	212	209	213	234	238	231	229	228	212	232	227

3.2.
Fuel Combustion (CRT 1.A.)

This sector covers GHG emissions from the combustion of fossil, biomass fuels (excluding CO_2 emissions from biomass fuels) and incineration of waste with energy recovery for heat or mechanical work.

The main sections under the fuel combustion activities comprise:

- 1.A.1. Energy Industries: Emissions from fuel combustion by fuel extraction or energy-producing industries.
- 1.A.2. Manufacturing industries and construction: Emissions from combustion of fuels in industry.
- 1.A.3. Transport: Emissions from fuel combustion for all transport activities.
- 1.A.4. Other Sectors: Emissions from combustion activities including combustion for electricity generation used in commercial/institutional sector, residential sector, and agriculture, forestry, fishing and fishing industries.
- 1.A.5. Others: All remaining emissions from fuel combustion not specified elsewhere.

3.2.1. Comparison of the Sectoral Approach with the Reference Approach

As a global trading hub with a high trade-to-GDP ratio, Singapore experiences volatility in trade data as a direct result of our large and varying trade volumes coupled with the presence of a large refining and petrochemical sector. This gives rise to large discrepancies between emissions calculated using the reference approach and the sectoral approach. As such, emissions calculated using the sectoral approach would be more accurate than using the reference approach in Singapore's context. Singapore is building its capacity to understand the discrepancies. The results will be included in future reports.

3.2.2. International Bunker Fuels

As Singapore is a major international air and sea transportation hub, aviation and marine bunker fuels are uplifted in Singapore as part of the services provided to passing aircraft and ships on international routes. Emissions from international aviation and marine bunker fuels are therefore excluded from Singapore's national GHG inventory and national GHG totals. In accordance with the 2006 IPCC Guidelines and UNFCCC reporting guidance, emissions from fuels used for international aviation and navigation are reported under Memo items International Bunkers (1.D.1.).

Singapore actively supports and contributes to the efforts led by the International Civil Aviation Organization (ICAO) and the International Maritime Organization (IMO) in addressing international aviation and maritime transport emissions on a global basis.

CO_2, CH_4 and N_2O emissions from international aviation and international navigation are estimated using Tier 1 methods by multiplying the consumption data of each fuel type with their respective implied emission factors. The emissions from international bunkers in 2022 can be found in Table 30.

Table 30: Emissions from international bunkers in 2022

International Bunkers	CO_2 Emissions (kt CO_2 eq)
Aviation	10,213
Marine	151, 299

3.2.3. Feedstocks and Non-Energy Use of Fuels

Fossil fuels, apart from combustion for generating heat or mechanical work to a process, are also utilised for non-energy purposes like in the manufacturing processes of iron, steel, non-ferrous metals, solvents and lubricants. The GHG emissions of excluded carbon are those used as feedstock, reductant or non-energy products reported under the IPPU sector (CRT Category 2).

3.2.4. Energy Industries (CRT Category 1.A.1.)

3.2.4.1. Category Description

In 2022, emissions from Energy Industries totalled 21,421 kt CO_2 eq making up 37% of Singapore's total GHG emissions. Under the CPA, facilities that attain the first emissions threshold of 2,000 tonnes of carbon dioxide equivalent (t CO_2 eq) are required to register as a reportable facility and submit an annual Emissions Report (ER) to NEA but they will not be subject to carbon tax liability. Companies that attain the second emissions threshold of 25,000 t CO_2 eq are required to register as a taxable facility and submit an MP and an annual third-party verified ER. These taxable facilities will be liable for the carbon tax for the verified reckonable emissions reported in the ERs. Clearer reporting guidelines coupled with increased stringency of Measurement, Reporting and Verification (MRV) have reduced emissions from the Energy Industries sector. More information on the reporting requirements under the CPA can be found in the "Greenhouse Gas (GHG) Emissions Measurement and Reporting Guidelines".

The Energy Industries category encompasses all emissions from stationary fuel combustion sources related to electricity generation and Combined Heat and Power Generation (CHP) for utilities, and the production, processing and refining of fossil fuels.

The different sources are categorised into the following three subcategories:

1.A.1.a. Public electricity and heat production
1.A.1.b. Petroleum refining
1.A.1.c. Manufacture of solid fuels and other energy industries

Table 31: Total GHG emissions from Energy industries (2000 to 2022)

Greenhouse Gas Category	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
	GHG Emissions (kt CO_2 eq)											
1.A.1. Energy industries	20,880	21,136	22,948	18,877	19,125	18,117	18,764	18,885	18,789	18,894	20,979	21,388
1.A.1.a. Public electricity and heat production	20,880	21,136	22,948	18,877	19,125	18,117	18,764	18,885	18,789	18,894	20,979	21,388
1.A.1.b. Petroleum refining	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1.A.1.c. Manufacture of solid fuels and other energy industries	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

Greenhouse Gas Category	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
	GHG Emissions (kt CO_2 eq)										
1.A.1. Energy industries	20,660	19,624	19,677	19,688	20,125	20,262	20,303	20,224	19,831	21,066	21,421
1.A.1.a. Public electricity and heat production	20,660	19,624	19,677	19,688	20,125	20,262	20,303	20,224	19,831	21,066	21,421
1.A.1.b. Petroleum refining	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1.A.1.c. Manufacture of solid fuels and other energy industries	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

Notation keys:
NO - Not occurring, IE - Included elsewhere

Public Electricity and Heat Production

Singapore's electrical grid mainly comprises combustion generated energy, with relatively smaller inputs from solar and wind energy. As per the 2006 IPCC Guidelines, this subcategory includes emissions from main activity producers of electricity generation, CHP and heat plants. Main activity producers (formerly known as public utilities) are defined as enterprises, whose primary activity is to produce and supply the public with electricity, that may be under public or private ownership. Emissions from own on-site use of fuel should be included under this subcategory except for autoproducers, which are defined as enterprises that, in support of its primary activity, generate electricity and/or heat for its own use or for sale, but not as its main business.

The Public Electricity and Heat Production subcategory is further divided into:
1.A.1.a.i. Electricity generation
1.A.1.a.ii. Combined heat and power generation
1.A.1.a.iii. Heat plants

Electricity generation (1.A.1.a.i.) comprises emissions from all fuel combustion for electricity generation from main activity producers except those from CHP plants.

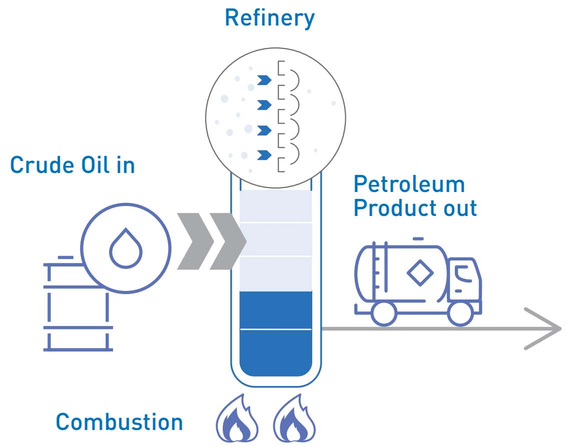
Combined heat and power generation (1.A.1.a.ii.) includes emissions from the combustion of fuel from the production of heat and electrical power, at a single facility, from main activity producers for sale to the public.

Heat plants (1.A.1.a.iii.) comprise emissions from fuel combustion for the production of heat from main activity producers for sale through steam pipe networks.

Petroleum Refining

This category includes all combustion activities supporting the refining of petroleum products including on-site combustion for the generation of electricity and heat for own use. In a petroleum refinery, crude oil is converted to a broad range of products. For the refining process to occur, part of the energy content of the products obtained is used in the refinery (See Figure 20). In principle, all petroleum products can be combusted to use as a fuel to provide the process heat and steam needed for the refining process.

Figure 20: A refinery uses energy to transform crude oil into petroleum products

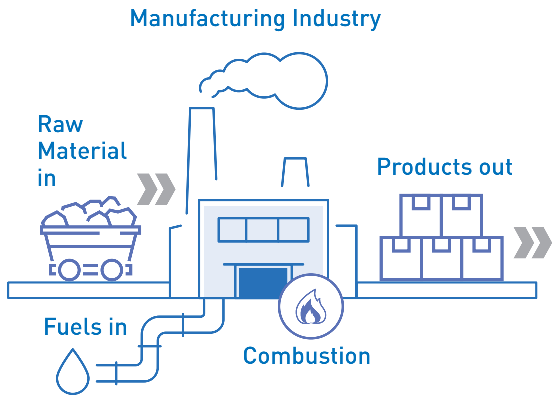


Emissions from flaring and venting during refinery processes are calculated and reported under Fugitive Emissions (1.B.2).

Manufacture of Solid Fuels and other Energy Industries

In manufacturing industries, raw materials are converted into products (See Figure 21). The combustion emissions from fuel use during the manufacture of secondary and tertiary products from solid fuels including production of charcoal are accounted for under this subcategory. Emissions from own on-site fuel use should be included. This subcategory also includes combustion for the generation of electricity and heat for facilities' own use in these industries.

Figure 21: Fuels are used as an energy source in manufacturing industries to convert raw materials into products



Manufacturing industries are generally classified according to the nature of their products using the International Standard Industrial Classification (ISIC) of all Economic Activities. The Manufacture of solid fuels and other energy industries subcategory is further divided into:
1.A.1.c.i. Manufacture of solid fuels
1.A.1.c.ii. Oil and gas extraction
1.A.1.c.iii. Other energy industries

There are no known facilities that manufacture solid fuels, conduct oil and gas extraction, including such facilities that are able to produce own-energy use in Singapore.

3.2.4.2. Methodological Issues

Table 32:Methods and emission factors used for the emissions estimation for Energy industries sector

GHG source and sink category	CO_2		CH_4		N_2O	
	Method applied	Emission Factor	Method applied	Emission Factor	Method applied	Emission Factor
1.A.1.a. Public electricity and heat production	T1, T3	D, PS	T1	D	T1, T3	D, PS
1.A.1.b. Petroleum refining	T1	D	T1	D	T1	D

Notation keys:
T1 - Tier 1, T3 - Tier 3, D - IPCC Default, PS - Plant-specific

Public electricity and Heat Production

The methodology used for estimating GHG emissions from Electricity generation (1.A.1.a.i.) adheres to a modified IPCC Tier 1 method for CO_2, CH_4 and N_2O emissions. The implied emission factors are derived based on the fuel consumption aggregate data and the measured CO_2, CH_4, and N_2O emissions using the formula in this section. Tier 1 equation for GHG emissions from public electricity and heat production:

$$Emissions_{GHG,\,fuel} = Fuel\ Consumption_{fuel} \times Emission\ Factor_{GHG,fuel}$$

Where:
$Emissions_{GHG,\,fuel}$ = emissions of a given GHG by fuel type
$Fuel\ Consumption_{fuel}$ = amount of fuel combusted (TJ)
$Emission\ Factor_{GHG,\,fuel}$ = emission factor for respective GHG and fuel type

Fuel consumption and GHG emissions data for Heat plants (1.A.1.a.iii.) (except for liquid, solid and gaseous fuels which are indicated as NO and Other fossil fuels and biomass which are indicated as IE for the years in which the Heat Plants are operational) and are reported under CHP (1.A.1.a.ii.). Due to the small number of facilities that are reporting as steam producers, the activity data have been aggregated to protect the data confidentiality of those facilities.

Fuel consumption and GHG emissions data for CHP (1.A.1.a.ii.) for liquid fuels, solid fuels and gaseous fuels are indicated as IE and reported under Electricity Generation (1.A.1.a.i.). Due to a small number of facilities that are reporting as combined heat and power producers, the activity data and emissions have been aggregated to protect the data confidentiality of those facilities. For solid fuels reported under Electricity Generation, it is further aggregated and reported under liquid fuels within the same CRT subcategory for data confidentiality.

Choice of activity data

The following fuels are used in Electricity Generation (1.A.1.a.i.):

Liquid fuels:
- Residual fuel oil
- Gas/Diesel Oil

Gaseous fuels:
- Natural gas

Biomass:
- Gas biomass

Fuel consumption activity data used are extracted from:
- 2000 – 2020 data are taken from EDMA site which is supplied by Energy Market Authority (EMA)
- 2021 – 2022 data are taken from EDMA site which is collected from individual companies under CPA

For subsection Other fossil fuels, the aggregate consumption data used are obtained from:
- MSW: 2000-2018 data are taken from Municipal Solid Waste (MSW) fossil fraction based on waste sampling tests conducted by NEA
- MSW: data for 2019 onwards are taken from WTE fossil fraction data submitted by companies under CPA
- Sludge incineration: data from 2009 onwards from PUB

The following fuels are used in CHP (1.A.1.a.ii.):

Liquid fuels:
- Gas/Diesel Oil
- Residual Fuel Oil

Solid fuels:
- Other bituminous coal

Gaseous fuels:
- Natural gas

Other fossil fuels:
- WtE fossil fraction
- Waste sludge

Biomass:
- WtE biogenic fraction
- Solid biofuels
- Gas biomass

The following fuels are used in Heat Plants (1.A.1.a.iii.):

Other fossil fuels:
- WtE fossil fraction

Biomass:
- WtE biogenic fraction
- Solid biofuels

There is no capture of CO_2 under 1.A.1.a. Public electricity and heat production, hence it is indicated as NO.

Choice of emission factor

Liquid fuel:

The emission factors for gas/diesel oil and residual fuel oil were extracted from 2006 IPCC Guidelines, Volume 1, Chapter 1, Table 1.2 and Table 1.3. The CO_2, CH_4 and N_2O emission factors used for gas/diesel oil and residual fuel oil can be found in Table 33 below.

Table 33: Emission factor used for liquid fuel in Public electricity and heat production

Fuel type	CO_2 emission factor (kg CO_2/TJ)	CH_4 emission factor (kg CH_4/TJ)	N_2O emission factor (kg N_2O/TJ)
Diesel	74,067	3	0.6
Fuel Oil	77,367	3	0.6

Solid fuel:

The emission factor for other bituminous coal was extracted from 2006 IPCC Guidelines, Volume 1, Chapter 1, Table 1.2 and Table 1.3. The CO_2, CH_4 and N_2O emission factors used for other bituminous coal can be found in Table 34 below.

Table 34: Emission factor used for solid fuel in Public electricity and heat production

Fuel type	CO_2 emission factor (kg CO_2/TJ)	CH_4 emission factor (kg CH_4/TJ)	N_2O emission factor (kg N_2O/TJ)
Other bituminous coal	94,600	1	1.5

Gaseous fuel:

The emission factor for natural gas was extracted from 2006 IPCC Guidelines, Volume 1, Chapter 1, Table 1.2 and Table 1.3. The CO_2, CH_4 and N_2O emission factors used for natural gas can be found in Table 35 below.

Table 35: Emission factor used for gaseous fuel in Public electricity and heat production

Fuel type	CO_2 emission factor (kg CO_2/TJ)	CH_4 emission factor (kg CH_4/TJ)	N_2O emission factor (kg N_2O/TJ)
Natural gas	56,100	1	0.1

Other fossil fuels and biomass:

The emission factor for WtE and waste sludge can be found in Section 7.2 and 7.4. For year 2000 to 2018, default factors were used for WtE. From 2019 onwards, with the implementation of CPA, some CPA facilities used plant-specific emission factor to compute the GHG emissions.

Petroleum Refining

The methodology used for estimating GHG emissions from Petroleum Refining (1.A.1.b.) follows a modified Tier 1 method for CO_2, CH_4 and N_2O emissions. The implied emission factors are calculated based on the aggregate fuel consumption data and the measure of CO_2, CH_4 and N_2O using the formula below.

Tier 1 equation for GHG emissions from petroleum refinery:

$$\text{Emission}_{GHG,\,fuel} = \text{Fuel Consumption}_{fuel} \times \text{Emission Factor}_{GHG,fuel}$$

Where:

$\text{Emissions}_{GHG,\,fuel}$ = emissions of a given GHG by fuel type
$\text{Fuel Consumption}_{fuel}$ = amount of fuel combusted (TJ)
$\text{Emission Factor}_{GHG,\,fuel}$ = emission factor for respective GHG and fuel type

Choice of activity data

Gaseous fuels:
- Natural gas

Fuel consumption activity data used are extracted from:
- 2000 – 2022 data taken from EDMA site which is supplied by EMA

Flaring and venting emissions are calculated and reported separately under the Fugitive emissions – Venting and flaring (1.B.2.c.).

Since there is no CO_2 captured under this subcategory, the amount of CO_2 captured under 1.A.1.c. is reported as NO.

Choice of emission factor

Gaseous fuel:

The emission factor for natural gas was extracted from 2006 IPCC Guidelines, Volume 1, Chapter 1, Table 1.2 and Table 1.3. The CO_2, CH_4 and N_2O emission factors used for natural gas can be found in Table 36 below.

Table 36: Emission factor used for gaseous fuel in Petroleum refining

Fuel type	CO_2 emission factor (kg CO_2/TJ)	CH_4 emission factor (kg CH_4/TJ)	N_2O emission factor (kg N_2O/TJ)
Natural gas	56,100	1	0.1

Manufacture of solid fuels and other energy industries

As there is no manufacturing of solid fuels in Singapore, Manufacture of solid fuels (1.A.1.c.i.) is indicated as NO. Likewise, Oil and gas extraction (1.A.1.c.ii.) is also indicated as NO.

As there is no occurrence of CO_2 capture under this subcategory, the amount CO_2 capture is indicated as NO.

3.2.4.3. Description of any Flexibility Applied

Flexibility for time series which starts from year 2000 to 2022 as described in Section 1.9. Summary of any flexibility applied had been applied throughout the report.

3.2.4.4. Uncertainty assessment and time series consistency

The uncertainty estimates for the 1.A.1. Energy Industries category are estimated to be ±15% for CO_2, ±342% for CH_4 and ±283% for N_2O respectively.

Uncertainty assessment for 1.A.1. Energy industries is performed using Approach 1 – Propagation of Error. Uncertainty estimates are calculated according to the type of fuel consumed in the respective subcategories in 1.A.1. The uncertainty factors used for activity data and emission factors are dependent on the availability of data in both the base year and reporting year.

The reporting year 2022 utilises company-level data collected under CPA where each company reports the uncertainty from the measurement/collection of fuel consumption activity data and the uncertainty associated with the emission factors used to estimate GHG emissions.

As CPA only came into effect in 2019, the site-specific level of precision of uncertainty data used in the reporting year 2022 would not be available for base year 2000. Hence, default uncertainty values are used for uncertainty assessment for the base year. The uncertainties for activity data and emission factors used for IPCC category 1.A.1. are presented in Table 37.

Table 37: Uncertainty factors used for base year 2000 for 1.A.1. Energy Industries

Uncertainty Parameters	Liquid Fuels			Gaseous fuels			Other fossil fuels			Biomass		
	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
Activity Data	2%			2%			2%			2%		
Emission factor	2%	150%	200%	2%	150%	200%	2%	150%	200%	2%	150%	200%

The uncertainty factor of 2% for activity data was referenced from the upper range of the level of uncertainty associated with main activity electricity and heat production of data collection through surveys in less developed statistical systems.

The CH_4 uncertainty factors for base year 2000 as seen in the tables above reference the upper limit of the range of the default uncertainty estimates for stationary combustion emissions factors for Commercial, Institutional and Residential combustion in Table 2.12 of 2006 IPCC Guidelines.

As there are no default uncertainty factors provided by IPCC Guidelines for N_2O emission factor for 1.A.1 subcategory, the N_2O emission factor uncertainty for base year 2000 as seen in the tables above are determined from USA's uncertainty range Table 2.14 in the 2006 IPCC Guidelines. Considering the similarity in method of emissions calculations (Tier 1), referencing the upper limit of the uncertainty range implemented in USA's 2003 GHG inventory submission. This provides a modest estimate of the uncertainty associated with the emission factor of N_2O. The breakdown of the uncertainty calculations for 1.A.1. Energy Industries can be found in Annex II.

3.2.4.5. Category-specific QA/QC and verification

Compliant with QA/QC plan and implementation as outlined in Chapter 1, Section 1.5.

3.2.4.6. Category-specific recalculations

There are no recalculations of energy data collected from public electricity producers.

3.2.4.7. Category-specific planned improvements

For the key categories emissions estimated using Tier 1, work on the developing of a country-specific EF for fuels used in Singapore to move to Tier 2 to be in line with the 2006 IPCC guidelines.

3.2.5. Manufacturing Industries and Construction (CRT Category 1.A.2.)

3.2.5.1. Category description

The Manufacturing industries and construction category accounts for several industrial components. Emissions from the combustion of fuels for heat or mechanical work are included in this category. This comprises emissions from combustion for the generation of electricity and heat for own use in the industries. The emissions from this category should be specified by the subcategories corresponding to the ISIC.

In 2022, the total GHG emissions for Manufacturing industries and construction sector is 18,980 kt CO_2 eq, a decrease from 21,092 kt CO_2 eq in 2018.The reduction is partly attributed to the implementation of the CPA that came into effect in 2019. With additional reporting scrutiny and requirement for industrial facilities to compute GHG emissions for fuel combustion activities, there is greater responsibility at a company-level to curb emissions, improve the transparency of emission reporting and reduce business costs. To ensure consistency in reporting, facilities regulated under CPA are required to submit an ER, and companies that attain the second emission threshold of 25,000 t CO_2 eq are required to register as a taxable facility and submit an MP and an annual third-party verified ER. More information on the reporting requirements under the CPA can be found in the "Greenhouse Gas (GHG) Emissions Measurement and Reporting Guidelines".

The breakdown of emissions from Manufacturing industries and construction into subcategories according to ISIC is as follows:

1.A.2.a. Iron and steel
1.A.2.b. Non-ferrous metals
1.A.2.c. Chemicals
1.A.2.d. Pulp, paper, and print
1.A.2.e. Food processing, beverages and tobacco
1.A.2.f. Non-metallic minerals
1.A.2.g. Other

The presence of manufacturing industries and construction activities here in Singapore is relatively limited compared to other developing states due to the restricted amount of land space available for factories coupled with a small labour workforce. Hence, there is only a small number of companies reporting fuel consumption activity data under this category.

Figure 22: Total emissions from Manufacturing industries and construction (2000 to 2022)

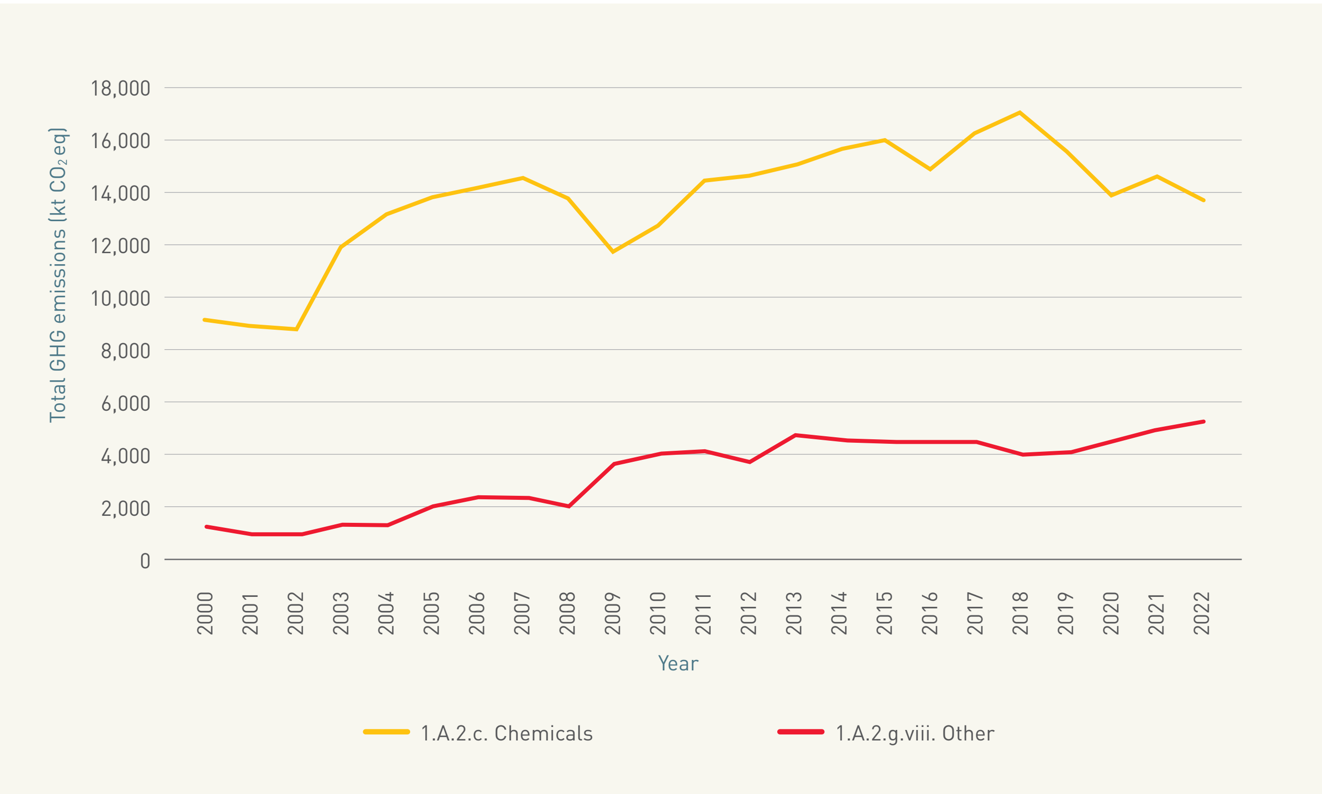


Table 38: Total emissions from Manufacturing industries and construction (2000 to 2022)

Greenhouse Gas Category	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
	GHG Emissions (kt CO_2 eq)											
1.A.2. Manufacturing industries and construction	10,452	9,933	9,766	13,294	14,463	15,899	16,556	16,862	15,918	15,357	16,888	18,583
1.A.2.a. Iron and steel	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1.A.2.b. Non-ferrous metals	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1.A.2.c. Chemicals	9,194	8,958	8,819	11,920	13,180	13,808	14,189	14,553	13,821	11,779	12,834	14,456
1.A.2.d. Pulp, paper and print	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1.A.2.e. Food processing, beverages and tobacco	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1.A.2.f. Non-metallic minerals	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1.A.2.g.i. Manufacturing of machinery	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1.A.2.g.ii. Manufacturing of transport equipment	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1.A.2.g.iii. Mining (excluding fuels) and quarrying	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1.A.2.g.iv. Wood and wood products	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1.A.2.g.v. Construction	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1.A.2.g.vi. Textile and leather	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1.A.2.g.vii. Off-road vehicles and other machinery	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1.A.2.g.viii. Other	1,258	975	947	1,374	1,283	2,091	2,367	2,309	2,097	3,579	4,053	4,128

Notation keys:
NO - Not occurring, IE - Included elsewhere

Greenhouse Gas Category	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
	GHG Emissions (kt CO_2 eq)										
1.A.2. Manufacturing industries and construction	18,445	19,781	20,189	20,536	19,442	20,793	21,092	19,661	18,387	19,527	18,980
1.A.2.a. Iron and steel	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1.A.2.b. Non-ferrous metals	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1.A.2.c. Chemicals	14,672	15,099	15,674	16,029	14,886	16,315	17,072	15,596	13,954	14,628	13,744
1.A.2.d. Pulp, paper and print	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1.A.2.e. Food processing, beverages and tobacco	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1.A.2.f. Non-metallic minerals	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1.A.2.g.i. Manufacturing of machinery	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1.A.2.g.ii. Manufacturing of transport equipment	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1.A.2.g.iii. Mining (excluding fuels) and quarrying	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1.A.2.g.iv. Wood and wood products	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1.A.2.g.v. Construction	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1.A.2.g.vi. Textile and leather	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1.A.2.g.vii. Off-road vehicles and other machinery	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1.A.2.g.viii. Other	3,773	4,682	4,515	4,507	4,556	4,478	4,020	4,065	4,434	4,899	5,236

Notation keys:
NO - Not occurring, IE - Included elsewhere

Iron and steel

This subcategory comprises emissions from the combustion of fuel for the reduction of ferrous waste and scrap in electric arc furnaces.

Non-ferrous metals

This subcategory comprises emissions from the combustion of fuel during the process of smelting and refining of tin and production of tin ingot.

Chemicals

This subcategory comprises emissions from the combustion of fuels for the manufacturing of industrial chemicals. This includes the manufacturing of industrial acids and alkalis and the manufacture of liquified or compressed inorganic industrial or medical gases, elemental gases, liquid or compressed air, refrigerant gases, mixed industrial gases and inert gases such as carbon dioxide and/or isolating gases.

Pulp, paper and print

This subcategory comprises emissions from fuel combustion for the manufacturing process of pulp, paper and paperboard.

Food processing, beverages and tobacco

This subcategory comprises emissions from the combustion of fuels in food processing establishments during the manufacturing, processing, preparation and packing of food and the manufacture of beverages and tobacco.

Non-metallic minerals

This subcategory comprises emissions from the combustion of fuels for the manufacturing of non-metallic minerals. These include products such as ceramics, cement, glass and glass products (including the yarn of glass fibres).

Other

This subcategory comprises emissions from the combustion of fuels for the manufacturing of products not included in the above subcategories. This includes manufacturing of transport equipment, mining and quarrying, wood and wood products, textile and leather, off-road vehicles and other machinery.

3.2.5.2. Methodological issues

Table 39: Method and emission factors used for emissions estimation in Manufacturing industries and construction sector

GHG source and sink category	CO_2		CH_4		N_2O	
	Method applied	Emission Factor	Method applied	Emission Factor	Method applied	Emission Factor
1.A.2.a. Iron and steel	T1	D	T1	D	T1	D
1.A.2.c. Chemicals	T1, T3	D, PS	T1	D	T1	D
1.A.2.g. Other	T1, T3	D, CS, PS	T1	D	T1, T3	D, PS

Notation keys:
T1 - Tier 1, T3 - Tier 3, D - Default, CS - Country-specific, PS - Plant-specific

Iron and steel

Choice of activity data

The following fuels are used in Iron and steel (1.A.2.a.):

- Liquid fuels (gas/diesel oil, residual fuel oil)
- Solid fuels (such as Gas Work Gas)
- Gaseous fuels (natural gas)

As there is no disaggregated data (e.g. industrial diesel, light fuel oils) collected for this subcategory for liquid fuels, solid fuels and gaseous fuels, the notation key "IE" have been applied for these fuels in the manufacturing of iron and steel (1.A.2.a.) subcategory. Other fossil fuels, peat and biomass are indicated as NO.

There is no capture of CO_2, therefore the amount of CO_2 captured is indicated as NO.

Non-ferrous metals

Choice of activity data

The following fuels are used in Non-ferrous metals Iron and steel (1.A.2.b.):

- Liquid fuels (gas/diesel oil, residual fuel oil)
- Solid fuels (Gas Work Gas)
- Gaseous fuels (natural gas)

As there is no disaggregated data (e.g. industrial diesel, light fuel oils)collected for this subcategory for liquid fuels, solid fuels and gaseous fuels, the notation key "IE" have been applied for these fuels in manufacturing of non-ferrous metals (1.A.2.b.) subcategory.

As there is no capture of CO_2, the amount of CO_2 captured is indicated as NO.

Chemicals

The methodology used for estimating GHG emissions from manufacturing of chemicals (1.A.2.c.) follows a modified Tier 1 method and Tier 3 method for compiling CO_2, CH_4 and N_2O emissions. The implied emission factors are calculated based on the aggregate fuel consumption data and the measure of CO_2, CH_4 and N_2O using the formula below.

Tier 1 equation for GHG emissions from Chemicals industry:

$$Emission_{GHG,\,fuel} = Fuel\ Consumption_{fuel} \times Emission\ Factor_{GHG,\,fuel}$$

Where:

$Emissions_{GHG,\,fuel}$ = emissions of a given GHG by fuel type
$Fuel\ Consumption_{fuel}$ = amount of fuel combusted (TJ)
$Emission\ Factor_{GHG,\,fuel}$ = emission factor for respective GHG and fuel type

While Tier 3 approach was applied, the emissions estimate was not dependent on combustion technology but rather, the facility computed the emissions using plant-specific emission factor.

Choice of activity data

The following fuels are used in the manufacturing of chemicals (1.A.2.c.):

- Liquid fuels
- Solid Fuels (such as Gas Work Gas)
- Gaseous fuels (Natural Gas)
- Other fossil fuels (such as waste oils, waste gas)

Liquid fuels comprise:

- Residual fuel oil
- Refinery gas
- Other Petroleum Products
- Liquefied petroleum gas (LPG)
- Petroleum coke
- Jet kerosene
- Others

Choice of emission factor

Liquid fuel:

The emission factors for residual fuel oil and refinery gas were extracted from 2006 IPCC Guidelines, Volume 1, Chapter 1, Table 1.2 and Table 1.3. The CO_2, CH_4 and N_2O emission factors used for residual fuel oil and refinery gas can be found in Table 40. Due to data confidentiality under the regulations, for other petroleum products, LPG and petroleum coke, jet kerosene and other emission factors used would not be disclosed.

Table 40: Emission factor used for liquid fuel in Chemical industry

Fuel type	CO_2 emission factor (kg CO_2/TJ)	CH_4 emission factor (kg CH_4/TJ)	N_2O emission factor (kg N_2O/TJ)
Refinery Gas	57,567	1	0.1
Residual Fuel oil	77,367	3	0.6

Solid fuel:

The emission factor for solid fuel was mainly reported by CPA facilities where plant-specific emission factors were used.

Gaseous fuel:

The emission factor for natural gas was extracted from 2006 IPCC Guidelines, Volume 1, Chapter 1, Table 1.2 and Table 1.3. The CO_2, CH_4 and N_2O emission factors used for natural gas can be found in Table 41 below.

Table 41: Emission factor used for gaseous fuel in Chemical industry

Fuel type	CO_2 emission factor (kg CO_2/TJ)	CH_4 emission factor (kg CH_4/TJ)	N_2O emission factor (kg N_2O/TJ)
Natural gas	56,100	1	0.1

Other fossil fuels:

The emission factor for other fossil fuels was mainly reported by CPA facilities where plant-specific emission factors were used.

As there is no capture of CO_2, the amount of CO_2 captured is indicated as NO.

Pulp, paper and print

Similar to 1.A.2.b. Non-ferrous metals, the fuels used are the same. As there is no disaggregated data (e.g. industrial diesel, light fuel oils) collected for this subcategory for liquid fuels, solid fuels and gaseous fuels, the notation key "IE" has been applied for these fuels in the manufacturing of pulp, paper and print (1.A.2.d.) subcategory. Other fossil fuels, peat and biomass are indicated as NO.

The amount of captured CO_2 is indicated as NO as there is no capture of CO_2 occurring for this process.

Food processing, beverages and tobacco

Similar to 1.A.2.b. Non-ferrous metals, the fuels used are the same. As there is no disaggregated data (e.g. industrial diesel, light fuel oils) collected for this subcategory for liquid fuels, solid fuels and gaseous fuels, the notation key "IE" has been applied for these fuels in the manufacturing of food processing, beverages and tobacco (1.A.2.e.) subcategory. Other fossil fuels, peat and biomass are indicated as NO.

As there is no capture of CO_2, the amount of CO_2 captured is indicated as NO.

Non-metallic minerals

Similar to 1.A.2.b. Non-ferrous metals, the fuels used are the same. As there is no disaggregated data (e.g. industrial diesel, light fuel oils) collected for this subcategory for liquid fuels, solid fuels and gaseous fuels, the notation key "IE" has been applied for these fuels in manufacturing of non-metallic metals (1.A.2.f.) subcategory. Other fossil fuels, peat and biomass are indicated as NO.

As there is no capture of CO_2, the amount of CO_2 captured is indicated as NO.

Other

The methodology used for estimating GHG emissions from Other (1.A.2.g.) follows a modified Tier 1 method for compiling CO_2, CH_4 and N_2O emissions. The implied emission factors are calculated based on the aggregate fuel consumption data and the measure of CO_2, CH_4 and N_2O using the formula below.

Tier 1 equation for GHG emissions from Others:

$$Emission_{GHG,\,fuel} = Fuel\ Consumption_{fuel} \times Emission\ Factor_{GHG,fuel}$$

Where:

$Emissions_{GHG,\,fuel}$ = emissions of a given GHG by fuel type
$Fuel\ Consumption_{fuel}$ = amount of fuel combusted (TJ)
$Emission\ Factor_{GHG,\,fuel}$ = emission factor for respective GHG and fuel type

While Tier 3 approach was applied, the emission estimate was not dependent on combustion technology but rather, the facility computed the emissions using plant-specific emission factor.

Choice of activity data

The following fuels are used in Other (1.A.2.g.):

- Liquid fuels
- Solid Fuels (such as Gas Work Gas)
- Gaseous Fuels (Natural Gas)
- Other fossil fuels

Liquid fuels comprise:

- Gas/diesel oil
- Other Kerosene
- Residual fuel oil (e.g. light fuel oils, heavy fuel oils)

Liquid fuel consumption activity data used are extracted from:

- 2000 – 2018 data on residual fuel oil and refinery gas used by refineries and petrochemicals, and data on industrial fuels such as light fuel oils, heavy fuel oils, industrial diesel and other kerosene are collected from NEA's Pollution Control Division (PCD).
- 2019 – 2022 data on residual fuel oil and refinery gas used by refineries and petrochemicals are collected under CPA. Data on industrial fuels such as light fuel oils, heavy fuel oils, industrial diesel and other kerosene are collected from NEA PCD.

Solid fuel consumption activity data used is extracted from:

- 2000 – 2022 solid fuel data collected from EMA

Gaseous fuel consumption activity data used is extracted from:

- 2000 – 2022 natural gas fuel data collected from EMA

Activity data and GHG emissions from Other fossil fuels are already accounted for in Other fossil fuels under 1.A.2.c. Chemicals as the activity data and GHG emissions could not be disaggregated in this report and are therefore indicated with the notation key IE.

Solid fuel aggregate activity data are indicated as C in Other (1.A.2.g.viii.) to protect the confidentiality of the data from the facility.

The amount of captured CO_2 is indicated as NO as there is no capture of CO_2 occurring for this process.

Choice of emission factor

Liquid fuel:

The emission factors for gas/diesel oil and residual fuel oil were extracted from 2006 IPCC Guidelines, Volume 1, Chapter 1, Table 1.2 and Table 1.3. The CO_2, CH_4 and N_2O emission factors used for gas/diesel oil and residual fuel oil can be found in Table 42 below.

Table 42: Emission factor used for liquid fuel in other energy industries

Fuel type	CO_2 emission factor (kg CO_2/TJ)	CH_4 emission factor (kg CH_4/TJ)	N_2O emission factor (kg N_2O/TJ)
Gas/diesel oil	74,067	3	0.6
Residual fuel	77,367	3	0.6

Solid fuel:

The emission factor for Gas Work Gas used was a country-specific carbon content of 15.2 t C/TJ.

Gaseous fuel:

The emission factor for natural gas was extracted from 2006 IPCC Guidelines, Volume 1, Chapter 1, Table 1.2 and Table 1.3. This includes Transformation losses from the production of Gas Work Gas included under the fuel type "Natural Gas". Gas Work Gas was mainly produced from Natural Gas in Singapore. The CO_2, CH_4 and N_2O emission factors used for natural gas can be found in Table 43 below.

Table 43: Emission factor used for gaseous fuel in other energy industries

Fuel type	CO_2 emission factor (kg CO_2/TJ)	CH_4 emission factor (kg CH_4/TJ)	N_2O emission factor (kg N_2O/TJ)
Natural gas	56,100	1	0.1

Other fossil fuels:

The emission factor for other types of fossil fuel was mainly reported by CPA facilities where plant-specific emission factor was used.

3.2.5.3. Description of any flexibility applied

Flexibility for time series which starts from year 2000 to 2022 as described in Section 1.9. Summary of any flexibility applied had been applied throughout the report.

3.2.5.4. Uncertainty assessment and time series consistency

The uncertainty values for the 1.A.2. Manufacturing Industries and Construction category are estimated to be ±15% for CO_2, ±151% for CH_4 and ±201% for N_2O.

The uncertainty assessment for this subcategory utilises Approach 1 – Propagation of Error. Uncertainty estimates are calculated according to the type of fuel used in the respective subcategories in 1.A.2.

As there is no country-specific/site-specific data on the uncertainty factors for this category, default uncertainty values referenced from the 2006 IPCC Guidelines are used to calculate the uncertainty for base year 2000. The uncertainty values used can be found in the table below.

Table 44: Uncertainty factors used for 1.A.2. Manufacturing industries and Construction category

Uncertainty Parameters	Liquid fuels			Solid fuels			Gaseous fuels		
	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
Activity Data (AD)		15%			15%			15%	
Emission factor (EF)	2%	150%	200%	2%	150%	200%	2%	150%	200%

The uncertainty factor of 15% for activity data was referenced from the upper limit of the range of the level of uncertainty associated with industrial fuel combustion activity data for data collection through surveys in less developed statistical environments. Considering that 1.A.2. Manufacturing industries and construction comprises manufacturing sectors that may not be considered energy intensive and that there is no disaggregation of activity for these subcategories, using a 15% uncertainty factor for uncertainty calculations may provide a more modest estimate of the uncertainty associated with activity data for this category.

The CH_4 uncertainty factors for base year 2000 as seen in the tables above reference the upper limit of the range of the default uncertainty estimates for stationary combustion emission factors for Commercial, Institutional and Residential combustion in Table 2.12 of 2006 IPCC Guidelines.

As there are no default uncertainty factors provided by IPCC Guidelines for N_2O emission factor for 1.A.2. subcategory, the N_2O emission factor uncertainty for base year 2000 as seen in the tables above are determined from USA's uncertainty range Table 2.14 in the 2006 IPCC Guidelines. Considering the similarity in method of emissions calculations (Tier 1), referencing the upper limit of the uncertainty range implemented in USA's 2003 GHG inventory submission, this provides a modest estimate of the uncertainty associated with the emission factor of N_2O.

The breakdown of the uncertainty calculations for 1.A.2. Manufacturing industries and Construction can be found in Annex II.

3.2.5.5. Category-specific QA/QC and verification

Compliant with QA/QC plan and implementation as outlined in Chapter 1, Section 1.5.

3.2.5.6. Category-specific recalculations

There are no recalculations of energy data collected for LPG, solid fuel and natural gas. However, for liquid fuel, with the inclusion of new data available from CPA, the new fuel used in manufacturing of chemicals was included in this category. This led to an increase of emissions from 1.A.2. Manufacturing industries and construction from 20,083 Gg CO_2 eq to 21,092 Gg CO_2 eq in 2018.

3.2.5.7. Category-specific planned improvements

Fugitive emissions from (i) systems used to transport processed natural gas to market, that is, to industrial consumers and natural gas distribution systems, (ii) natural gas storage systems and (iii) distribution of natural gas to end users are currently not estimated. Further assessment would have to be conducted to estimate the emissions for reporting in future reports. For key categories, discussion with stakeholders will be conducted to assess if higher tier for key category sources could be reported in order to be in line with good practice of the 2006 IPCC Guidelines.

3.2.6. Transport (CRT category 1.A.3.)

3.2.6.1. Category description

In 2018, the transport sector contributed 7,558 Gg CO_2 eq, which accounted for about 13.3% of Singapore's total GHG emissions. In 2022, the transport sector's emissions have decreased to 7,036 kt CO_2 eq (12.0% of Singapore's total GHG emissions), due to the transport policies and infrastructure implemented. Singapore has reduced the need for personal vehicles by increasing the reach and efficacy of the public transport system. Currently, Singapore's extensive rail network spans around 270 km and is set to grow to about 360km by early 2030s. By then, eight in 10 households will be within 10 minutes walking distance of a train station.

In addition to improving public transport accessibility, Singapore implemented policies to limit the emissions of vehicles on the road.

Under the Environmental Protection and Management (Vehicular Emissions) Regulations, drivers are mandated to switch off the engine of their motor vehicles while stationary for reasons other than traffic conditions. This reduces fuel consumption, and in turn GHG emissions.

Singapore also strictly manages the number of cars allowed on the roads, and limits vehicle population growth. Through the Vehicle Quota System, the number of new vehicles that can be registered in Singapore is capped.

The Transport category covers all GHG emissions from the combustion of fuel by all forms of transportation (excluding military transport), encompassing all sectors in Singapore.

The five subcategories in the Transport category are:
- Domestic Aviation
- Road Transportation
- Railways
- Domestic Navigation
- Other Transportation (Off-road vehicles)

Figure 23: Total GHG emissions from Transport sector (2000 to 2022)

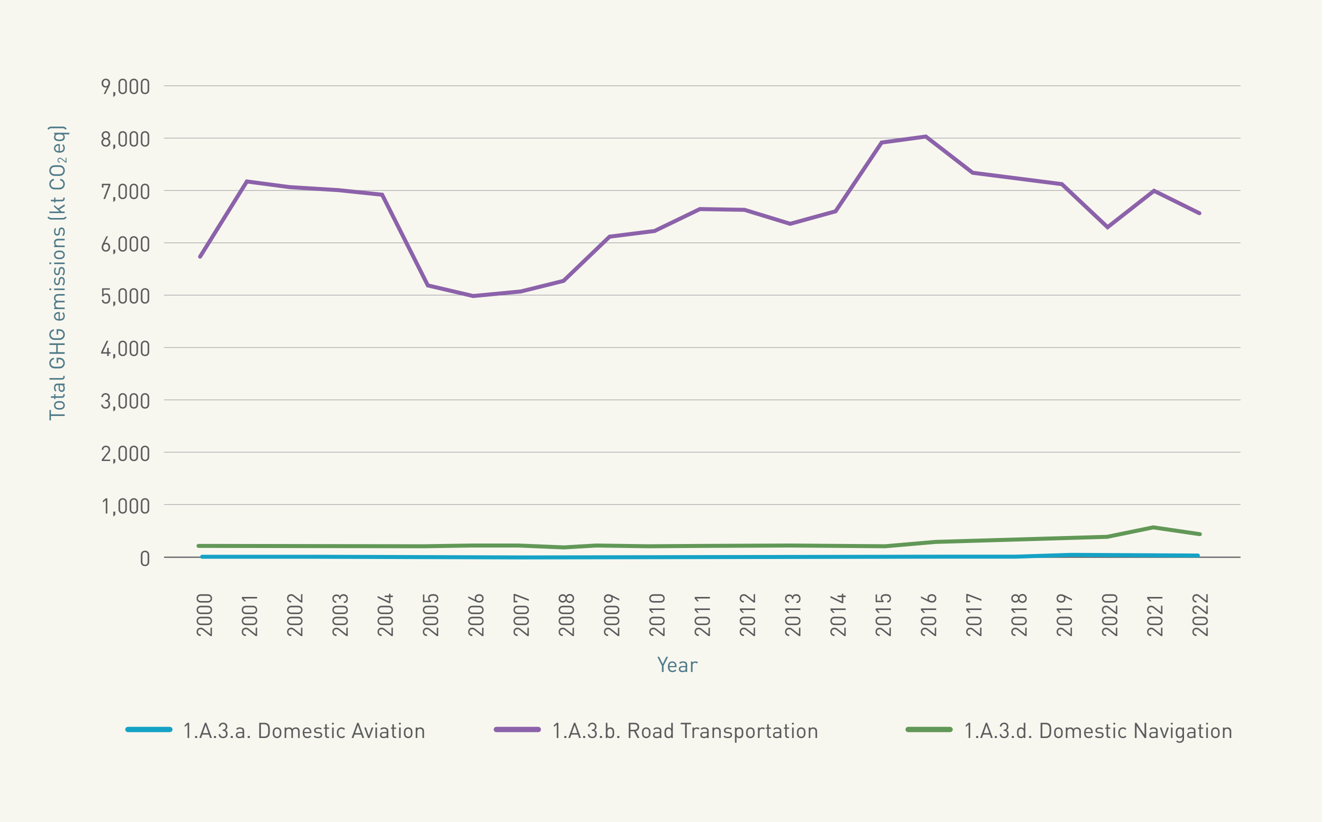


Table 45: Total GHG emissions from Transport sector (2000 to 2022)

Greenhouse Gas Category	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
	GHG Emissions (kt CO_2 eq)											
1.A.3. Transport	5,982.02	7,383.16	7,265.07	7,240.23	7,140.27	5,374.48	5,177.26	5,266.68	5,462.97	6,321.41	6,436.56	6,848.25
1.A.3.a. Domestic Aviation	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Aviation Gasoline	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Jet Kerosene	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
1.A.3.b. Road Transportation	5,767.06	7,168.35	7,047.59	7,027.62	6,925.92	5,172.13	4,979.64	5,063.50	5,272.59	6,121.12	6,224.88	6,652.18
Cars - Gasoline	2,165.83	2,157.98	2,192.64	4,805.98	2,254.74	1,991.27	2,138.38	2,261.67	2,277.71	2,616.42	2,429.83	2,394.13
Cars - Gaseous fuels	0.00	0.00	0.00	0.30	0.24	0.42	3.38	5.20	15.30	33.20	50.90	63.37
Light Duty Trucks - Diesel oil	3,601.22	5,010.36	4,854.95	2,221.34	4,670.94	3,180.44	2,837.89	2,796.62	2,979.59	3,471.50	3,744.15	4,194.68
Heavy duty trucks and buses - gasoline/ diesel/ gaseous fuels	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
Motorcycles - gasoline	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1.A.3.c. Railways	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1.A.3.d. Domestic Navigation	214.97	214.81	217.47	212.61	214.35	202.35	197.62	203.19	190.38	200.29	211.68	196.08
Gas/Diesel oil	214.97	214.81	217.47	212.61	214.35	202.35	197.62	203.19	190.38	200.29	211.68	196.08
Gaseous fuels	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1.A.3.e. Other Transportation	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE

Notation keys:
NO - Not occurring, IE - Included elsewhere, NE - Not estimated

Greenhouse Gas Category	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
	GHG Emissions (kt CO_2 eq)										
1.A.3. Transport	6,846.20	6,617.50	6,835.67	8,130.27	8,282.70	7,662.70	7,557.57	7,449.31	6,729.64	7,564.99	7,035.56
1.A.3.a. Domestic Aviation	NE	NE	NE	NE	NE	NE	NE	1.04	1.21	3.84	2.33
Aviation Gasoline	NE	NE	NE	NE	NE	NE	NE	0.30	0.22	0.28	0.27
Jet Kerosene	NE	NE	NE	NE	NE	NE	NE	0.74	1.00	3.56	2.06
1.A.3.b. Road Transportation	6,632.81	6,379.98	6,633.51	7,910.96	8,010.88	7,358.38	7,248.39	7,107.38	6,340.63	7,005.58	6,594.51
Cars - Gasoline	2,387.51	2,370.36	2,342.24	2,401.42	2,518.11	2,570.49	2,511.80	2,542.06	2,631.50	2,942.85	2,839.13
Cars - Gaseous fuels	48.66	44.15	42.10	35.11	27.51	16.78	6.43	6.10	4.55	7.49	10.06
Light Duty Trucks - Diesel oil	4,196.64	3,965.48	4,249.17	5,474.43	5,465.27	4,771.11	4,730.16	4,559.22	3,704.58	4,055.25	3,745.32
Heavy duty trucks and buses - gasoline/ diesel/ gaseous fuels	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
Motorcycles - gasoline	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1.A.3.c. Railways	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1.A.3.d. Domestic Navigation	213.39	237.52	202.16	219.31	271.82	304.31	309.18	340.89	387.79	555.57	438.72
Gas/Diesel oil	213.39	237.52	202.16	219.31	271.82	304.31	308.53	338.64	385.21	552.60	435.53
Gaseous fuels	NO	NO	NO	NO	NO	NO	0.65	2.25	2.59	2.96	3.19
1.A.3.e. Other Transportation	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE

Notation keys:
NO - Not occurring, IE - Included elsewhere, NE - Not estimated

Domestic aviation

This subcategory includes all GHG emissions from the combustion of fuel for domestic civil aviation. Emissions from flights that depart from Singapore and land in another country are accounted for under Memo Items – International Bunkers (1.D.1.a.). As per 2006 IPCC Guidelines, military planes are excluded from this category and accounted for under Other – (Not specified elsewhere) (1.A.5.).

Data on domestic aviation emissions before 2019 are not available as aviation companies did not retain older records. We will study the possibility of performing backwards projection for these years in future submissions.

Road transportation

This subcategory includes all GHG emissions from combustion of fuel used in road vehicles as per 2006 IPCC Guidelines.

Railways

This subcategory includes all GHG emissions from combustion of fuel for freight and passenger transport as per 2006 IPCC Guidelines. However, as there is no railway transport for freight in Singapore and railway transport for passenger uses electricity which is already accounted for in 1.A.1. Energy Industries, 1.A.3.c. Railway will be indicated as NO.

Domestic Navigation

This subcategory includes all GHG emissions from combustion of fuels used to propel harbour craft operating in Singapore's waters. For this NID submission, only activity data of gas/diesel oil and gaseous fuels are reported. There is currently no biomass fuel activity, which we will include in future rounds of reporting when it becomes available. Emissions from fuel combustion for international voyages are reported under Memo Items - International Bunkers (1.D.1.b.). Emissions from fuel used by fishing ships are reported under Agriculture/forestry/fishing (1.A.4.c.). Emissions from combustion of fuel for military vessels are reported under Other (Not specified elsewhere) – Mobile subcategory (1.A.5.b.).

Other transportation

This subcategory includes combustion emissions from all remaining transport activities including pipeline transport and ground activities in airports and harbours. Emissions from off-road activities that are not otherwise reported under Agriculture (1.A.4.c.) or Manufacturing Industries and Construction (1.A.2.) are reported under this subcategory. Emissions from military transport are reported under Other (Not specified elsewhere) – Mobile subcategory (1.A.5.b.). The natural gas transmission and distribution network conveys gas to power plants and industrial users in Singapore. The pipeline network is owned and operated by SP Group as the licensed gas transporter, and is mostly buried underground. Emissions from transport of processed natural gas from natural gas distribution system to facilities are currently not estimated.

3.2.6.2. Methodological issues

Table 46: Method and emission factors used for emissions estimation in Transport sector

GHG source and sink category	CO_2		CH_4		N_2O	
	Method applied	Emission Factor	Method applied	Emission Factor	Method applied	Emission Factor
1.A.3.a. Domestic Aviation	T1	D	T1	D	T1	D
1.A.3.b. Road transportation	T1	D	T1	D	T1	D
1.A.3.d. Domestic navigation	T1	D	T1	D	T1	D

Notation keys:
T1 - Tier 1, D - IPCC Default

Prior to the shift to use 2006 IPCC Guidelines, CH_4 and N_2O emissions were computed using Revised 1996 IPCC Guidelines Tier 2 methodology. With the transition to 2006 IPCC Guidelines, the parameter (fuel consumed by emission control technology) required for Tier 2 methodology is currently not available. Hence, Transport category emissions is calculated using Tier 1 methodology under the 2006 IPCC Guidelines.

Domestic aviation

The fuel consumption data reported under Domestic Aviation (1.A.3.a.) come from jet kerosene and aviation gasoline. Biomass aggregate fuel consumption data are indicated as NO.

The methodology for this subcategory follows a modified IPCC Tier 1 approach of calculating emissions. Using the equation (IPCC, 2006) in this section, the aggregate quantity of fuel consumption data are divided by measured CO_2, CH_4, N_2O emissions, and the implied emission factors are derived.

Tier 1 equation for Domestic Aviation emissions of CO_2, CH_4, and N_2O:

$$Emission = \sum_a [Fuel_a \times EF_a]$$

Where:
Emission = Emissions of CO_2, CH_4, N_2O respectively
$Fuel_a$ = fuel consumed, (kt or TJ) (as represented by fuel sold)
EF_a = emission factor (kg/kg or kg/TJ)
a = fuel type (Aviation gasoline, Jet kerosene)

Choice of activity data

Table 47: Choice of activity data for domestic aviation

Fuel type	Source of activity data
Aviation Gasoline	CAAS annual fuel consumption data compilation
Jet Kerosene	

Choice of emission factor

For CO_2 emissions calculation, it follows the fuel conversion factor of 3.16 kg CO_2/kg fuel for Jet-A/Jet A-1 fuel and 3.10kg CO_2/kg fuel for Aviation Gasoline, as listed in the ICAO's Standards and Recommended Practices Annex 16 Volume IV.

For CH_4 and N_2O, the default emission factors used were taken from the 2006 IPCC Guidelines, Volume 2, Chapter 3, Table 3.6.5 as shown in table below.

Table 48: Emission factors used for domestic aviation

Fuel type	CH_4 EF (kg CH_4/TJ)	N_2O EF (kg N_2O/TJ)
Aviation Gasoline	0.5	2
Jet Kerosene	0.5	2

Road transportation

There is no disaggregation of fuel consumption data in terms of the different vehicle types. Hence, the activity data and emission data for motor gasoline and compressed natural gas (CNG) consumption are reported under Cars (1.A.3.b.i.) and gas/diesel oil is reported under Light Duty Trucks (1.A.3.b.ii.).

The methodology for this subcategory follows a modified IPCC Tier 1 approach of calculating emissions. Using the equations seen below (IPCC, 2006), the aggregate quantity of fuel consumption data under Cars (1.A.3.b.i.) are divided by measured CO_2, CH_4, N_2O emissions, the implied emission factors are derived.

Tier 1 equation for road transport emissions of CO_2, CH_4, and N_2O:

$$Emission = \sum_a [Fuel_a \times EF_a]$$

Where:
Emission = Emissions of CO_2, CH_4, N_2O respectively
$Fuel_a$ = fuel consumed, (TJ) (as represented by fuel sold)
EF_a = emission factor (kg/TJ)
a = fuel type (motor gasoline, gas/diesel oil, gaseous fuels)

Choice of activity data

Table 49: Choice of activity data for Road transportation

Fuel Type	Source of activity data
Motor gasoline	PC1D Yearly fuel sales submission
Gas/diesel oil	
Gaseous fuel – Compressed Natural Gas (From 2003 onwards)	EMA's annual Singapore Energy Statistics (SES) publication

Liquid fuel:

The emission factors for motor gasoline and gas/diesel oil were extracted from 2006 IPCC Guidelines, Volume 2, Chapter 3, Table 3.2.1 and Table 3.2.2. The CO_2, CH_4 and N_2O emission factors used for motor gasoline and gas/diesel oil can be found in Table 50 below.

Table 50: Emission factor of liquid fuel used in Road transportation

Fuel type	CO_2 emission factor (kg CO_2/TJ)	CH_4 emission factor (kg CH_4/TJ)	N_2O emission factor (kg N_2O/TJ)
Motor gasoline	69,300	25	8
Gas/Diesel Oil	74,067	3.9	3.9

Gaseous fuel:

The emission factor for compressed natural gas was extracted from 2006 IPCC Guidelines, Volume 2, Chapter 3, Table 3.2.1 and Table 3.2. 2.. The CO_2, CH_4 and N_2O emission factors used for CNG can be found in Table 51 below.

Table 51: Emission factor of gaseous fuel used in Road transportation

Fuel type	CO_2 emission factor (kg CO_2/TJ)	CH_4 emission factor (kg CH_4/TJ)	N_2O emission factor (kg N_2O/TJ)
CNG	56,100	92	3

As Singapore does not collect granular data on evaporative emissions or the use of urea-based catalysts in vehicles, Other (1.A.3.b.v.) are indicated as IE.

Railways

Since there is no presence of freight transport in Singapore and railway transport for passenger uses electricity which is already accounted for in 1.A.1. Energy Industries, emissions under this subcategory will be indicated as NO.

Domestic Navigation

The methodology used for this category follows a Tier 1 approach of calculating CO_2, CH_4, N_2O emissions (IPCC, 2006). Gas/diesel oil and gaseous fuel consumption data for domestic navigation vessels are collected from the Maritime and Port Authority of Singapore (MPA).

Tier 1 equation for water-borne navigation emissions:

$$Emission = \sum [Fuel\ Consumed_a \times Emission\ Factor_a]$$

Where:
Emission = Emissions of CO_2, CH_4, N_2O respectively
Fuel Consumed$_a$ = fuel consumed, (TJ) (as represented by fuel sold)
Emission Factor$_a$ = emission factor (kg/TJ)
a = fuel type (gas/diesel oil, LNG)

Choice of activity data

Gas/diesel oil consumption activity data are obtained from MPA's annual compilation of bunker fuel sales as submitted by MPA-licensed bunker suppliers as part of the Terms and Conditions of the Bunker License (Bunker Supplier). MPA collects the domestic statistics submitted by bunker suppliers and conducts checks to ensure that the receiving vessel is a harbour craft/ pleasure craft. The bunker fuel sales from year 2000 to 2012 were back-extrapolated considering harbour craft fleet size and bunker fuel sales data and relevant trends.

The only type of fuel type consumption data for gaseous fuel collected are Liquefied Natural Gas (LNG). LNG fuel consumption activity data have been collected from MPA from year 2018 to 2022.

Choice of emission factor

Liquid fuel:

The emission factor for gas/diesel oil was extracted from 2006 IPCC Guidelines, Volume 2, Chapter 3, Table 3.5.2 and Table 3.5.3. The CO_2, CH_4 and N_2O emission factors used for gas/diesel oil can be found in the table below.

Table 52: Emission factor for liquid fuel used for domestic navigation

Fuel type	CO_2 emission factor (kg CO_2/TJ)	CH_4 emission factor (kg CH_4/TJ)	N_2O emission factor (kg N_2O/TJ)
Gas/Diesel Oil	74,100	7	2

Gaseous fuel:

The emission factor for LNG was extracted from 2006 IPCC Guidelines, Volume 2, Chapter 3, Table 3.2.1 and Table 3.2. 2. The CO_2, CH_4 and N_2O emission factors used for LNG can be found in the table below.

Table 53: Emission factor for gaseous fuel used for domestic navigation

Fuel type	CO_2 emission factor (kg CO_2/TJ)	CH_4 emission factor (kg CH_4/TJ)	N_2O emission factor (kg N_2O/TJ)
LNG	56,100	7	2

Residual fuel oil and gasoline consumption data are indicated as NO.

Other transportation

As there is no granular data collected on fuel consumption for activities under this subcategory, including fuel combustion data for the transport of gases, liquids, slurry and other commodities via pipelines, Pipeline Transport (1.A.3.e.i.) and Other (1.A.3.e.ii.) are indicated as IE.

3.2.6.3. Description of any flexibility applied

Flexibility for time series which starts from year 2000 to 2022 as described in Section 1.9. Summary of any flexibility applied had been applied throughout the report.

3.2.6.4. Uncertainty assessment and time series consistency

The uncertainty estimates are calculated within the respective subcategories of transport before summation to determine the overall uncertainty in the Transport category.

Uncertainty assessment for 1.A.3. Transport sector utilises Approach 1 – Propagation of Error.

Domestic Aviation

The uncertainty values for the 1.A.3.a. Domestic Aviation subcategory is estimated to be ±10% for CO_2, ±142% for CH_4 and ±212% for N_2O respectively.

Uncertainty factors for emission factors are referenced from the 2006 IPCC Guidelines Volume 2 Chapter 3.6.1.7 as shown in the table below.

Table 54: Uncertainty factors for uncertainty estimation for base year 2000 and reporting year 2022

Uncertainty Parameters	Aviation gasoline			Jet kerosene		
	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
Activity Data	5%			5%		
Emission factor	5%	100%	150%	5%	100%	150%

The activity data uncertainty is influenced by the accuracy of disaggregation of the data collection on domestic aviation from international aviation.

Emission factors of CH_4 and N_2O vary with technology, hence there is significant inherent uncertainty in the quantification of emissions without accounting for the different types of aircraft technology. However, since the contribution of emissions from this subcategory is minimal with respect to the total national GHG inventory, the corresponding uncertainty on the inventory is minimal.

Road Transportation

The uncertainty values for the 1.A.3.b. Road Transportation subcategory is estimated to be ±11% for CO_2, ±1596% for CH_4 and ±2487% for N_2O respectively.

Table 55: Uncertainty factors for Road transportation for base year 2000 and reporting year 2022

Uncertainty Parameters	Gasoline			Diesel Oil			CNG		
	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
Activity Data (AD)	5%			5%			5%		
Emission factor (EF)	5%	233%	244%	2%	144%	207%	4%	1574%	2467%

The uncertainty factor of 5% used for activity data uncertainty computation for the Transport category 1.A.3.b. was referenced from the 2006 IPCC Guidelines (paragraph 3.2.2) which is derived from the innate uncertainty from data acquisition through national survey and complete data returns.

With reference to the 2006 IPCC Guidelines, the uncertainty value associated with CO_2 emission factors for the three fuel types are calculated from the Road Transport Default CO_2 emission factors. At Tier 1, the default emissions factors and its uncertainty values are based on the assumption that 100 percent of the carbon present in the fuel is oxidised during or immediately following the combustion process.

The emissions data for the Road transportation category is aggregated, hence it is difficult to separate. As CH_4 and N_2O emissions from mobile sources are not key categories in Singapore's national GHG inventory, the default CH_4 and N_2O emission factors as per the 2006 IPCC Guidelines are used to calculate the uncertainty values.

Domestic Navigation

The uncertainty values for the 1.A.3.d. Domestic Navigation subcategory are estimated to be ±8% for CO_2, ±1541% for CH_4 and ±2471% for N_2O respectively.

Table 56: Uncertainty factors for Domestic navigation for base year 2000 and reporting year 2022

Uncertainty Parameters	Diesel Oil			Gaseous fuels - LNG		
	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
Activity Data	5%			5%		
Emission factor	1.5%	50%	140%	4%	1540%	2467%

A large part of the activity data uncertainty in documenting emissions from domestic navigation originates from disaggregating the domestic and international fuel consumption. With the complete survey of bunker fuel sales data performed annually by MPA, the uncertainty of the activity data of diesel oil and LNG can be assumed to be 5%.

Gas/diesel oil uncertainty factors

The emission factor uncertainty of gas/diesel oil used for uncertainty calculations references the default uncertainty values for diesel fuel used in water-borne navigation. According to the 2006 IPCC Guidelines, CO_2 emission factors for fuels are determined based on the carbon content of the fuel but the uncertainty of non-CO_2 emission factors is estimated to be much greater.

As the magnitude of CH_4 and N_2O emissions is much smaller compared to that of CO_2, the contribution to the overall uncertainty of the national inventory will be diminished.

LNG uncertainty factors

The emission uncertainty factors for LNG for Domestic Navigation are calculated using the emission factors for Energy Industries (2006 IPCC Guidelines Table 3.2.2.). This is consistent with the methodology and emission factors used for calculating emissions from LNG consumption as mentioned in 3.2.6.2. Methodological issues.

The breakdown of the uncertainty calculations for 1.A.3. Transport category can be found in Annex II.

3.2.6.5. Category-specific QA/QC and verification

Random checks are done monthly to verify that the information provided by MPA-licensed bunker suppliers tally with the bunker delivery notes issued by them.

3.2.6.6. Category-specific recalculations

There is no recalculation for this subcategory.

3.2.6.7. Category-specific planned improvements

As domestic aviation data are not available for the years before 2019, we will study the possibility of performing backwards projections for these years in future submissions.

3.2.7. Other Sectors (CRT category 1.A.4.)

3.2.7.1. Category description

This category compiles emissions from commercial, institutional and agriculture sectors. In 2018, the Other Sectors tracked a total of 647 kt CO_2 eq of GHG emissions which is about 1.1% of Singapore's total GHG emissions. The Commercial/Institutional sector (1.A.4.a.) comprises about 66.6%, making it the largest subcategory within the Other Sectors category in 2018. The relatively small contribution of emissions from this category to the total national GHG emissions can be attributed to the small population size in Singapore. In 2022, 765 kt CO_2 eq of GHG emissions was recorded, marking an 18.3% increase from 2018. This increase may be attributed to the increase in population size from 2018 to 2022.

Natural gas is the primary source of fuel used for temperature control and powering Singapore's buildings, including commercial, institutional and residential establishments. The majority of cooking stoves in Singapore run on piped town gas (i.e. gas work gas) or electricity, emissions from which are included under residential emissions under this category. The town gas network serves about 62% of households in Singapore and is largely used for cooking and water heating. In 2021, there were about 875,000 town gas accounts in Singapore, with commercial and industrial customers accounting for 1.74%.

The Other Sectors category, comprising all GHG emissions from the combustion of fuel for heat or mechanical work, consists of three subcategories:

1.A.4.a. Commercial/Institutional

1.A.4.b. Residential

1.A.4.c. Agriculture/forestry/fishing

All three subcategories can be further broken down into two sectors, namely: Stationary combustion and off-road vehicles and other machinery.

Figure 24: Total GHG emissions from Commercial and Residential sectors (2000 to 2022)

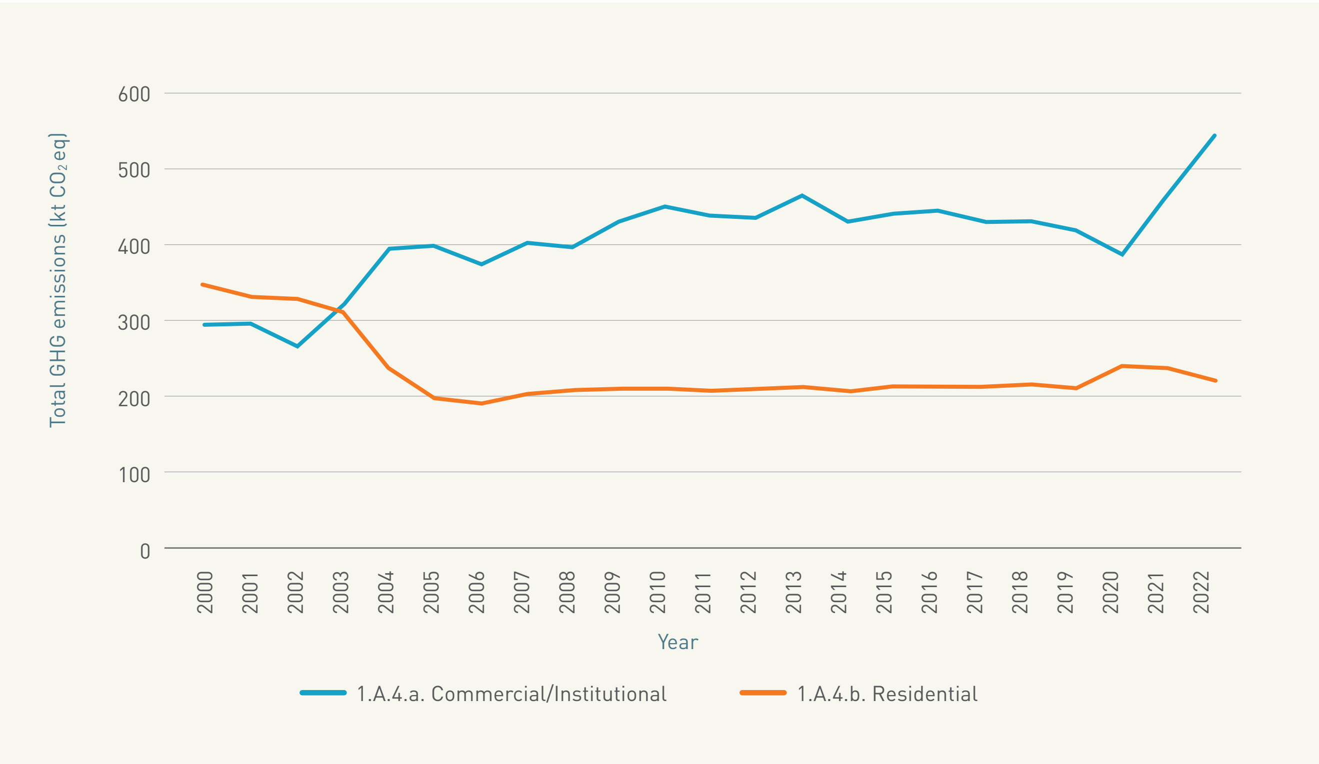


Table 57: Total GHG emissions from Commercial and Residential sectors (2000 to 2022)

Greenhouse Gas Category	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
	GHG Emissions (kt CO_2 eq)											
1.A.4. Other Sectors	642	627	595	632	633	599	567	606	605	641	661	646
1.A.4.a. Commercial/ Institutional	295	296	266	321	396	400	375	401	398	431	450	439
1.A.4.b. Residential	347	331	329	312	236	199	192	204	207	210	211	207
1.A.4.c. Agriculture/ forestry/fishing	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE

Greenhouse Gas Category	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
	GHG Emissions (kt CO_2 eq)										
1.A.4. Other Sectors	646	679	640	655	659	646	647	630	627	705	765
1.A.4.a. Commercial/ Institutional	436	465	431	442	447	432	431	419	387	468	542
1.A.4.b. Residential	211	214	209	213	212	214	216	211	240	237	223
1.A.4.c. Agriculture/ forestry/fishing	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE

Notation key:
IE - Included elsewhere

Commercial/institutional

The emissions from fuel combusted for commercial/ institutional end-users are reported under this subcategory in accordance with the 2006 IPCC Guidelines.

Residential

All emissions from fuel combustion in households, used for cooking and water heating, are included under this subcategory as per IPCC 2006 Guidelines.

Agriculture/forestry/fishing

This subcategory includes emissions from fuel combustion in agriculture/forestry/fishing and fishing industries such as fish farms. Emissions from crop and animal production, forestry and logging are accounted for under this subcategory. Emissions from fuels combusted in pumps, grain drying, horticultural greenhouses and other agriculture, or stationary combustion in the agriculture/ forestry/fishing industry are included under this subcategory as well. Emissions from fuel combustion for highway agricultural transportation are included under Transport Sector (1.A.3.) instead.

3.2.7.2. Methodological issues

Table 58: Method and emission factors used for emission estimation in Commercial and Residential sectors

GHG source and sink category	CO_2		CH_4		N_2O	
	Method applied	Emission Factor	Method applied	Emission Factor	Method applied	Emission Factor
1.A.4.a. Commercial/ institutional	T1	D, CS	T1	D	T1	D
1.A.4.b. Residential	T1	D, CS	T1	D	T1	D

Notation keys:
T1 - Tier 1, D - IPCC Default, CS - Country-specific

Singapore is currently still utilising default emission factors referenced from 2006 IPCC Guidelines for the calculation of CH_4 and N_2O emissions for 1.A.4. Other Sectors. We are in the process of developing country-specific emission factors for CH_4 and N_2O to improve the GHG accounting methodology to T2 in future BTR submissions.

Commercial/institutional

The methodology for the Commercial/institutional subcategory follows a modified Tier 1 Approach of calculating the CO_2, CH_4 and N_2O emissions.

Tier 1 equation for GHG emissions from Commercial/ institutional subcategory:

$$Emissions_{GHG,\ fuel} = Fuel\ Consumption_{fuel} \times Emission\ Factor_{GHG,fuel}$$

Where:
$Emissions_{GHG,\ fuel}$ = emissions of a given GHG by fuel type
$Fuel\ Consumption_{fuel}$ = amount of fuel combusted (TJ)
$Emission\ Factor_{GHG,\ fuel}$ = emission factor for respective GHG and fuel type

Choice of activity data

The following fuels are used in Commercial/institutional (1.A.4.a.):
- Liquid fuels (such as LPG)
- Solid fuels (such as gas work gas)
- Gaseous fuels (natural gas)

The data source for fuel consumption activity data under Stationary combustion (1.A.4.a.) can be found in the table below. Other fossil fuels, peat and biomass are indicated as NO.

Table 59: Data source for fuel type under Commercial/ institutional

Fuel type	Data Source
Liquid fuels	Department of Statistics (DOS)'s SingStat Table Builder
Solid fuels	EMA's annual Singapore Energy Statistics Publication
Gaseous fuels	

As there is no granular data for fuel consumption activity data for off-road vehicles and other machinery (1.A.4.a.ii.), liquid fuels under this subsector are indicated as IE, with the rest of the fuel types indicated as NO.

Choice of emission factor

Liquid fuel:

The emission factor for LPG was extracted from 2006 IPCC Guidelines, Volume 2, Chapter 2, Table 2.2. The CO_2, CH_4 and N_2O emission factors used for LPG can be found in the table below.

Table 60: Emission factor of liquid fuel used for Commercial/ institutional

Fuel type	CO_2 emission factor (kg CO_2/TJ)	CH_4 emission factor (kg CH_4/TJ)	N_2O emission factor (kg N_2O/TJ)
LPG	63,067	5	0.1

Gaseous fuel:

The emission factor for natural gas was extracted from 2006 IPCC Guidelines, Volume 2, Chapter 2, Table 2.2. The CO_2, CH_4 and N_2O emission factors used for natural gas can be found in the table below.

Table 61: Emission factor of gaseous fuel used for Commercial/institutional

Fuel type	CO_2 emission factor (kg CO_2/TJ)	CH_4 emission factor (kg CH_4/TJ)	N_2O emission factor (kg N_2O/TJ)
Natural gas	56,100	5	0.1

Solid fuel:

The emission factor for CH_4 and N_2O for Gas Work Gas was extracted from 2006 IPCC Guidelines, Volume 2, Chapter 2, Table 2.2. A country-specific carbon content of 15.2 t C/TJ was used. The CO_2, CH_4 and N_2O emission factors used for gas work gas can be found in the table below.

Table 62 : Emission factor of solid fuel used for Commercial/ institutional

Fuel type	CO_2 emission factor (kg CO_2/TJ)	CH_4 emission factor (kg CH_4/TJ)	N_2O emission factor (kg N_2O/TJ)
Gas Work Gas	55,733	5	0.1

There is no capture of CO_2 in this subcategory, hence the amount of CO_2 captured is indicated as NO.

Residential

The methodology for the Residential subcategory follows a modified Tier 1 Approach of calculating the CO_2, CH_4 and N_2O emissions.

Tier 1 equation for GHG emissions from Residential subcategory:

$$Emissions_{GHG,\ fuel} = Fuel\ Consumption_{fuel} \times Emission\ Factor_{GHG,fuel}$$

Where:
$Emissions_{GHG,\ fuel}$ = emissions of a given GHG by fuel type
$Fuel\ Consumption_{fuel}$ = amount of fuel combusted (TJ)
$Emission\ Factor_{GHG,\ fuel}$ = emission factor for respective GHG and fuel type

Choice of activity data

The following fuels are used in Residential (1.A.2.b.):
- Liquid fuels (such as LPG)
- Solid fuels (such as gas work gas)

The data source for fuel consumption activity data under Stationary combustion (1.A.4.b.i.) can be found in the table below. Gaseous fuels, other fossil fuels, peat and biomass are indicated as NO.

Table 63: Data source for fuel type under Residential sector

Fuel type	Data Source
Liquid Fuels	DOS's SingStat Table Builder
Solid Fuels	EMA's annual SES publication

Choice of emission factor

Liquid fuel:

The emission factors for LPG was extracted from 2006 IPCC Guidelines, Volume 2, Chapter 2, Table 2.2. The CO_2, CH_4 and N_2O emission factors used for LPG can be found in the table below.

Table 64: Emission factor of liquid fuel used for Residential sector

Fuel type	CO_2 emission factor (kg CO_2/TJ)	CH_4 emission factor (kg CH_4/TJ)	N_2O emission factor (kg N_2O/TJ)
LPG	63,067	5	0.1

Solid fuel:

The emission factor for CH_4 and N_2O for Gas Work Gas was extracted from 2006 IPCC Guidelines, Volume 2, Chapter 2, Table 2.2.. A country-specific carbon content of 15.2 t C/TJ is used. The CO_2, CH_4 and N_2O emission factors used for Gas Work Gas can be found in Table 65.

Table 65: Emission factor of solid fuel used for Residential sector

Fuel type	CO_2 emission factor (kg CO_2/TJ)	CH_4 emission factor (kg CH_4/TJ)	N_2O emission factor (kg N_2O/TJ)
Gas Work Gas	55,733	5	0.1

As there are no granular data for fuel consumption activity data for off-road vehicles and other machinery (1.A.4.b.ii.), liquid fuels under this subsector are indicated as IE as it is included under liquid fuels of Stationary combustion (1.A.4.b.i.), with the rest of the fuel types indicated as NO.

As there is no capture of CO_2 in this subcategory, the amount of CO_2 captured is indicated as NO.

Agriculture/forestry/fishing

There is no granular data for the fuel consumption under the agriculture/forestry/fishing (1.A.4.c.) subcategory, hence the aggregate activity data for the fuel streams in this subcategory are indicated as IE. Emissions from vehicles used for agriculture are included under 1.A.3. Transport category.

3.2.7.3. Description of any flexibility applied

Flexibility for time series which starts from year 2000 to 2022 as described in Section 1.9. Summary of any flexibility applied had been applied throughout the report.

3.2.7.4. Uncertainty assessment and time series consistency

As there are no country-specific uncertainty factors for the Others (1.A.4.) category, the default uncertainty factors from 2006 IPCC Guidelines are used for the calculation of uncertainty estimates in this category. The upper limit of the range of default uncertainty factors is deliberately used for uncertainty calculations considering that this is the first round of quantitative uncertainty estimation done for Singapore's NID. Future improvements and further discretion by the data owners and inventory compilers may shift the uncertainty factors used for estimations into the mid or lower range of the default uncertainty factors.

The uncertainty for the 1.A.4.a. Commercial/institutional subcategory is estimated to be ±26% for CO_2, ±261% for CH_4 and ±347% for N_2O respectively.

Table 66 : Uncertainty factors for 1.A.4.a. Commercial/institutional for base year 2000 and reporting year 2022

Uncertainty Parameters	Liquid Fuels			Solid Fuels			Gaseous Fuels		
	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
Activity Data	15%			15%			15%		
Emission factor	1%	150%	200%	1%	150%	200%	1%	150%	200%

The uncertainty for the 1.A.4. Residential subcategory is estimated to be ±21% for CO_2, ±213% for CH_4 and ±284% for N_2O respectively.

Table 67 : Uncertainty factors for 1.A.4.b. Residential for base year 2000 and reporting year 2022

Uncertainty Parameters	Liquid Fuels			Gaseous Fuels		
	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
Activity Data	15%			15%		
Emission factor	1%	150%	200%	1%	150%	200%

Assuming the upper limit of the range of default uncertainty values for obtaining activity data through surveys in a less developed statistical environment, the uncertainty factor for activity data is assumed to be 15%.

The CO_2 emission factor uncertainty references the upper limit of the range of USA's uncertainty range Table 2.13 in the 2006 IPCC Guidelines. Considering the similarity in complexity in method of emissions calculations (Tier 1), referencing the upper limit of the uncertainty range implemented in USA's 2003 GHG inventory submission, this provides a modest estimate of the uncertainty associated with the emission factor of CO_2.

The CH_4 uncertainty factor seen in the tables above references the upper limit of the range of the default uncertainty estimates for stationary combustion emission factors for Commercial, Institutional and Residential combustion in Table 2.12 of 2006 IPCC Guidelines.

As there are no default uncertainty factors provided by 2006 IPCC Guidelines for N_2O emission factor for this subcategory, the N_2O emission factor uncertainty seen in the tables above is determined from USA's uncertainty range Table 2.14 in the 2006 IPCC Guidelines. This is based on the similarity in complexity in method of emissions calculations (Tier 1), referencing the upper limit of the uncertainty range implemented in USA's 2003 GHG inventory submission. This provides a modest estimate of the uncertainty associated with the emission factor of N_2O.

The breakdown of uncertainty calculations for 1.A.4. Other Sectors can be found in Annex II.

3.2.7.5. Category-specific QA/QC and verification

Compliant with QA/QC plan and implementation as outlined in Chapter 1, Section 1.5.

3.2.7.6. Category-specific recalculations

There is no recalculation for this subcategory.

3.2.7.7. Category-specific planned improvements

There is no planned improvement for this subcategory.

3.2.8. Other (Not specified elsewhere) (CRT category 1.A.5.)

3.2.8.1. Category description

This category comprises all remaining emissions from fuel combustion that are not specified elsewhere. This includes emissions from fuel delivered to the military of other countries that are not engaged in multilateral operations. Any emission from fuel sold to any air or marine vessel engaged in multilateral operation pursuant to the Charter of United Nations should be excluded from the total emissions of military transport and should be reported separately under Category 1.D.3. However, there are no emissions from fuel delivered to the military of other countries in Singapore.

There is no previous emissions data under this category as military emissions were previously not included under Singapore's National GHG Inventory. In efforts to improve the transparency of GHG emission reporting in our national inventory, the Ministry of Defence (MINDEF) has provided fuel consumption and GHG emission data for this category.

The Other (Not specified elsewhere) category, comprising all GHG emissions from the combustion of fuel for heat or mechanical work, consists of two subcategories:

1.A.5.a. Stationary
1.A.5.b. Mobile

Table 68: Total emissions from all remaining emissions from fuel combustion (2000 to 2022)

Greenhouse Gas Category	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
	GHG Emissions (kt CO_2 eq)											
1.A.5. Other (Not specified elsewhere)	IE, NE	IE, NE	IE, NE	IE, NE	IE, NE	IE, NE	IE, NE	IE, NE	IE, NE	IE, NE	IE, NE	IE, NE
1.A.5.a Other (Stationary)	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1.A.5.a Other (Mobile)	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE

Greenhouse Gas Category	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
	GHG Emissions (kt CO_2 eq)										
1.A.5. Other (Not specified elsewhere)	IE, NE	IE, NE	IE, NE	IE, NE	IE, NE	IE, NE	IE, NE	IE, NE	289.69	247.28	252.36
1.A.5.a Other (Stationary)	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1.A.5.a Other (Mobile)	NE	NE	NE	NE	NE	NE	NE	NE	289.69	247.28	252.36

Notation keys:
IE - Included elsewhere, NE - Not estimated

Stationary

According to the IPCC 2006 Guidelines, emissions from fuel combustion in stationary sources that are not specified or included elsewhere are accounted for under this subcategory.

Mobile

Emissions from vehicles, machinery used in marine and aviation that are not included in the subcategory 1.A.4.c.ii. Off-road vehicles and Other Machinery 1.A.4.c.ii. are accounted for under this subcategory. This includes emissions from fuel combustion from military aviation, water-borne navigation and land transport.

3.2.8.2. Methodological issues

Table 69: Method and emission factors used for emission estimation of all remaining emissions from fuel combustion

GHG source and sink category	CO_2		CH_4		N_2O	
	Method applied	Emission Factor	Method applied	Emission Factor	Method applied	Emission Factor
1.A.5.a. Stationary	T1	D, CS	T1	D	T1	D
1.A.5.b. Mobile	T1	D, CS	T1	D	T1	D

Notation keys:
T1 - Tier 1, D - IPCC Default, CS - Country-specific

Stationary

The methodology for Other (Stationary) subcategory follows a modified Tier 1 Approach of calculating the CO_2, CH_4 and N_2O emissions.

Tier 1 equation for GHG emissions from Other (Stationary) subcategory:

$$\textit{Emissions}_{GHG,\,fuel} = \textit{Fuel Consumption}_{fuel} \times \textit{Emission Factor}_{GHG,fuel}$$

Where:
$Emissions_{GHG,\ fuel}$ = emissions of a given GHG by fuel type
$Fuel\ Consumption_{fuel}$ = amount of fuel combusted (TJ)
$Emission\ Factor_{GHG,\ fuel}$ = emission factor for respective GHG and fuel type

Choice of activity data

The following fuels are used in Stationary (1.A.5.a.):
- Solid fuels – Gas Work Gas
- Gaseous fuels – natural gas

Table 70: Data source for all remaining emissions from fuel combustion (Stationary)

Fuel type	Data Source
Gaseous Fuels	EMA's annual SES publication
Solid Fuels	

In consideration of the data sensitivity of military Gas Work Gas and natural gas usage, the activity data and emissions are indicated as IE and are included under 1.A.4.a. Commercial/institutional.

Choice of emission factor

Gaseous fuel:

The emission factor for natural gas was extracted from 2006 IPCC Guidelines, Volume 2, Chapter 2, Table 2.2.. The CO_2, CH_4 and N_2O emission factors used for natural gas can be found in the table below.

Table 71: Emission factor of gaseous fuel used for all remaining emissions from fuel combustion

Fuel type	CO_2 emission factor (kg CO_2/TJ)	CH_4 emission factor (kg CH_4/TJ)	N_2O emission factor (kg N_2O/TJ)
Natural Gas	56,100	5	0.1

Solid fuel:

The emission factor for CH_4 and N_2O for Gas Work Gas was extracted from 2006 IPCC Guidelines, Volume 2, Chapter 2, Table 2.2.. A country-specific carbon content of 15.2 t C/TJ is used. The CO_2, CH_4 and N_2O emission factors used for Gas Work Gas can be found in the table below.

Table 72: Emission factor of solid fuel used for all remaining emissions from fuel combustion

Fuel type	CO_2 emission factor (kg CO_2/TJ)	CH_4 emission factor (kg CH_4/TJ)	N_2O emission factor (kg N_2O/TJ)
Gas Work Gas	55,733	5	0.1

Mobile

The methodology for Other (Mobile) subcategory follows a modified IPCC Tier 1 approach of calculating emissions. Using the equation seen below, the fuel consumed is multiplied by the emission factor of the particular fuel, measured by CO_2, CH_4 and N_2O emissions where the implied emission factors are derived.

Tier 1 equation for road transport emissions of CO_2, CH_4 and N_2O:

$$Emission = \sum_a [Fuel_a \times EF_a]$$

Where:
Emission = Emissions of CO_2, CH_4, N_2O respectively
EF_a = emission factor (kg/TJ)
$Fuel_a$ = fuel consumed, (TJ) (as represented by fuel sold)
a = fuel type (Liquid fuels)

Mobile

Choice of activity data

The following fuels are used in Mobile (1.A.5.b.):

Liquid fuels:

Gas/Diesel Oil, motor gasoline, jet kerosene, aviation gasoline

Table 73: Data source for all remaining emissions from fuel combustion (Mobile)

Fuel type	Data Source
Liquid Fuels	Billing information obtained from contract managers

Due to the sensitive nature of the data under this subcategory, the activity data and emission factor are indicated as "Confidential".

3.2.8.3. Description of any flexibility applied

Flexibility for time series which starts from year 2000 to 2022 as described in Section 1.9. Summary of any flexibility applied had been applied throughout the report.

3.2.8.4. Uncertainty assessment and time series consistency

Uncertainty assessment is not performed for this category to protect the sensitive and confidential nature of the activity data.

Time series for this category only has data from 2020 to the reporting year 2022 as there is insufficient fuel consumption aggregate archival data to perform backward projection of GHG emission for fuel combustion for military use and applications for this BTR submission round. The time series data up to 1990 would be reported in the subsequent BTRs.

3.2.8.5. Category-specific QA/QC and verification

QA/QC had been conducted as per Section 1.5 Brief general description of QA/QC plan and implementation. Further details on the QA/QC process can be found below:

- After data collection, the reported data would be checked against the billing information
- Prior to submission of data collected, internal checks would be conducted if it meets the requirement of the inventory compiler such as if data is reported in the correct units.
- Internal documentation on the validation checks would also be maintained and archived thereafter.

3.2.8.6. Category-specific recalculations

There is no recalculation for this subcategory since emissions from 1.A.5.a. Other (Stationary) is included elsewhere and the reporting of 1.A.5.a. Other (Mobile) had been newly included in this category.

3.2.8.7. Category-specific planned improvements

As the activity data and emissions from military activities are not available and reported as "Not Estimated" for 2000 to 2019, the possibility of quantifying the activity data and emissions from military activities for these years in future submissions will be assessed.

3.3. Fugitive emissions from solid fuels and oil and natural gas and other emissions from energy production (CRT 1.B.)

3.3.1. Other (Not specified elsewhere) (CRT category 1.B.1.b.)

Fuel transformation occurs when energy products are transformed into other energy products respective to their end usage. The transformation refers to a physical or chemical conversion of a fuel into another fuel product with intrinsically different properties.

3.3.1.1. Category description

Fuel Transformation

Fugitive emissions from two groups of transformation are included under this subcategory, solid to solid transformation processes and gasification transformation processes.

This subcategory can be further broken down into five different types of fuel transformation processes:

1.B.1.b.i. Charcoal and biochar production
1.B.1.b.ii. Coke production
1.B.1.b.iii. Coal to liquids
1.B.1.b.iv. Gas to liquids
1.B.1.b.v. Other

Other

Fugitive emissions as a result of any other solid fuel-related activities, such as emissions from waste pile and surface mines are included under this category.

3.3.1.2. Methodological issues

Fuel Transformation

Fugitive emissions activity data from the charcoal and biochar production of the biomass plant is NO.

Other

Since there are no solid fuel mining activities here in Singapore, emissions under this subcategory are reported as NO.

3.3.1.3. Description of any flexibility applied

Flexibility for time series which starts from year 2000 to 2022 as described in Section 1.9. Summary of any flexibility applied had been applied throughout the report.

3.3.1.4. Uncertainty assessment and time series consistency

Uncertainty assessment for this category will be included in the next round of submission of the BTR, if applicable.

3.3.1.5. Category-specific QA/QC and verification

No QA/QC is required under this category since there is no activity reported.

3.3.1.6. Category-specific recalculations

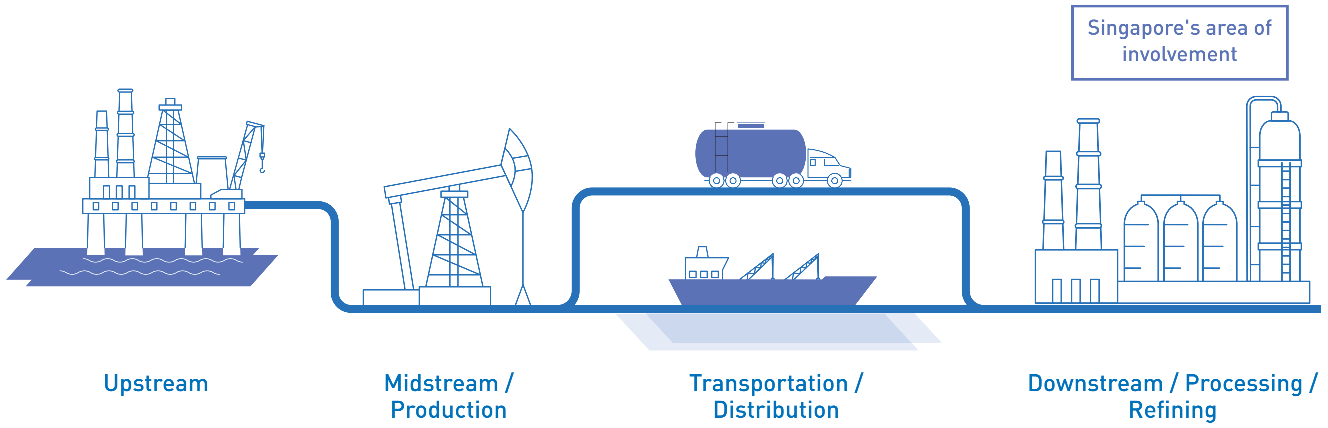
There is no recalculation for this subcategory.

3.3.1.7. Category-specific planned improvements

There is no planned improvement for this subcategory.

3.3.2. Oil, Natural Gas and other emissions from energy production (CRT category 1.B.2.)

Figure 25: Value chain of Oil, Natural Gas and other processes in energy production



As seen in the figure above, from upstream to downstream, every segment of the value chain emits fugitive emissions. The primary sources of these fugitive emissions may include fugitive equipment leaks, evaporation losses, venting, flaring and accidental releases. While there are no exploration or production activities in Singapore, there is significant involvement in the downstream portion of the value chain.

Refineries process crude oils, natural gas liquids and synthetic crude oils to produce final refined products (e.g. primarily fuels and lubricants). During the refinery process, it is inevitable that fugitive emissions are emitted. This occurs during equipment leaks, evaporation losses and filling during the refining process.

Venting emissions typically occur due to process-related losses from chemical transformations or processing steps. Examples include hydrogen plants (steam reformers), sour gas processing plants (sulfur recovery units) or storage tanks (due to flashing losses at upstream production operations). Venting may also occur due to routine activities such as maintenance/turnaround, or non-routine releases such from emergency or pressure-relieving equipment.

Similarly, flaring of produced gas may occur in emergency situations when pressure must be relieved from process vessels and equipment in order to avoid an unsafe condition or catastrophic failure, or when produced gas volumes do not meet user/consumer specifications.

Under the ECA introduced in 2013, energy-intensive companies in the industrial sector are mandated to monitor and report their energy use and GHG emissions annually. These emissions, which include fugitive emissions as defined in the 2006 IPCC Guidelines as well as the American Petroleum Institute (API) compendium, are estimated using a mix of Tier 1 and 3 calculation methods. With the implementation of CPA requirements from 2019 onwards, a drop in CO_2 and N_2O emissions and increase in CH_4 emissions were observed with a standardisation of reporting through the ER and the adherence to the "Greenhouse Gas (GHG) Emissions Measurement and Reporting Guidelines". Notwithstanding, the emissions from oil and other emissions from energy production remains at about 1% of national GHG totals similar to before the introduction of CPA. ERs are submitted in the EDMA system where emissions are automatically computed with the provision of activity data and site-specific emission factor, if default emission factor was not used, by facilities.

3.3.2.1. Category description

Figure 26: Total GHG emissions from oil and other emissions from energy production (2000 to 2022)

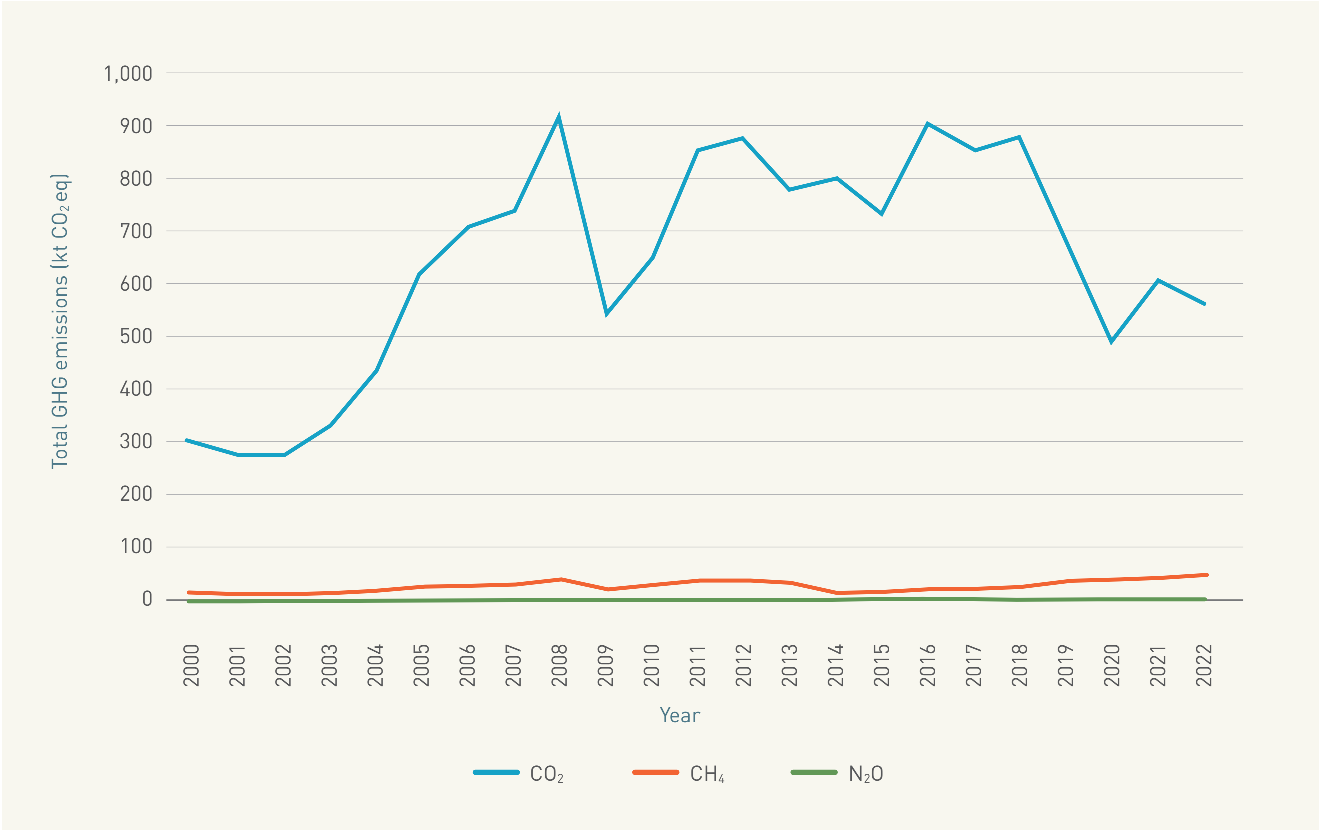


Table 74: Total GHG emissions from oil and other emissions from energy production (2000 to 2022)

Greenhouse Gas Category	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
	GHG Emissions (kt CO_2 eq)											
CO_2	303.11	274.2	273.57	328.35	432.77	618.57	706.81	739.60	921.30	541.16	648.18	859.45
CH_4	12.48	11.29	11.27	13.52	17.83	25.48	29.11	30.46	37.95	22.29	26.7	35.4
N_2O	0.25	0.22	0.22	0.27	0.35	0.5	0.57	0.6	0.75	0.44	0.53	0.7

Greenhouse Gas Category	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
	GHG Emissions (kt CO_2 eq)										
CO_2	878.87	780.34	797.84	734.49	906.25	854.86	879.49	683.59	493.26	609.47	564.93
CH_4	36.2	32.14	14.18	14.24	18.92	22.79	26.2	36.45	39.53	41.43	47.97
N_2O	0.71	0.63	1.06	0.97	1.25	1.29	1.78	0.98	0.81	0.99	1.01

Oil

This subcategory comprises emissions from venting, flaring and all other fugitive sources at oil facilities. Under fugitive emissions, there are three emission stream types, referencing the API Compendium[7], Section 6, that is (i) equipment leaks, (ii) wastewater management related to oil industry and (iii) other type of fugitive emissions such as from pipelines, evaporation losses from storage tanks and equipment leaks.

This subcategory can be further broken down into the following:

1.B.2.a.i. Exploration
1.B.2.a.ii. Production and upgrading
1.B.2.a.iii. Transport
1.B.2.a.iv. Refining/storage
1.B.2.a.v. Distribution of oil products
1.B.2.a.vi. Other

As there were no activities related to 1.B.2.a.i. Exploration, 1.B.2.a.ii. Production and upgrading, and 1.B.2.a.vi. Others, they were reported as NO. Since there was no disaggregation of emissions by 1.B.2.a.iii. Transport, 1.B.2.a.iv. Refining/storage and 1.B.2.a.v. Distribution of oil products, aggregated emissions had been reported under 1.B.2.a.iv. Refining/storage while the notation key 'IE' was used for 1.B.2.a.iii. Transport, and 1.B.2.a.v. Distribution of oil products.

Natural Gas

This subcategory comprises emissions from all other fugitive sources associated with the exploration, production, processing, transmission, storage and distribution of natural gas. As there are no natural gas facilities in Singapore involved in exploration, production and processing, they were reported as NO. The natural gas transmission and distribution network conveys gas to power plants and industrial users in Singapore. The pipeline network is owned and operated by SP Group as the licensed gas transporter, and is mostly buried underground. Emissions from transport of processed natural gas from natural gas distribution system to facilities are currently not estimated.

Venting

This subcategory accounts for all GHG emissions from the venting activities from oil facilities only (as there are no natural gas facilities in Singapore). Due to data confidentiality, venting from power generation facilities has been aggregated with oil facilities. There are 19 emission stream types for vents, taking reference from the API Compendium. The emission stream types represent a series of activities within the oil and gas sector that results in the release of GHG emissions from vents i.e. process vents. The emission stream types are aligned to the Section 5 of the API Compendium.

Flaring

This subcategory accounts for all GHG emissions from the flaring activities from oil facilities only (as there are no natural gas facilities in Singapore). There are eight emission stream types for flares, taking reference from the API Compendium. The emission stream types represent a series of activities that commonly use a flare:

(i) Gas Production
(ii) Sweet Gas Production
(iii) Sour Gas Production
(iv) Conventional Oil Production
(v) Heavy Oil / Cold Bitumen Production
(vi) Thermal Oil Production
(vii) Refining
(viii) Other (e.g. incineration or combustion of material that does not involve the recovery of energy commodities e.g. heat, steam)

3.3.2.2. Methodological issues

Table 75: Method and emission factor used in Oil and natural gas and other emissions from energy production

GHG source and sink category	CO_2		CH_4		N_2O	
	Method applied	Emission Factor	Method applied	Emission Factor	Method applied	Emission Factor
1.B.2.a. Oil	T1, T3	D, PS	T1, T3	D, PS	T1	D
1.B.2.c. Venting and flaring	T1, T3	D, PS	T1, T3	D, PS	T1	D

Notation keys:
T1 - Tier 1, T3 - Tier 3, D - Default, PS - Plant-specific

Oil

The calculation approach was adopted to quantify emissions. It is based on industry methods detailed in the API Compendium. The API Compendium provides a number of approaches to estimate fugitive emissions where facility would be able to select the most appropriate approach with reference to the applicable sections, tables, formulae, conversion factors or exhibits from the API Compendium. For flexibility, the generic emission stream equation allows the facility to specify the GHG types (CO_2, CH_4, N_2O) for wastewater treatment plants to be reported.

[7] American Petroleum Institute. (2009, August). Compendium of Greenhouse Gas Emissions Methodologies for the Oil and Natural Gas Industry.

$$E_{g,p} = E_{CO_2} + (E_{CH_4} \times GWP_{CH_4}) + (E_{N_2O} \times GWP_{N_2O})$$

Parameter	Parameter description	Units
$E_{g,p}$	Emissions for GHG (g) i.e. CO_2, CH_4 and N_2O for fugitive type (p)	tonne CO_2 eq
E_{CO_2}, E_{CH_4}, E_{N_2O}	Emissions for CO_2, CH_4 and N_2O	tonne
p	Type of fugitive emission i.e. emission stream type	Nil
GWP_g	Global warming potential for CH_4 and N_2O	Nil

For wastewater management, the relevant equations in the API Compendium are equations 6-11, 6-12, 6-13 and 6-14.

CH_4 emissions from either aerobic or anaerobic wastewater treatment	Equation 6-11
N_2O emissions from either aerobic or anaerobic wastewater treatment	Equation 6-12
CO_2 emissions from aerobic waste-water treatment	Equation 6-13
CH_4 emissions from anaerobic wastewater treatment	Equation 6-14

The API Compendium equation 6-12 can be simplified to the following:

$$E_{N_2O}\left(\frac{tonne}{year}\right) = Q\left(\frac{m^3}{year}\right) \times N\left(\frac{kg\ N}{m^3}\right) \times EF_{N_2O}\frac{kg\ N_2O - N}{kg\ N} \times \frac{44}{28} \times 0.001\ \frac{tonne}{kg}$$

Where:
Q = volume of wastewater treated
N = average concentration of N in effluent, $[N]_{out}$. Instead, $([N]_{in} - [N]_{out}]$ is more accurate. However, if $[N]_{out}$ is not measured, $[N]_{in}$ can be used but this will lead to an overestimation of N_2O emissions.
EF_{N_2O} = emission factor from discharged wastewater, 0.005 kg N_2O-N / kg N
44/28 = nitrogen to N_2O conversion factor

The API Compendium equation 6-13 can be simplified to following:

$$E_{CO_2} = Q\left(\frac{m^3}{year}\right) \times \frac{[BOD_5]}{0.7}\left(\frac{mg}{L}\right) \times \frac{44}{32} \times 1000\ \frac{L}{m^3} \times 10^{-9}\left(\frac{tonne}{mg}\right)$$

Where:
Q = wastewater flow rate
$BOD_5/0.7$ = approximation of the ultimate BOD i.e. total BOD initially present at the inlet before treatment. Alternatively, you could (i) replace BOD5/0.7 with ($BOD_{inlet} - BOD_{outlet}$), or (ii) replace $BOD_5/0.7$ with just BOD_{inlet} if you assume BOD_{outlet} is 0.
44/32 = oxygen to CO_2 conversion factor

When submitting the report under ECA or CPA, the facility would need to specify how the site-specific conversion factors will be calculated, including an option to use a Tier 1 site-specific conversion factor e.g. emission factors based on the API Compendium. When refineries are integrated with other facilities, it is difficult to disaggregate the stream of fugitive emissions that solely arises from refinery activities. Hence, for some facilities, there is no disaggregated data for the different types of streams of fugitive emissions namely from pipelines, evaporation losses or equipment leaks from oil refineries.

Choice of activity data and emission factors

The activity data and emissions were extracted from CPA from 2019 onwards and ECA from 2013 to 2018, which collects fugitive emissions data from reports submitted by oil refinery companies. For years prior to 2013, projection was conducted using the Manufacturing Output In Manufacturing By Industry (Refined Petroleum Products) obtained from DOS's Singstat Table Builder as the surrogate parameter.

Any Tier 1 site-specific conversion factors to be used for fugitive emissions should be derived from the API Compendium or any other international or industry guideline. For equipment leaks using the facility-level average emission factors approach in the API Compendium, when the CO_2 or CH_4 composition of the gas for fugitive sources is different from the API Compendium default factors[8], the site-specific CO_2 or CH_4 concentration must be specified in the report. The 2006 IPCC Guidelines, Volume 2, Chapter 4, Table 4.2.4 also provides some alternative facility-level emission factors.

The API Compendium equation 6-11 is based on the 2006 IPCC Guidelines on wastewater treatment and discharge[9]. The relevant Methane Correction Factor (MCF) are found in Tables 6-23 and 6-24 and these factors are referenced from the 2006 IPCC Guidelines[10]. The API Compendium also makes reference to the 2006 IPCC Guidelines, which provide default Chemical Oxygen Demand (COD) factors and the default wastewater generation rates, as tabulated in Table 76.

[8] Refer to Table 6-2 of API Compendium for Facility-Level Average Fugitive Emission Factors; Tables 6-3 to 6-11 for Equipment-Level Average Fugitive Emission Factors; and Tables 6-12 to 6-22 for Component-Level Average Fugitive Emission Factors.
[9] Refer to the 2006 IPCC Guidelines, Volume 5, Chapter 6: Wastewater Treatment and Discharge, Section 6.2.3 on industrial wastewater for more details.
[10] Refer to the 2006 IPCC Guidelines, Volume 5, Chapter 6: Wastewater Treatment and Discharge, Table 6.8 in page 6-21 for more details.

Table 76: Default Chemical Oxygen Demand (COD) factors and wastewater generation rates

Industry type	Wastewater generation rate, W (m^3/ton)	Range for W (m^3/ton)	Chemical Oxygen Demand (COD) (kg/m^3)	Range for COD (kg/m^3)
Petroleum Refineries	0.6	0.3 - 1.2	1	0.4 - 1.6
Organic Chemicals	67	0 - 400	3	0.7 - 5

The emissions from 1.B.2.a. Oil Refining/Storage are aggregated under 1.B.2.b. Flaring Oil and are indicated as IE since the disaggregation between fugitive emissions, venting and flaring from year 2013 to 2018 is not available.

Natural Gas

There are no emissions data collected on the transport of processed natural gas to natural gas distribution from natural gas facilities. Hence, the emissions under this subcategory are indicated as NE.

Venting

There are three emissions quantification methods to compute the emissions from vents. These included Method 1: Calculation approach for all emission stream types, Method 2: Material balance and Method 3: Direct measurement for certain emission stream types.

Most methods are based on Method 1: Calculation approach, unless otherwise specified. The general formula for vents is as follow:

$$E_{g,f} = E_{CO_2} \times (E_{CH_4} \times GWP_{CH_4})$$

Parameter	Parameter description	Units
$E_{g,f}$	Emissions for GHG (g) i.e. CO_2 and CH_4 for vent (f)	tonne CO_2 eq
E_{CO_2}	Emissions for CO_2	tonne
E_{CH_4}	Emissions for CH_4	tonne
f	Type of vent i.e. emission stream type	Nil
GWP_{CH_4}	Global warming potential for CH_4	Nil

Table 77 tabulates the respective sections and chapters of the API Compendium according to each emission stream type i.e. process vent. Most methods are based on Method 1: Calculation approach.

Table 77: Emission stream types for vents

Emission stream type	API Compendium references	Description
Process Vents - Dehydration Processes	5.1.1	CH_4 emission factors per m^3 gas processed by glycol dehydrators (table 5-2 and table 5-3) CO_2 emissions based on relative gas concentration (Exhibit 5.1 Section 2)
	5.1.3	Engineering approach for desiccant dehydrators (equation 5-1)
	5.1.4	Alternative glycol dehydrator equipment
Process Vents - Dehydrator Kimray Pumps	5.1.2	Additional CH_4 and CO_2 emissions from the use of gas-assisted glycol pumps (table 5-4) Ensure no double counting with dehydration processes
Process Vents - Acid gas removal processes	5.1.5	CH_4 emission factors per m^3 gas processed by acid gas removal units (table 5-5 or API's AMINECalc tool)
Process Vents - Sulphur recovery units	5.1.5	CO_2 emissions from sour gas processing using a material balance approach (equation 5-2 or equation 5-3)
Process Vents – Catalytic cracking	5.2.2	Three approaches are provided for the estimation of CO_2 emissions from coke removal from catalyst. (Figure 5-3 provided a decision tree to select the appropriate approach), being either: • Equation 5-4 • Equation 5-5 • Equation 5-6
Process Vents - Catalytic reforming	5.2.1	
Process Vents - Catalyst regeneration	5.2.1	
	5.2.4	An alternative approach to estimating CO_2 emissions based on weight fraction of coke on spent catalyst (equation 5-10)
Process Vents - Steam methane reforming (hydrogen plants)	5.2.2	Estimation of CO_2 emissions from feedstock based on one of: • Feedstock composition (equation 5-8) • H2 production and stoichiometric relationship (equation 5-9) • Default emission factors for measured natural gas feedstock and H2 production (Exhibit 5.8) • Flue rates and exhaust composition (equation 5-6)
	Material balance	Where CO and CO_2 are captured for transfer or re-use elsewhere, a material balance approach can be used
	Direct measurement	CO_2 emissions can be directly measured by exhaust stack monitoring
Process Vents - Delayed coking	5.2.3 Or 5.2.4	Combustion of coke based on carbon content (equation 5-4 and Exhibit 5.9)
Process Vents - Flexi-coking		
Process Vents - Asphalt blowing	5.2.5	CH_4 and CO_2 emission factors are provided (table 5-7 and equations 5-12 and 5-13 respectively)
Process Vents - Thermal cracking	5.2.6	CO_2 emissions from coke calcination and coke drum blowdowns (engineering estimate)
	Direct measurement	CO_2 emissions can be directly measured by exhaust stack monitoring
Cold Process Vents	5.3	Physical direct measurement (equation 5-14) or estimation of GHG releases using Method 1: Calculation approach
Process Vents - Storage tanks	5.4.1, 5.4.3	CH_4 and CO_2 emissions from flashing losses at upstream production operations. Figure 5-5 provided a decision tree to select the appropriate approach, being either: • Direct measurement • API's E&P TANK or other process simulators • Equation 5-16 (Vasquez-Beggs Equation) and equation 5-17 • Equation 5-18, equation 5-19 or equation 5-20 (Correlation equation approach) • Simple emission factors in Table 5-8 or estimate emissions using the flashing loss chart approach (figure 5-6) • Methane flashing loss emission factors (table 5-8) • Methane condensate flashing loss default emission factors • Methane-produced saltwater tank flashing loss default emission factors (table 5-10)
	5.4.2	No fugitive emissions are assumed for "weathered" crude and other refined petroleum products as they are assumed to contain no CH_4 or CO_2
Process Vents - Storage tanks and drain vessels	5.4.4	CH_4 and CO_2 emissions from natural gas blanketed tanks (equation 5-15)
Process Vents - Loading / Unloading / Transit	5.5	CH_4 and CO_2 emissions from handling and transfer of live (not weathered) crude oil. Where CH_4 and/or CO_2 is measured in the vented gas use • 5.5.1 Loading loss emissions (table 5-12) • 5.5.2 Ballasting emissions (table 5-13) • 5.5.3 Transit loss emissions (table 5-14)
Process Vents - Pneumatic devices	5.6.1	Calculation approach (equation 5-21) and industry average emission factors for CH_4 and CO_2 emissions from the use of pneumatic and chemical injection devices using hydrocarbon gases (table 5-15)
Process Vents - Chemical Injection Pumps	5.6.2	Calculation approach (equation 5-22) and industry average emission factors for CH_4 and CO_2 emissions from the use of pneumatic and chemical injection devices using hydrocarbon gases (table 5-16)
Non-routine activities	5.7	CH_4 and CO_2 emissions from non-routine events. Section 5.7.1 details an engineering approach to non-routine releases (equation 5-24 or 5-27) Section 5.7.2 details production segment emission factors for a number of activities such as blowdowns, compressor starts (using fuel gas) (table 5-23 and table 5-24) Section 5.7.3 details gas processing sector factor (table 5-25) Section 5.7.4 details gas transmission sector factors by activity type (table 5-26) Section 5.7.5 details gas distribution sector factors by activity type (table 5-27) Section 5.7.6 refers to table 5-23 for compressor states at refineries where fuel gas is used or other applicable activities

Method 1: Calculation approach

The API Compendium provides a number of approaches using Method 1: Calculation approach to compute emissions for the various emission stream types referenced in Table 77. The most appropriate approach selected would be reported with references to the API Compendium e.g. applicable sections, tables, formulae, conversion factors or exhibits. There are two options under Method 1: Calculation approach according to the API Compendium[11]. The two options are:

i Feedstock use i.e. quantity of feedstock used, assuming all carbon in the feedstock is combusted to CO_2. This is equivalent to equation 5-8 in the API Compendium.

ii Hydrogen production i.e. the quantity of hydrogen produced, based on the stoichiometric relationship between CH_4 (in feedstock) and H_2 (produced). This is equivalent to equation 5-9 in the API Compendium. Only applicable to emissions from the 'process vent – steam methane reforming (hydrogen plants)'.

Method 2: Material balance

The facility can also use Method 2: Material balance to determine the quantity of carbon converted to CO_2 based on the difference in the quantity of carbon contained in the feedstock, products and waste streams. For vents, the applicable emission stream type is 'process vent – steam methane reforming (hydrogen plants)', where CO_2 or other by-products are captured and stored or sold. Method 2: Material balance copies the Feedstock option under Method 1: Calculation approach, but with the total carbon input estimated from the quantity of feedstock. If the quantity of feedstock is not physically measured, the quantity of Hydrogen produced could be used to generate an engineering estimate of the quantity of feedstock required.

Method 3: Direct measurement

Method 3: Direct measurement may be applicable if an exhaust stack or ducting that allows measurement of the exhaust gas flow rate and GHG concentration has been installed.

Choice of activity data and emission factors

The activity data and emissions were extracted from CPA from 2019 onwards and ECA from 2013 to 2018, which collects venting data from reports submitted by oil refinery and power generation companies. The emissions from 1.B.2.c.i. Venting are aggregated under 1.B.2.b. Flaring and is indicated as IE since the disaggregation between fugitive emissions, venting and flaring from year 2013 to 2018 is currently not available. For years prior to 2013, projection was conducted using the Manufacturing Output In Manufacturing By Industry (Refined Petroleum Products) obtained from DOS's Singstat Table Builder as the surrogate parameter.

Regarding Method 1: Calculation approach, Tier 1 site-specific conversion factors to be used for vented emissions could be derived from the API Compendium where Table 77 details the applicable sections within the API Compendium for each emission stream.

Regarding Method 2: Material balance, the facility can refer to the default carbon content values in the 2006 IPCC Guidelines[12] for determining the carbon content of the feedstock or provide Tier 1 site-specific carbon content values.

Flaring

For flaring, only calculation approach is used. The calculation approach uses the following formula:

$$E_g = Q_p \times \sum(EF_{p,g,fe} \times GWP_g)$$

Parameter	Parameter description	Units
E_g	Emissions for GHG (g) i.e. CO_2, CH_4 and N_2O	tonne CO_2 eq
Q_p	Quantity of flare gas produced by process (p)	tonne
$EF_{p,CO_2,fe}$	Emission factor for CO_2 based on process (p) and flare efficiency (fe)	tonne CO_2/ tonne flare gas
$EF_{p,CH_4,fe}$	Emission factor for CH_4 based on process (p) and flare efficiency (fe)	tonne CH_4/ tonne flare gas
EF_{p,N_2O}	Emission factor for N_2O based on process (p) **Note that EF_{p,N_2O} is independent of the flare combustion efficiency*	tonne N_2O/ tonne flare gas
p	Process type i.e. emission stream type	Nil
fe	Flare combustion efficiency	Percentage (%)
GWP_g	Global warming potential for GHG (g)	Nil

Choice of activity data and emission factors

The activity data and emissions were extracted from CPA from 2019 onwards and ECA from 2013 to 2018, which collects flaring data from reports submitted by oil refinery companies. The emissions from 1.B.2.b. Flaring include data from 1.B.2.c.i. Venting since the disaggregation between fugitive emissions, venting and flaring from year 2013 to 2018 is currently not available. For years prior to 2013, the projection was derived using the Manufacturing Output In Manufacturing By Industry (Refined Petroleum Products) obtained from DOS's Singstat Table Builder as the surrogate parameter.

[11] Refer to API Compendium, Section 5, Chapter 2, pages 5-17 to 5-30.
[12] Refer to 2006 IPCC Guidelines, Volume 1, Chapter 1, Tables 1.2 and 1.3.

The calculation of emissions from flaring is similar to the calculation of emissions from fuel combustion with the following differences:

i. There is an additional parameter i.e. flare combustion efficiency which affects the computation of flare emissions, with default values of 99.5% for flares at refineries and similar petrochemical facilities and 98% for upstream facilities.

ii. According to the API Compendium[13] and 2006 IPCC Guidelines, the flare combustion efficiency is used to calculate CH_4 emissions from non-combusted CH_4 composition of the flare gas. Should there be a site-specific flare efficiency such that the default CH_4 emission factor is no longer appropriate, the facility would have to report the site-specific flare efficiency and CH_4 emission factor.

iii. If the facility's gas stream has a high CO_2 content, the site-specific CO_2 and CH_4 emission factors can be derived from the carbon content of the gas stream including the impact of oxidation, using the following formulae:

$$EF_{f,CO_2} = \left[\sum_{y}^{\neq CO_2} (mol\%_y \times f_{C,y} \times FE) + mol\%_{CO_2} \right] \times \frac{MW_{CO_2}}{\sum_y (mol\%_y \times MW_y)}$$

Where:
EF_{f,CO_2} is the emission factor for CO_2 for the fuel (f) in tonne CO_2/tonne fuel
$mol\%_y$ is the molar percentage of each component gas type (y) within the fuel
$mol\%_{CO_2}$ is the molar percentage of CO_2 within the fuel
MW_y is the molecular weight of the component gas type (y) measured in g/mol
MW_{CO_2} is the molecular weight of CO_2 (i.e. 44 g/mol)
$f_{c,y}$ is the number of carbon atoms in 1 molecule of the component gas type (y) (e.g. for CH_4, $f_{c,CH_4} = 1$, C_2H_6, $f_{c,C_2H_6} = 2$)
FE is the combustion efficiency of the flare

$$EF_{f,CH_4} = \frac{mol\%_{CH_4} \times MW_{CH_4}}{\sum_y (mol\%_y \times MW_y)} \times (1 - FE)$$

Where:
EF_{f,CH_4} is the emission factor for CH_4 for the fuel (f) in tonne CH_4/tonne fuel
$mol\%_y$ is the molar percentage of each component gas type (y) within the fuel
$mol\%_{CH_4}$ is the molar percentage of CH_4 within the fuel
MW_{CH_4} is the molecular weight of CH_4 (i.e. 16 g/mol)
MW_y is the molecular weight of the component gas type (y) measured in g/mol
FE is the combustion efficiency of the flare

The Tier 1 default flare efficiency (FE) and CO_2, CH_4 and N_2O emission factors are shown in the table below.

Table 78: Tier 1 default flare conversion factors

Emission stream type	Flare efficiency	CO_2 emission factor EF_{p,CO_2} (tonne CO_2/tonne flare gas)	CO_2 emission factor $EF_{p,CO_2,fe}$ (including flare efficiency) (tonne CO_2/tonne flare gas)	CH_4 emission factor EF_{p,CH_4} (tonne CH_4/tonne flare gas)	CH_4 emission factor $EF_{p,CH_4,fe}$ (including flare efficiency) (tonne CH_4/tonne flare gas)	N_2O emission factor (tonne N_2O/tonne flare gas)
Gas Production	98%	2.7	2.646	0.8	0.016	0.00003
Sweet Gas Production	98%	2.7	2.646	0.8	0.016	0.00003
Sour Gas Production	98%	2.7	2.646	0.8	0.016	0.00003
Conventional Oil Production	98%	2.7	2.646	0.8	0.016	0.00003
Heavy Oil / Cold Bitumen Production	99.50%	2.7	2.6865	0.8	0.004	0.00003
Thermal Oil Production	99.50%	2.7	2.6865	0.8	0.004	0.00003
Refining	99.50%	2.7	2.6865	0.8	0.004	0.00003
Other	99.50%	2.7	2.6865	0.8	0.004	0.00003

[13] Refer to API Compendium, Section 4, Chapter 6, page 4-40.

The default CO_2, CH_4 and N_2O emission factors based on the IPCC recommended values[14] for direct estimation of CO_2, CH_4 and N_2O emissions from reported flared volumes are 2.0, 0.012 and 0.000023 Gg, respectively, per 10^6 m^3 of gas flared for a flaring efficiency (i.e. oxidation factor) of 98% and a generic upstream gas composition as shown in the table below. A density of 0.745 kg/m^3 has been used to convert the CH_4, CO_2 and N_2O emission factors from a volumetric to mass basis.

Table 79: Generic gas composition in upstream gas processing operations

Component	Gas processing plant gas composition (volume %)
CH_4	91.9%
Non-methane hydrocarbon	6.84% (Molecular weight is unspecified) Further assume breakdown of 4.56% ethane and 2.28% propane
N2	0.68%
CO_2[15]	0.58%

3.3.2.3. Description of any flexibility applied

Flexibility for time series which starts from year 2000 to 2022 as described in Section 1.9. Summary of any flexibility applied had been applied throughout the report.

3.3.2.4. Uncertainty assessment and time series consistency

The uncertainty for the 1.B.2. Fugitive Emissions category is estimated to be ±2% for CO_2, ±4% for CH_4 and ±4% for N_2O respectively.

Uncertainty factors used for uncertainty estimates for base year 2000 are referenced from 2019 Refinement of 2006 IPCC Guidelines (Table 4.2.4c Chapter 4.2.2.3) as seen in the table below.

Table 80: Uncertainty factors used for uncertainty estimates for base year 2000

Uncertainty Parameters	CO_2	CH_4	N_2O
Activity data		25%	
Emission factor	139%	139%	141%

Uncertainty estimates performed for reporting year 2022 used weighted-aggregated site-specific uncertainty factors declared by reporting facilities under CPA.

The breakdown of uncertainty calculations for 1.B.2 Fugitive Emissions can be found In Annex II.

3.3.2.5. Category-specific QA/QC and verification

Compliant with QA/QC plan and implementation as outlined in Chapter 1, Section 1.5.

3.3.2.6. Category-specific recalculations

Previously, emissions from flaring and venting for all industries were reported under 1.B.2. Oil and natural gas and other emissions from energy production category. In this NID, the emissions from flaring and venting apart from oil industries would be reported in the relevant category such as chemical industries in the IPPU sector. As such, the emissions from this category decreased from 1,286 kt CO_2 eq to 907 kt CO_2 eq in 2018.

3.3.2.7. Category-specific planned improvements

Since plant-specific factors were used, comparison with the default range would be conducted and assessed if there are any differences from the 2006 IPCC Guidelines in future reports.

3.4. Carbon Dioxide Transport and Storage (CRT category 1.C.)

There is currently no long-term CO_2 transport and storage activities from Singapore.

3.5. International aviation and international navigation (international bunkers) and multilateral operations (CRT category 1.D.)

3.5.1. Category description

Due to its location in the Asia Pacific region, Singapore hosts one of the busiest maritime and aviation hubs which is further buttressed by strong international trading links. In 2022, the international aviation sector decreased to 10,213 kt CO_2 eq from 15,917 kt CO_2 eq in 2019 due to the impacts of COVID-19.

The proliferation of international trade boosts the volume of ships and cargo calling at Singapore's port. In 2022, the contribution of emissions from international navigation was 151,299 kt CO_2 eq.

[14] Refer to the 2006 IPCC Guidelines, Volume 2, Section 4.2.2.3, Tables 4.2.4 & 4.2.5 footnote 'e'.

[15] According to the API Compendium, CO_2 present in the stream to the flare is emitted directly as CO_2. Neither the flare combustion efficiency nor the conversion of flare gas carbon to CO_2 apply to the CO_2 already contained in the flared stream.

International aviation (aviation bunkers)

Emissions from international flights are included under this subcategory. According to the 2006 IPCC Guidelines, the boundary between domestic and international aviation is demarcated in the table below. As emissions under this subcategory is included under Memo Items, it would not be included in the national totals.

Criteria for defining international or domestic aviation (applies to individual legs of journeys with more than one take-off and landing)		
Journey type between two airports	Domestic	International
Departs and arrives in the same country	Yes	No
Departs from one country and arrives in another	No	Yes

International navigation (marine bunkers)

Emissions from international navigation (marine bunkers) are included under this subcategory. According to the 2006 IPCC Guidelines, the boundary between domestic and international navigation is demarcated in the table below. As emissions under this subcategory are included under Memo Items, it will not be included in the national totals.

Criteria for defining international or domestic navigation (applies to individual legs of journeys with more than one departing and docking)		
Journey type between two ports	Domestic	International
Departs and docks in the same country	Yes	No
Departs from one country and docks in another	No	Yes

Multilateral operations

Emissions from the sale of fuel to air or marine vessels activities that are pursuant to the Charter of the United Nations are included under this category. This subcategory is subtotalled under Memo Items in the CRT and would not be included in the national inventory totals.

3.5.2. Methodological issues

International aviation (aviation bunkers)

For CO_2 emissions calculation, the fuel conversion factor of 3.16 kg CO_2/kg fuel for Jet-A/Jet A-1 fuel, as listed in the ICAO's Standards and Recommended Practices Annex 16 Volume IV is used.

For CH_4 and N_2O, the default emission factors used were referenced to the 2006 IPCC Guidelines, Volume 2, Chapter 3, Table 3.6.5.

Table 81: Default CH_4 and N_2O emission factor used for international aviation

Fuel type	CH_4 EF (kgCH_4/TJ)	N_2O EF (kgN_2O/TJ)
Jet Kerosene	0.5	2

International navigation (marine bunkers)

The methodology used for this category follows a Tier 1 approach of calculating CO_2, CH_4, N_2O emissions (IPCC, 2006). Residual fuel oil, gas/diesel oil and LNG consumption data for international navigation vessels are collected from MPA.

Tier 1 equation for water-borne navigation emissions:

$$Emission = \sum [Fuel\ Consumed_a \times Emission\ Factor_a]$$

Where:

Emission = Emissions of CO_2, CH_4, N_2O respectively

Emission $Factor_a$ = emission factor (kg/TJ)

Fuel $Consumed_a$ = fuel consumed, (TJ) (as represented by fuel sold)

a = fuel type a (Residual fuel oil, gas/diesel oil, LNG)

Choice of activity data

Gas/diesel oil and fuel oil consumption activity data are obtained from MPA's annual compilation of bunker fuel sales as submitted by MPA-licensed bunker suppliers as part of the Terms and Conditions of the Bunker Licence (Bunker Supplier). MPA collects the international statistics submitted by the bunker suppliers and conducts checks to ensure that the receiving vessel is an ocean-going vessel. The existing data published are from 2013 to date. Prior to 2013, data on international bunker sales data from 2000-2012 period were collected to facilitate public announcements on bunker sales.

The only type of fuel type consumption data for gaseous fuel collected are LNG. LNG fuel consumption activity data have been collected by MPA from 2017 to 2022.

Gasoline consumption data are indicated as NO.

Multilateral operations

As there is no disaggregated data for the fuel consumption activity data, the emissions under this subcategory are indicated as NO.

3.5.3. Description of any flexibility applied

Flexibility for time series which starts from year 2000 to 2022 as described in Section 1.9. Summary of any flexibility applied will be applied throughout the report.

3.5.4. Uncertainty assessment and time series consistency

Uncertainty assessment of emissions streams under 1.D. Memo Items not estimated as GHG emissions are not included in the national GHG inventory, hence the uncertainty from this category would not be included in the uncertainty of the national totals.

3.5.5. Category-specific QA/QC and verification

Random checks are done monthly to verify that the information provided by MPA-licensed bunker suppliers tally with the bunker delivery notes issued by them.

3.5.6. Category-specific recalculations

There is no recalculation for this category.

3.5.7. Category-specific planned improvements

There is no planned improvement for this category.

Chapter 4

INDUSTRIAL PROCESSES AND PRODUCT USE (CRT SECTOR 2)

4.1.

Overview of the sector and background information

While most GHG emissions occur in the Energy sector, GHG emissions also occur from a wide variety of industrial activities (i.e., for non-energy use). Examples include the use of GHG in products (e.g., for 2.E.1. Integrated circuit or semiconductor production), and non-energy uses of fossil sources (e.g., as feedstock, petrochemical production). The main emissions sources are releases from industrial processes that chemically or physically transform materials where GHG such as CO_2, CH_4, N_2O, HFCs and PFCs are produced. The non-energy uses of fossil fuels encompass their uses as feedstock, reductants, and non-energy products in which their physical properties are used directly rather than combusted for energy purposes.

Similar to some of the fugitive emissions streams reported under the energy sector, the ECA introduced in 2013 mandates energy-intensive companies in the industrial sector to monitor and report their energy use and GHG emissions from IPPU on an annual basis. Companies under the ECA will compute their fugitive emissions and IPPU emissions based on the 2006 IPCC Guidelines and submit their GHG reports in the EDMA system as part of their regulatory requirements. The EDMA system would then conduct a year-on-year emissions estimate which allows for early identification of abnormalities in the data submitted. Prior to 2013, fugitive emissions from oil and natural gas were based on company-level surveys.

From 1 January 2019, measurement and reporting requirements for GHG emissions are imposed under CPA. Under CPA, there are 15 emissions sources resulting in GHG emissions which are applicable to the IPPU processes as follows:

- Ethylene Production
- Ethylene Oxide Production
- Flares
- Vents
- Fugitive Emissions
- Coal Gasification
- Integrated Circuit or Semiconductor Production
- TFT-FPD or LCD Production
- Iron and Steel Production
- Use of GHGs in Fire Protection Equipment
- Use of HFCs or PFCs in RAC Equipment
- Use of HFCs or PFCs in Solvents
- Use of Lubricants or Paraffin Waxes
- Use of SF_6 in Electrical Equipment
- Any Other Process or Activity Resulting in GHG Emissions

Unlike the submission of GHG reports in EDMA for ECA, which was largely in the form of Excel spreadsheets, EDMA system allows full electronic reporting via the Emissions Reports (ER) for various emissions streams for CPA. Furthermore, QA/QC of ER submitted by taxable facilities under CPA would have to be verified by an accredited third-party verification company. Singapore enforced regulation for emissions reporting starting from 2013 under the ECA and transitioned to CPA starting from 2019. The dataset prior to 2013 had been projected based on manufacturing output obtained from DOS's Singstat Table Builder as the surrogate parameter to produce the time series.

In general, IPPU emissions reported by companies under CPA, it can be quantified by the three methodological approaches:

(i) Method 1: Calculation approach

(ii) Method 2: Material balance (generally applicable to IPPU emissions, where carbon is contained in the inputs and outputs of the process. The amount of carbon in the applicable inputs and outputs must be measured to quantify the carbon unaccounted for that is assumed to be oxidised)

(iii) Method 3: Direct measurement

The GHG emissions from the IPPU sector contribute to about 9,088 kt CO_2 eq of the 2022 total GHG emissions with the highest emissions from HFCs (4,168 kt CO_2 eq). Detailed time series are presented in Table 82 and Table 83. The IPPU emissions represented about 16% of total national GHG emissions in 2022, mostly occurring in 2.F. Product uses as substitutes for ODS, followed by 2.E. Electronics Industry.

Figure 27: Total GHG emissions by IPPU sectors (2000 to 2022)

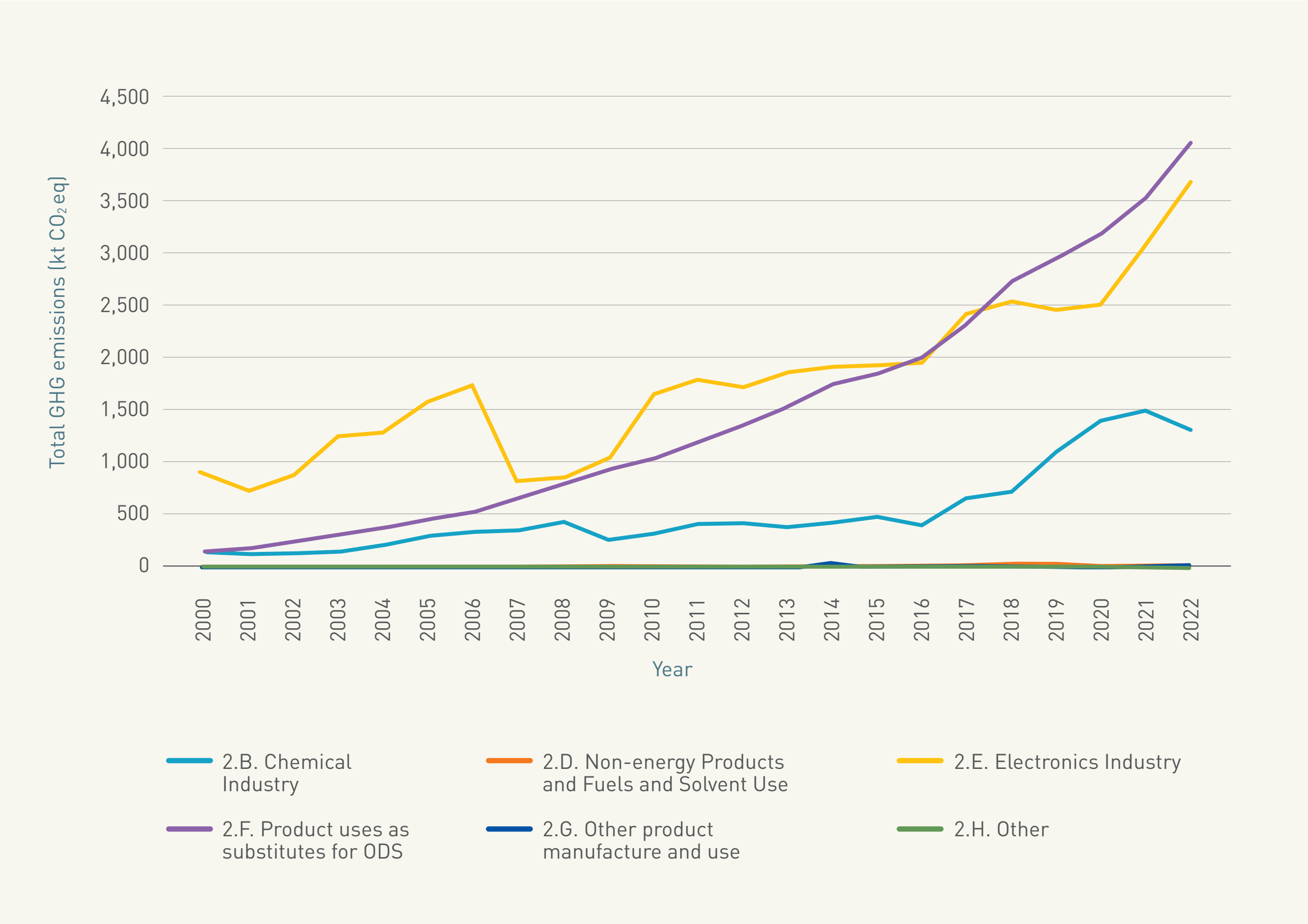


Table 82: Total GHG emissions from IPPU subsectors (2000 to 2022)

Greenhouse Gas Category	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
	GHG Emissions (kt CO_2 eq)											
Industrial Processes and Product Use	1,199.09	1,055.18	1,272.38	1,747.23	1,899.26	2,365.81	2,635.22	1,876.95	2,091.31	2,234.14	3,004.11	3,433.79
2.B. Chemical Industry	145.90	132.49	134.08	161.84	213.52	299.95	343.95	360.82	442.99	265.13	321.65	420.74
2.C. Metal Production	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
2.D. Non-energy Products and Fuels and Solvent Use	0.23	0.19	0.21	0.22	0.27	0.31	0.34	0.36	0.37	0.32	0.38	0.41
2.E. Electronics Industry	903.48	722.98	874.13	1,252.09	1,286.83	1,580.80	1,740.37	829.36	831.44	1,019.28	1,621.78	1,786.25
2.F. Product uses as substitutes for ODS	137.47	189.14	253.15	321.88	385.03	469.27	533.33	668.04	797.02	933.39	1,041.88	1,206.60
2.G. Other product manufacture and use	2.57	2.29	2.20	2.15	2.48	2.58	2.87	3.05	3.14	2.63	2.50	2.51
2.H. Other	9.44	8.08	8.62	9.05	11.13	12.90	14.36	15.33	16.34	13.40	15.92	17.28

Greenhouse Gas Category	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
	GHG Emissions (kt CO_2 eq)										
Industrial Processes and Product Use	3,523.82	3,797.21	4,148.71	4,278.92	4,394.00	5,440.99	6,012.58	6,569.09	7,135.42	8,153.39	9,088.05
2.B. Chemical Industry	428.86	389.94	428.19	483.90	412.95	666.53	720.61	1,105.89	1,407.24	1,500.11	1,315.97
2.C. Metal Production	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
2.D. Non-energy Products and Fuels and Solvent Use	0.42	0.42	0.61	0.40	0.45	0.79	1.43	0.99	0.95	1.04	0.99
2.E. Electronics Industry	1,710.42	1,846.29	1,917.46	1,928.16	1,962.71	2,420.81	2,533.00	2,460.93	2,511.18	3,076.73	3,673.67
2.F. Product uses as substitutes for ODS	1,363.94	1,540.81	1,750.64	1,847.42	1,994.64	2,314.14	2,705.44	2,954.39	3,184.82	3,530.92	4,050.33
2.G. Other product manufacture and use	2.61	2.61	34.92	1.06	3.74	4.37	15.37	15.37	7.79	20.57	25.74
2.H. Other	17.57	17.14	16.90	17.98	19.52	34.35	36.73	31.53	23.43	24.02	21.35

Notation key:
IE - Included elsewhere

Figure 28: Total GHG emissions in IPPU sector by GHG type (2000 to 2022)

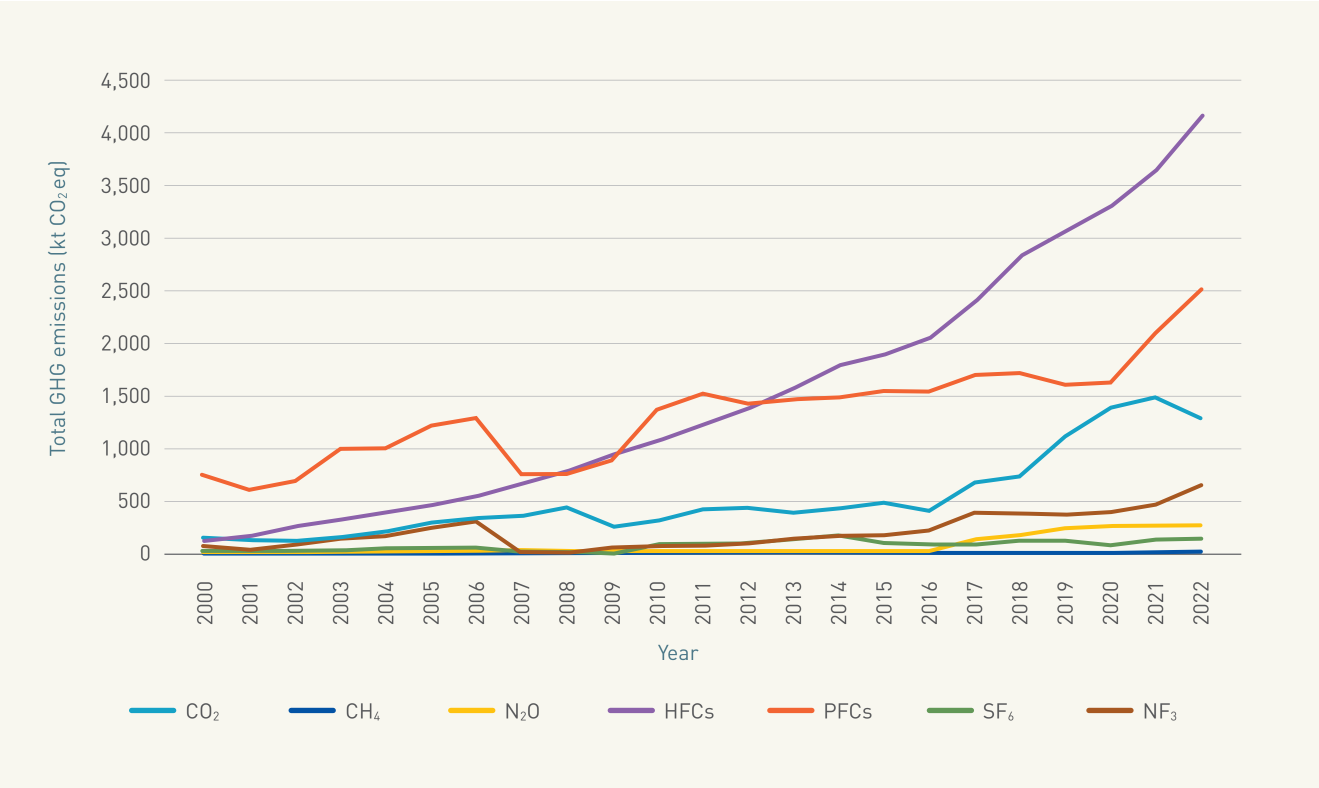


Table 83: Total GHG emissions in IPPU sector by GHG type (2000 to 2022)

Greenhouse Gas Category	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
	GHG Emissions (kt CO_2 eq)											
Industrial Processes and Product Use	1,199.09	1,055.18	1,272.38	1,747.23	1,899.26	2,365.81	2,635.22	1,876.95	2,091.31	2,234.14	3,004.11	3,433.79
CO_2	155.20	140.42	142.56	170.69	224.35	312.39	357.77	375.57	458.58	278.16	337.10	437.33
CH_4	0.31	0.28	0.28	0.34	0.45	0.64	0.73	0.76	0.95	0.56	0.67	0.88
N_2O	32.66	24.51	24.34	24.22	28.26	30.51	29.57	30.23	28.82	29.13	37.39	34.95
HFCs	146.97	196.98	285.06	349.68	403.21	493.30	564.43	676.15	805.95	957.77	1,084.20	1,252.29
PFCs	764.06	623.52	703.91	1,014.22	1,021.11	1,227.41	1,308.45	770.91	776.92	903.57	1,383.44	1,531.31
SF_6	32.32	29.85	29.32	37.56	49.25	52.00	59.07	18.17	15.03	5.24	87.31	95.17
NF_3	67.57	39.62	86.92	150.52	172.63	249.56	315.21	5.17	5.06	59.71	73.99	81.84

Greenhouse Gas Category	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
	GHG Emissions (kt CO_2 eq)										
Industrial Processes and Product Use	3,523.82	3,797.21	4,148.71	4,278.92	4,394.00	5,440.99	6,012.58	6,569.09	7,135.42	8,153.39	9,088.05
CO_2	445.74	406.46	444.98	501.45	429.46	697.23	753.20	1,111.66	1,403.42	1,498.63	1,310.38
CH_4	0.90	0.81	0.50	0.55	2.92	3.68	4.93	12.82	12.66	13.62	13.00
N_2O	33.93	34.77	38.26	24.58	23.69	129.51	179.60	244.48	270.95	275.58	278.82
HFCs	1,409.79	1,596.10	1,811.41	1,912.65	2,066.81	2,409.44	2,837.09	3,087.92	3,321.11	3,664.84	4,167.77
PFCs	1,441.33	1,478.20	1,509.37	1,555.86	1,555.98	1,709.00	1,728.75	1,618.17	1,639.57	2,104.61	2,518.74
SF_6	95.15	139.01	179.61	103.70	94.63	100.83	127.76	120.41	90.63	131.81	154.58
NF_3	96.97	141.87	164.58	180.12	220.51	391.28	381.25	373.62	397.08	464.31	644.77

4.2. Mineral Industry (CRT category 2.A.)

As there were no known activities related to mineral industry, no emissions were reported from mineral industry.

4.3. Chemical Industry (CRT category 2.B.)

4.3.1. Category description

For the chemical industry, ethylene and ethylene oxide production accounts for most of the emissions including the flares, vents and fugitive emissions arising from other petrochemical facilities. Apart from petrochemical industrial activities in Singapore, there are also hydrogen production activities in Singapore but there are no industrial activities for ammonia production, nitric acid production, adipic acid production, caprolactam, glyoxal and glyoxylic acid production, carbide production, titanium dioxide production and soda ash production in Singapore.

Petrochemical and carbon black production

The petrochemical industry uses fossil fuels such as natural gas or petroleum refinery products such as naphtha as feedstocks. The following time series reflects the chemical industry activities that occurred in Singapore from year 2000 to 2022. Based on the 2022 emissions estimated, the chemical industry contributes to 1,316 kt CO_2 eq, 2.25% of the total GHG emissions.

Figure 29: Total GHG emissions for Chemical industry (2000 to 2022)

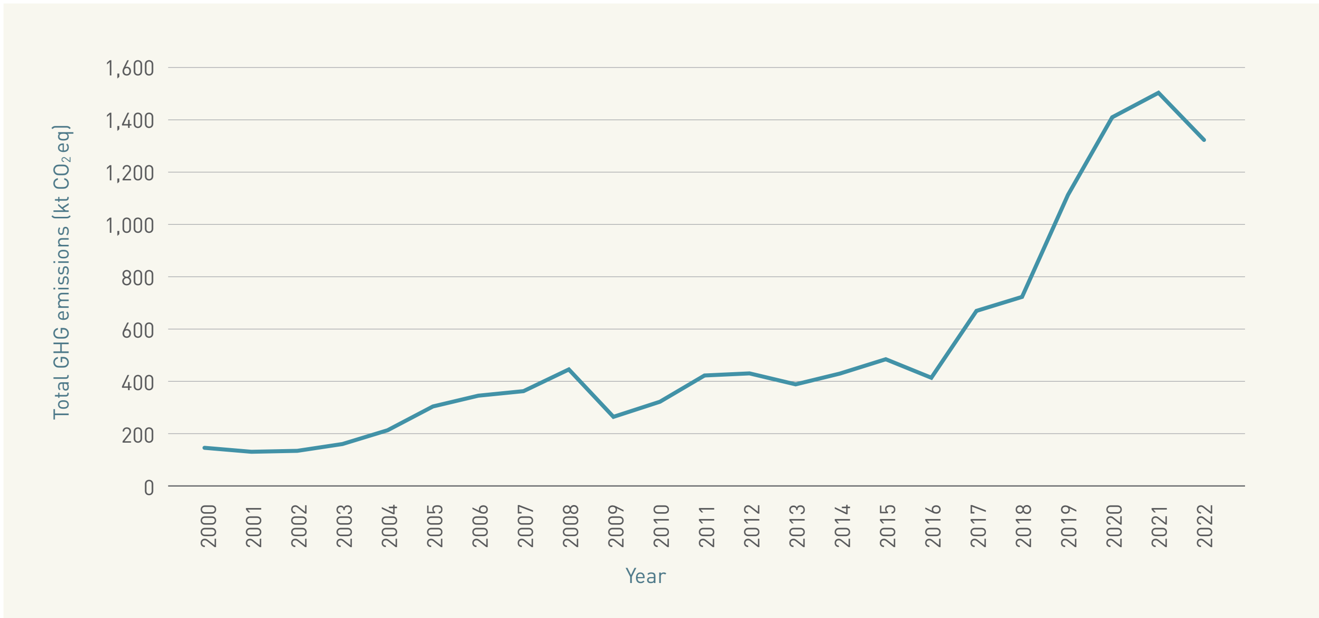


Table 84: Total GHG emissions for Chemical industry (2000 to 2022)

Greenhouse Gas Category	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
	GHG Emissions (kt CO_2 eq)											
2.B. Chemical Industry	146	132	134	162	214	300	344	361	443	265	322	421
2.B.8. Petrochemical and carbon black production	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
2.B.8.g.ii. Other (Total petrochemical production)[16]	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
2.B.10.b. Other (Total chemical production)	146	132	134	162	214	300	344	361	443	265	322	421

Greenhouse Gas Category	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
	GHG Emissions (kt CO_2 eq)										
2.B. Chemical Industry	429	390	428	484	413	667	721	1,106	1,407	1,500	1,316
2.B.8. Petrochemical and carbon black production	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
2.B.8.g.ii. Other (Total petrochemical production)[16]	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
2.B.10.b. Other (Total chemical production)	429	390	428	484	413	667	721	1,106	1,407	1,500	1,316

Notation key:
IE - Included elsewhere

Ethylene and Ethylene Oxide Production

Ethylene is produced by the process of steam cracking of petrochemical feedstocks as well as secondary products such as propylene and butadiene. For ethylene production, naphtha should be 100% of the feedstock carbon. Ethylene oxide, however, is manufactured by reacting ethylene with oxygen over a catalyst. The by-product CO_2 from the direct oxidation of the ethylene feedstock is removed from the process vent stream using a recycled carbonate solution, and the recovered CO_2 may be vented to the atmosphere or recovered for further utilisation such as for food production. In Singapore, the manufacturing of ethylene oxide is converted into ethylene glycols and high purity ethylene oxide.

Other

This category includes all emissions from flares, vents, fugitive emissions and other forms of IPPU emissions from petrochemical and chemical industries.

4.3.2. Methodological issues

Table 85: Methods and emission factors used for the emissions estimation in Petrochemical and carbon black production

GHG source and sink category	CO_2		CH_4		N_2O	
	Method applied	Emission Factor	Method applied	Emission Factor	Method applied	Emission Factor
2.B.8. Petrochemical and carbon black production	T1, T3	D, PS	T1, T3	D, PS	NA	NA
2.B.10. Other	T1, T3	D, PS	T1, T3	D, PS	T1, T3	D, PS

Notation keys:
T1 - Tier 1, T3 - Tier 3, D - Default, PS - Plant-specific, NA - Not applicable

[16] For CRT reporting, only CH_4 and N_2O emissions from 2.B.8 were aggregated under 2.B.10 due to data confidentiality and no N_2O emissions reporting under the CRT for 2.B.8. For Table 84, notation key "IE" is applied as CO_2 emissions from 2.B.8 are also reported in 2.B.10.

Petrochemical and carbon black production

Ethylene Production

According to the 2006 IPCC Guidelines, there are six emission stream types for ethylene production which are based on the feedstock-specific emission factors for CO_2 and CH_4.

i. Naphtha
ii. Gas Oil
iii. Ethane
iv. Propane
v. Butane
vi. Other feedstock

For ethylene production, there are three types of methodology that can be used by CPA facilities to compute the emissions.

Method 1: Calculation approach

The 2006 IPCC Guidelines provide the following equation:

$$E_g = Q_f \times \sum(EF_{f,g} \times GWP_g)$$

Parameter	Parameter description	Units
E_g	Emissions for GHG (g) i.e. CO_2, and CH_4	tonne CO_2 eq
Q_f	Quantity of ethylene produced using feedstock (f)	tonne
$EF_{f,g}$	Emission factor for GHG (g) based on feedstock (f)	tonne GHG/tonne ethylene produced
f	Feedstock type (f)	Nil
GWP_g	Global warming potential for GHG (g)	Nil

Method 2: Material balance

The facility can use Method 2: Material balance to determine the quantity of carbon converted to CO_2 based on the difference in the quantity of carbon contained in the feedstock, products and waste streams. The equation to be used is shown as below, with ethylene as the primary product, and propylene and butadiene as possible secondary products.

$$E_{CO_2} = [\sum_i (QF_i \times CCF_i) - \{\sum_j (QP_j \times CCP_j) + \sum_k (QS_k \times CCS_k) + \sum_l (QW_l \times CCW_l)\}] \times \frac{44}{12}$$

$$EF_{p,CO_2} = E_{CO_2} / Q_p$$

Parameter	Parameter description	Units
E_{CO2}	Emissions of CO_2	tonne CO_2
QF_i	Annual quantity of feedstock (i) consumed for the production of primary product and other secondary products and waste streams	tonne
CCF_i	Carbon content of feedstock (i)	% or ratio
QP_j	Annual quantity of primary product (j), produced	tonne
CCP_j	Carbon content of primary product (j)	% or ratio
QS_k	Annual quantity of secondary product (k) produced	tonne
CCS_k	Carbon content of secondary product (k)	% or ratio
QW_l	Annual quantity of waste stream (l) resulting from the production process	tonne
CCW_l	Carbon content of waste stream (l)	% or ratio
Q_p	Quantity of primary product produced for sub-process type (p)	Tonne
p	Sub-process type	tonne
EF_{p,CO_2}	Emission factor for CO_2 and primary product using sub-process type (p)	tonne CO_2/tonne

As the CH_4 emission factor is based on the quantity of ethylene produced, details of the production activity data are required. This is likely to have been reported as part of the primary production material stream. However, it could be an alternative measure of production such as that used for official production reporting.

$$E_g = E_{CO_2} + (Q_f \times EF_{f,CH_4} \times GWP_{CH_4})$$

Parameter	Parameter description	Units
E_g	Emissions for GHG (g) i.e. CO_2 and CH_4	tonne CO_2 eq
E_{CO_2}	Emissions for CO_2 from material balance	tonne CO_2 eq
Q_f	Quantity of ethylene produced using feedstock (f)	tonne
f	Feedstock type	Nil
EF_{f,CH_4}	Emission factor for CH_4 based on feedstock (f)	tonne CH_4/ tonne ethylene produced
GWP_{CH_4}	Global warming potential for CH_4	Nil

Method 3: Direct measurement

The facility can directly measure CO_2 emissions based on stack monitoring. Unlike CO_2, CH_4 emissions are not directly measured, hence Method 1: Calculation approach is used when Method 3: Direct measurement is adopted. Information on the quantity of ethylene produced and the CH_4 emission factor are required. The equation below can be used:

$$E_g = E_{CO_2} + (Q_f \times EF_{f,CH_4} \times GWP_{CH_4})$$

Parameter	Parameter description	Units
E_g	Emissions for GHG (g) i.e. CO_2 and CH_4	tonne CO_2 eq
E_{CO_2}	Emissions for CO_2 from direct measurement	tonne CO_2 eq
Q_f	Quantity of ethylene produced using feedstock (f)	tonne
f	Feedstock type	Nil
EF_{f,CH_4}	Emission factor for CH_4 based on feedstock (f)	tonne CH_4/ tonne ethylene produced
GWP_{CH_4}	Global warming potential for CH_4	Nil

For CH_4 emissions, as the CH_4 emission factor is based on the production quantity of ethylene, details of the production activity data are required.

Choice of activity data and emission factor

The activity data from year 2013 to 2022 were obtained from the reports submitted by facilities under ECA and CPA. For years prior to 2013, the data had been projected based on Manufacturing Output In Manufacturing By Industry (Refined Petroleum Products) obtained from DOS's Singstat Table Builder as the surrogate parameter.

The Tier 1 default CO_2 and CH_4 emission factors for ethylene production can be found in the table below.

Table 86: Tier 1 default ethylene production conversion factors

Emission stream type	CO_2 emission factor	CH_4 emission factor
	tonne CO_2 / tonne ethylene produced	tonne CH_4 / tonne ethylene produced
Naphtha	2.25	0.003
Gas Oil	2.98	0.003
Ethane	1.24	0.006
Propane	1.35	0.003
Butane	1.35	0.003
Other feedstock	2.25	0.003

These default emission factors do not include CO_2 emissions from flaring. According to the 2006 IPCC Guidelines[17], the emission factors may be used in the event that activity data are available only for the amount of ethylene produced by the steam cracking process. The 2006 IPCC Guidelines states that steam cracking is a multi-product process that leads to ethylene, propylene, butadiene, aromatics, and several other high-value chemicals. In order for IPCC to develop the emission factors for steam cracking, the total CO_2 process emissions of a steam cracker has been divided by the output of ethylene only i.e. ethylene has been chosen as the reference for estimating the total CO_2 emissions from the steam cracking process. Multiplication of the CO_2 emission factors by the ethylene production therefore leads to the total CO_2 emissions resulting not only from the production of ethylene but also from the production of propylene, butadiene, aromatics and all other chemicals produced by the steam cracking process. The default emission factors provide the total CO_2 emissions from the steam cracking process, not only the CO_2 emissions associated with the production of the ethylene from the steam cracking process as a whole.

The 2006 IPCC Guidelines also provide default CH_4 emission factors for CH_4 fugitive emissions. Therefore, the default CH_4 emission factors should not be used to estimate CH_4 emissions from steam cracker ethylene plants for which site-specific data for CH_4 fugitive emissions are available.

Ethylene Oxide Production

For ethylene oxide production, there are nine emission stream types based on the 2006 IPCC Guidelines. Three types of abatement options i.e. thermal, other, or no abatement, are included for each of the three processes, i.e. air process, oxygen process and other. According to the 2006 IPCC Guidelines, the selection of process type determines the default CO_2 emission factor, while the abatement options determine the default CH_4 emission factor.

[17] Refer to 2006 IPCC Guidelines, Volume 3, Chapter 3, page 3.75

i Air Process - Thermal abatement
ii Air Process - Other abatement
iii Air Process - No abatement
iv Oxygen Process - Thermal abatement
v Oxygen Process - Other abatement
vi Oxygen Process - No abatement
vii Other - Thermal abatement
viii Other - Other abatement
ix Other - No abatement

There are two methodologies that facilities can use to compute the emissions from ethylene oxide production.

Method 1: Calculation approach

The 2006 IPCC Guidelines provide the equation below:

$$E_g = Q_p + [EF_{p,CO_2} + (EF_{a,CH_4} \times GWP_{CH_4})]$$

Parameter	Parameter description	Units
E_g	Emissions for GHG (g) i.e. CO_2, and CH_4	tonne CO_2 eq
Q_p	Quantity of ethylene oxide produced in process (p)	tonne
EF_{p,CO_2}	Emission factor for CO_2 based on process (p)	tonne CO_2/tonne ethylene oxide produced
p	Process (p) type i.e. Air feed, Oxygen feed or Other	Nil
EF_{a,CH_4}	Emission factor for CH_4 based on abatement type (a)	tonne CH_4/tonne ethylene oxide produced
a	Abatement treatment (a) being Thermal, Other or None	Nil
GWP_{CH_4}	Global warming potential for CH_4	Nil

According to the 2006 IPCC Guidelines, when using Method 1: Calculation approach, there is no default CO_2 emission factor for the 'Other' process type and no default CH_4 emission factor for the 'Other abatement' type selections. The default CH_4 emission factor has taken into account CH_4 emissions from the ethylene oxide process vent, ethylene oxide purification process exhaust gas steam and fugitive sources.[18]

Method 2: Material balance

The facility can use Method 2: Material balance to determine the quantity of carbon converted to CO_2 based on the difference in the quantity of carbon contained in the feedstock, products and waste streams The equation to be used is shown as below, with ethylene oxide as the primary product, and propylene and butadiene as possible secondary products.

$$E_{CO_2} = [\sum_i (QF_i \times CCF_i) - \left\{\sum_j (QP_j \times CCP_j) + \sum_k (QS_k \times CCS_k) + \sum_l (QW_l \times CCW_l)\right\}] \times \frac{44}{12}$$

$$EF_{p,CO_2} = E_{CO_2} / Q_p$$

Parameter	Parameter description	Units
E_{CO_2}	Emissions of CO_2	tonne CO_2
QF_i	Annual quantity of feedstock (i) consumed for the production of primary product and other secondary products and waste streams	tonne
CCF_i	Carbon content of feedstock (i)	% or ratio
QP_j	Annual quantity of primary product (j), produced	tonne
CCP_j	Carbon content of primary product (j)	% or ratio
QS_k	Annual quantity of secondary product (k) produced	tonne
CCS_k	Carbon content of secondary product (k)	% or ratio
QW_l	Annual quantity of waste stream (l) resulting from the production process	tonne
CCW_l	Carbon content of waste stream (l)	% or ratio
Q_p	Quantity of primary product produced for sub-process type (p)	Tonne
p	Sub-process type	tonne
EF_{p,CO_2}	Emission factor for CO_2 and primary product using sub-process type (p)	tonne CO_2/tonne

[18] Refer to the 2006 IPCC Guidelines, Volume 3, Chapter 3, page 3.78.

As the CH_4 emission factor is based on the quantity of ethylene oxide produced, details of the production activity data are required. This is likely to have been reported as part of the primary production material stream. However, it could be an alternative measure of production such as that used for official production reporting. Similarly, there is no default CH_4 emission factor for the 'Other abatement' type selections. For ethylene oxide production, ethylene should be 100% of the feedstock carbon.

$$E_g = E_{CO_2} + (Q_p \times EF_{a,CH_4} \times GWP_{CH_4})$$

Parameter	Parameter description	Units
E_g	Emissions for GHG (g) i.e. CO_2 and CH_4	tonne CO_2 eq
E_{CO_2}	Emissions for CO_2	tonne CO_2 eq
Q_p	Quantity of ethylene oxide produced in process (p)	tonne
p	Process (p) type i.e. Air feed, Oxygen feed or Other	Nil
a	Abatement treatment (a) being Thermal, Other or None	Nil
EF_{a,CH_4}	Emission factor for CH_4 based on abatement type (a)	tonne CH_4/ tonne ethylene oxide produced
GWP_{CH_4}	Global warming potential for CH_4	Nil

Choice of activity data and emission factor

The activity data from year 2013 to 2022 were obtained from the reports submitted by facilities under ECA and CPA. For year prior to 2013, the data had been projected based on Manufacturing Output In Manufacturing By Industry (Refined Petroleum Products) obtained from DOS's Singstat Table Builder as the surrogate parameter.

The Tier 1 default emission factors for ethylene oxide production are shown in Table 87 below. Based on the 2006 IPCC Guidelines, there is no Tier 1 default CO_2 emission factor for the 'Other' process type and no Tier 1 default CH_4 emission factor for the 'Other abatement' type selections, i.e. listed as not available i.e. NA in Table 87.

Table 87: Tier 1 default ethylene oxide production conversion factors

Emission stream type	CO_2 emission factor	CH_4 emission factor
	tonne CO_2 / tonne ethylene produced	tonne CH_4 / tonne ethylene produced
Air Process - Thermal abatement	0.863	0.00079
Air Process - Other abatement	0.863	NA
Air Process - No abatement	0.863	0.00179
Oxygen Process - Thermal abatement	0.663	0.00079
Oxygen Process - Other abatement	0.663	NA
Oxygen Process - No abatement	0.663	0.00179
Other - Thermal abatement	NA	0.00079
Other - Other abatement	NA	NA
Other - No abatement	NA	0.00179

Other

Emissions from ethylene production and ethylene oxide production had been aggregated with emissions in this category due to data confidentiality.

The emission factor and methodology applied for flares, vents and fugitive emissions are consistent across all IPPU activities as per Section 3.3.2.2.

4.3.3. Description of any flexibility applied

Flexibility for time series which starts from year 2000 to 2022 as described in Section 1.9. Summary of any flexibility applied had been applied throughout the report.

4.3.4. Uncertainty assessment and time series consistency

The uncertainty for the 2.B. Chemical industry is estimated to be ±6% for CO_2, ±15% for CH_4 and ±47% for N_2O respectively.

Table 88:Uncertainty values used for base year and reporting year uncertainty calculations

Year	Base year 2000		
Uncertainty Parameters	CO_2	CH_4	N_2O
Activity Data	5%		
Emission factor	10%	50%	50%

Uncertainty estimates for Chemical industry category is calculated using Approach 1 – Error propagation method.

Uncertainty estimates performed for reporting year 2022 use weighted-aggregated site-specific uncertainty factors declared by reporting facilities under CPA.

The breakdown of uncertainty calculations for 2.B. Chemical industry can be found in Annex II.

4.3.5. Category-specific QA/QC and verification

Compliant with QA/QC plan and implementation as outlined in Chapter 1, Section 1.5.

4.3.6. Category-specific recalculations

Previously, emissions from flaring and venting for all industries were reported under 1.B.2. Oil, Natural Gas and other emissions from energy production. In this NID, the emissions from flaring and venting apart from oil industries would be reported in the relevant category such as chemical industries in the IPPU sector.

4.3.7. Category-specific planned improvements

There is no planned improvement for this category.

4.4. Metal Industry (CRT category 2.C.)

4.4.1. Category description

For metal industry, this industry comprised iron and steel, metallurgical coke production, ferroalloy production, aluminum production, magnesium production, lead production and zinc production. In particular, the non-energy emissions arose from the iron and steel production. The emissions from the Iron and Steel Production were included in 2.H. Other due to data sensitivity.

Iron and Steel production

The production of iron and steel leads to emissions of CO_2, CH_4 and N_2O. Singapore has only one steel mill with an integrated upstream and downstream operation, where steel is manufactured through recycling scrap and fabrication. The metal recycler processes more than half a million tonnes of locally generated metal waste, collected from marine, demolition and construction industries with a dedicated fleet of collection bins and trucks into steel each year.

There are 10 emissions stream types for iron and steel production based on the 2006 IPCC Guidelines. This is based on the numerous stages or process options in iron and steel making.

i) Sinter Production
ii) Coke Oven
iii) Iron Production
iv) Direct Reduced Iron Production
v) Pellet Production
vi) Basic Oxygen Furnace (BOF)
vii) Electric Arc Furnace (EAF)
viii) Open Hearth Furnace (OHF)
ix) Global Average Factor (default)
x) Other

Table 89: Total emissions for Metal industry (2000 to 2022)

Greenhouse Gas Category	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
	GHG Emissions (kt CO_2 eq)											
2.C.1. Iron and steel production	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
2.C.1.a. Steel	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE

Greenhouse Gas Category	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
	GHG Emissions (kt CO_2 eq)										
2.C.1. Iron and steel production	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
2.C.1.a. Steel	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE

Notation key:
IE - Included elsewhere

4.4.2. Methodological issues

Table 90: Methods and emission factors used for the emissions estimation

GHG source and sink category	CO_2		CH_4	
	Method applied	Emission Factor	Method applied	Emission Factor
2.C.1 Iron and Steel production	T3	PS	NA	NA

Notation keys:
T3 - Tier 3, PS - Plant-specific, NA - Not applicable

Iron and Steel production

For Iron and Steel production, the emissions could be calculated using either the calculation approach or material balance approach.

For calculation approach, the following methodology was used.

$$E_g = Q_p \times \sum (EF_{p,g} \times GWP_g)$$

Parameter	Parameter Description	Units
E_g	Emissions for GHG (g) i.e. CO_2, and CH_4	tonne CO_2 eq
Q_p	Quantity of Tonne coke, crude steel, pig iron, DRI, sinter or pallet produced using process or steelmaking method (p)	tonne
$EF_{p,g}$	Emission factor for GHG (g) and process or steelmaking method (p)	tonne or kg GHG/tonne production
p	Process or steelmaking method	Nil
GWP_g	Global warming potential for GHG (g)	Nil

For material balance approach, the following methodology was used.

Companies can use material balance to determine the quantity of carbon converted to CO_2 based on the difference in the quantity of carbon contained in the feedstock, products and waste streams. Material balance uses the following formula to calculate the CO_2 emissions and CO_2 emission factor:

$$E_{CO_2} = [\sum_i (QF_i \times CCF_i) - \left\{\sum_j (QP_j \times CCP_j) + \sum_k (QS_k \times CCS_k) + \sum_l (QW_l \times CCW_l)\right\}] \times \frac{44}{12}$$

$$EF_{p,CO_2} = E_{CO_2} / Q_p$$

Parameter	Parameter Description	Units
E_{CO_2}	Emissions of CO_2	tonne CO_2
QF_i	Annual quantity of feedstock (i) consumed for the production of primary product and other secondary products and waste streams	tonne
CCF_i	Carbon content of feedstock (i)	% or ratio
QP_j	Annual quantity of primary product (j), produced	tonne
CCP_j	Carbon content of primary product (j)	% or ratio
QS_k	Annual quantity of secondary product (k), produced	tonne
CCS_k	Carbon content of secondary product (k)	% or ratio
QW_l	Annual quantity of waste stream (l) resulting from the production process	tonne
CCW_l	Carbon content of waster stream (l)	% or ratio
Q_p	Quantity of primary product produced for sub-process type (p)	tonne
p	Sub-process type	
EF_{p,CO_2}	Emission factor for CO_2 and primary product using sub-process type (p)	tonne CO_2 / tonne

Iron and steel production has a comparatively high number of input streams. The percentage of carbon from each input stream must be estimated to correctly determine the overall uncertainty of the emission stream. The aggregated percentage for the input streams should be 100%. The aggregated percentage for the output streams should not add to 100%, but rather the percentage of carbon contained in these measured output streams. The remaining carbon is assumed to be released as CO_2.

The Tier 1 default CO_2 and CH_4 emission factors for iron and steel production are shown in Table 90. The emission factors and uncertainty values have been obtained from the 2006 IPCC Guidelines. The 2006 IPCC Guidelines provide default CH_4 emission factors only for (i) Sinter Production, (ii) Coke Oven and (iii) Direct Reduced Iron Production. CH_4 emissions are likely from any process involving the heating of carbon-containing products such as iron making, however, the uncertainty is high. The facility should use any available data to estimate if CH_4 emissions can be quantified.

Table 91: Tier 1 default Iron and steel production conversion factors and uncertainty values

Emission Stream Type	CO_2 Emission Factor	CH_4 Emission Factor
	Default (tonne CO_2/tonne production)	Default (kg CH_4/ tonne production)
Sinter Production	0.20	0.070
Coke Oven	0.56	0.0001
Iron Production	1.35	NA
Direct Reduced Iron Production	0.70	0.048
Pellet Production	0.03	NA
Basic Oxygen Furnace (BOF)	1.46	NA
Electric Arc Furnace (EAF)	0.08	NA
Open Hearth Furnace (OHF)	1.72	NA
Global Average Factor (Default)	1.06	NA
Other	NA	NA

4.4.3. Description of any flexibility applied

Flexibility for time series which starts from year 2000 to 2022 as described in Section 1.9. Summary of any flexibility applied had been applied throughout the report.

4.4.4. Uncertainty assessment and time series consistency

Uncertainty for 2.C. Iron and Steel subcategory is estimated under 2.H.3. Others as per the data masking in CRT.

Table 92: Tier 1 default Iron and steel production conversion factors and uncertainty values

Emission Stream Type	CO_2 Emission Factor		CH_4 Emission Factor	
	Tier 1 Default Uncertainty	Tier 1 Site-specific Uncertainty	Tier 1 Default Uncertainty	Tier 1 Site-specific Uncertainty
Sinter Production	25%	7.5%	25%	7.5%
Coke Oven	25%	7.5%	25%	7.5%
Iron Production	25%	7.5%	NA	7.5%
Direct Reduced Iron Production	25%	7.5%	25%	7.5%
Pellet Production	25%	7.5%	NA	7.5%
Basic Oxygen Furnace (BOF)	25%	7.5%	NA	7.5%
Electric Arc Furnace (EAF)	25%	7.5%	NA	7.5%
Open Hearth Furnace (OHF)	25%	7.5%	NA	7.5%
Global Average Factor (Default)	25%	7.5%	NA	7.5%
Other	NA	7.5%	NA	7.5%

4.4.5. Category-specific QA/QC and verification

Compliant with QA/QC plan and implementation as outlined in Chapter 1, Section 1.5.

4.4.6. Category-specific recalculations

There is no recalculations for this category.

4.4.7. Category-specific planned improvements

There is no planned improvement for this category.

4.5.
Non-energy products from fuels and solvent use (CRT category 2.D.)

4.5.1. Category description

This section reports the emissions from the first use of fossil fuels as products for primary purposes such as lubricants, paraffin waxes, bitumen/asphalt and solvents other than for combustion for energy purposes or feedstock or reducing agents as these would have been accounted for under the other sections such as under the chemical industry.

Lubricants are mostly used in industrial and transportation applications where their production could be from refineries through separation from crude oil or at petrochemical facilities. Primarily, lubricants used in engines is for their lubricating properties and therefore, the emissions are considered as non-combustion emissions, that is, to be reported in the IPPU Sector.

Paraffin waxes, also separated from crude oil, are produced during light (distillate) lubricating oil production. Paraffin waxes could be used in applications such as candles, paper coating, food production, wax polishes and surfactants used in detergents etc. Emissions from waxes could be due to combustion during use such as in moving parts of machineries, incineration or in wastewater treatment.

Both lubricant and paraffin wax are reported under then ECA and currently under CPA. On lubricant and paraffin wax use, there are three main emission stream types based on the 2006 IPCC Guidelines. This is based on the type of lubricants or paraffin waxes used. Lubricants that were topped up due to losses would be reported. Due to data confidentiality, emissions from paraffin wax use were reported as "Included Elsewhere (IE)" and had been aggregated under lubricant use.

i) Lubricating oil (motor oil / industrial oil)

ii) Grease

iii) Paraffin wax

A summary of the emissions and time series from year 2000 to 2022 can be found in the table below.

Table 93: Total GHG emissions for Non-energy Products and Fuels and Solvent Use (2000 to 2022)

Greenhouse Gas Category	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
	GHG Emissions (kt CO_2 eq)											
2.D. Non-energy Products and Fuels and Solvent Use	0.23	0.19	0.21	0.22	0.27	0.31	0.34	0.36	0.37	0.32	0.38	0.41
2.D.1. Lubricant use	0.23	0.19	0.21	0.22	0.27	0.31	0.34	0.36	0.37	0.32	0.38	0.41
2.D.2. Paraffin wax use	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE

Greenhouse Gas Category	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
	GHG Emissions (kt CO_2 eq)										
2.D. Non-energy Products and Fuels and Solvent Use	0.42	0.42	0.61	0.40	0.45	0.79	1.43	0.99	0.95	1.04	0.99
2.D.1. Lubricant use	0.42	0.42	0.61	0.40	0.45	0.79	1.43	0.99	0.95	1.04	0.99
2.D.2. Paraffin wax use	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE

Notation key:
IE - Included elsewhere

4.5.2. Methodological issues

Table 94: Method and emission factors used for emission estimation of non-energy products from fuel and solvent use

GHG source and sink category	CO_2		CH_4		N_2O	
	Method applied	Emission Factor	Method applied	Emission Factor	Method applied	Emission Factor
2.D.1. Lubricant use	T1, T3	D, PS	NO	NO	NO	NO
2.D.2. Paraffin wax use	T1	D	NO	NO	NO	NO

Notation keys:
T1 - Tier 1, T3 - Tier 3, D - IPCC Default, PS - Plant-specific, NO - Not occurring

The estimation of lubricants and paraffin wax had been computed based on the calculation reported by the regulated companies.

Based on the 2006 IPCC Guidelines, Method 1: Calculation approach uses the following formula:

$$E_{CO_2} = Q_f \times NCV_f \times C_f \times O_f \times \frac{44}{12}$$

Parameter	Parameter Description	Units
E_{CO_2}	Emissions of CO_2	tonne CO_2 eq
Q_f	Quantity of lubricant or paraffin wax (f) used	tonne or litre
NCV_f	Net calorific calue of lubricant or paraffin wax (f) used	TJ/tonne or TJ/litre
C_f	Carbon content of lubricant or paraffin wax (f)	tonne of Carbon/TJ
O_f	Fraction of the lubricant or paraffin wax (f) oxidised during use	Nil
f	lubricant or paraffin wax type (f)	Nil

The emissions quantification method for the use of lubricants or paraffin waxes is similar to that for fuel combustion, except that the emission factors used incorporate a low oxidation rate that represents the small proportion of lubricant or paraffin waxes that are used in a manner leading to GHG emissions. Only CO_2 emissions quantified as CH_4 and N_2O emissions are assumed to be negligible.

Choice of activity data and emission factor

The quantity of lubricant or paraffin wax used is usually reported in terms of tonne or litre. The activity data and emissions were extracted from CPA from 2019 onwards. However, activity data are not available for years prior to 2018. Due to data confidentiality, the quantity of paraffin wax from 2019 onwards had been aggregated with the quantity of lubricant. For years prior to 2013, the projection was conducted using the Manufacturing Output In Manufacturing By Industry (Total Manufacturing) obtained from DOS's Singstat Table Builder as the surrogate parameter.

The default net calorific values (NCV) to convert the quantity of lubricants and paraffin waxes from tonne or litre to TJ. Refer to Table 95.

Table 95: Net calorific values for lubricants and paraffin waxes

Emission Stream Type	Net calorific value, NCV_f	
	TJ/litre (l)	TJ/tonne
Lubricating oil (motor oil / industrial oil)	0.000037 (or 3.70896E-05)	0.0418
Grease		
Average lubricants (default)		
Other lubricants		
Paraffin Wax	0.000032 (or 3.19712E-05)	0.0399

The default carbon content (based on lower heating value) and oxidation fraction for the use of lubricant and paraffin wax are shown in the table below. These conversion factors are based on the 2006 IPCC Guidelines.

The default oxidation fractions developed by IPCC are very broad estimates, as they are based on limited knowledge of the typical lubricant oxidation rates and the limited knowledge of the circumstances of paraffin waxes used. The default oxidation fraction is four times smaller for greases than for lubricating oils or paraffin waxes.

Table 96: Tier 1 uncertainty values for the use of lubricants or paraffin waxes

Emission Stream Type	Carbon content factor, C_f	Oxidation fraction, O_f
	Tonne C/TJ	Fraction
Lubricating oil (motor oil / industrial oil)	20	0.2
Grease	20	0.05
Average lubricants (default)	20	0.2
Other lubricants	NA	NA
Paraffin Wax	20	0.2

4.5.3. Description of any flexibility applied

Flexibility for time series which starts from year 2000 to 2022 as described in Section 1.9. Summary of any flexibility applied had been applied throughout the report.

4.5.4. Uncertainty assessment and time series consistency

The uncertainty for 2.D.1 Lubricants subcategory is estimated to be ±30% for CO_2.

Uncertainty estimates for reporting year 2022 use the weighted average site-specific uncertainty factors reported by individual companies and facilities through CPA.

Uncertainty estimates for base year 2000 reference the default uncertainty factors from the 2006 IPCC Guidelines. The default uncertainty values for the use of lubricant and paraffin wax are shown in Table 96. These conversion factors and uncertainty values are based on the 2006 IPCC Guidelines.

Based on the assumption that site-specific carbon content and oxidation fraction are more accurate, the default uncertainty values for Tier 1 site-specific conversion factors assume a higher accuracy reflecting GHG-specific and equipment-specific data. The default uncertainty is assumed to be 2% for Tier 1 site-specific carbon content factor for lubricants, and 3% for paraffin waxes. These uncertainty values reflect facilities knowing the specific type of oil being used compared to the variability represented by the IPCC default uncertainty values, without actual ongoing analysis by the facility. Where a facility provides a Tier 1 site-specific oxidation fraction, the uncertainty is assumed to be 10%, significantly lower than the uncertainty for the IPCC default oxidation fraction which covers a wide variety of applications/circumstances. The 10% uncertainty has been used to represent the difficulty in measuring the actual combustion rates.

Table 97: Tier 1 default conversion factors and uncertainty values for the use of lubricants or paraffin waxes

Emission Stream Type	Carbon content factor, C_f		Oxidation fraction, O_f	
	Tier 1 Default Uncertainty	Tier 1 Site-specific Uncertainty	Tier 1 Default Uncertainty	Tier 1 Site-specific Uncertainty
Lubricating oil (motor oil / industrial oil)	3%	2%	50%	10%
Grease	3%	2%	50%	10%
Average lubricants (default)	3%	2%	50%	10%
Other lubricants	NA	2%	NA	10%
Paraffin Wax	5%	3%	100%	10%

4.5.5. Category-specific QA/QC and verification

Compliant with QA/QC plan and implementation as outlined in Chapter 1, Section 1.5.

4.5.6. Category-specific recalculations

There is no recalculations for this category.

4.5.7. Category-specific planned improvements

Plans to establish the mass balance of lubricant and paraffin wax are ongoing to ensure completeness and accuracy in the reporting of its consumption in Singapore. It is noted that the amount of lubricant used in 2-stroke engines should be excluded. The assessment of whether lubricant had been used by 2-stroke engines in the country is ongoing. That said, the preliminary use of such engines should be negligible due to the tightened in-use emissions standards for motorcycles. As of 31 December 2020, nearly 60% of about 27,000 eligible motorcycles have benefitted from this early de-registration incentive.

4.6. Electronics Industry (CRT category 2.E.)

4.6.1. Category description

Table 98: Total GHG emissions for Electronics industry (2000 to 2022)

Greenhouse Gas Category	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
	GHG Emissions (kt CO_2 eq)											
2.E. Electronics Industry	903	723	874	1,252	1,287	1,581	1,740	829	831	1,019	1,622	1,786
2.E.1. Integrated circuit or semiconductor[19]	903	723	874	1,252	1,287	1,581	1,740	829	831	1,019	1,622	1,786
2.E.2. TFT flat panel display	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
2.E.3. Photovoltaics	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE

Greenhouse Gas Category	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
	GHG Emissions (kt CO_2 eq)										
2.E. Electronics Industry	1,710	1,846	1,917	1,928	1,963	2,421	2,533	2,461	2,511	3,077	3,674
2.E.1. Integrated circuit or semiconductor[19]	1,710	1,846	1,917	1,928	1,963	2,421	2,533	2,461	2,511	3,077	3,674
2.E.2. TFT flat panel display	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
2.E.3. Photovoltaics	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE

Notation key:
IE - Included elsewhere

Based on the 2022 emissions estimated, the Electronics industry contributes to 3,674 kt CO_2 eq, 6.27% of the total GHG emissions. Amongst the seven reportable GHGs used in the Electronics Industry, PFCs contribute to the highest emissions of 2,519 kt CO_2 eq (68.6% of the total GHG emissions in the Electronics Industry), followed by NF_3 (17.6%), N_2O (7.2% including CO_2 and CH_4), SF_6 (3.5%) and HFCs (3.2%) in 2022. Due to data confidentiality, solvents (non-aerosol) in 2.F. Product uses as ozone depleting substances have been aggregated and reported under PFC in 2.E.1. Integrated circuit or semiconductor. PFCs, SF_6 and NF_3 from 2.E.2. TFT-FPD and N_2O and NF_3 from 2.E.3. PV have also been aggregated under 2.E.1. Integrated circuit or semiconductor due to data confidentiality.

[19] Emissions from solvents (non-aerosol) in 2.F. Product uses as ozone depleting substances have been aggregated and reported under 2.E.1. Integrated circuit or semiconductor due to data confidentiality. Please refer to Section 4.7 for more information on solvents (non-aerosols).

Figure 30: Total GHG emissions for Electronics industry by GHG type (2000 to 2022)

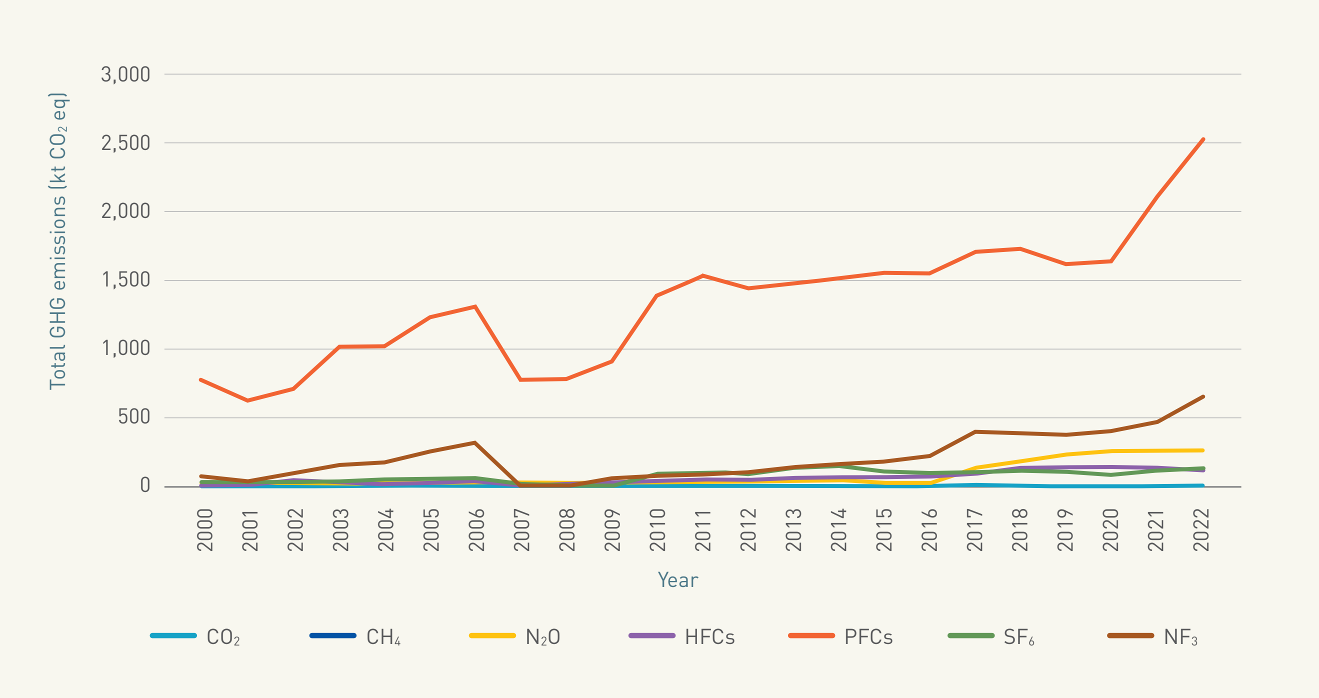


Table 99: Total GHG emissions for Electronics industry by GHG type (2000 to 2022)

Greenhouse Gas Category	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
	GHG Emissions (kt CO_2 eq)											
Total emissions	903	723	874	1,252	1,287	1,581	1,740	829	831	1,019	1,622	1,786
CO_2	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
CH_4	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
N_2O	33	24	24	24	28	30	29	30	29	29	37	35
HFCs	10	8	32	28	18	24	31	8	9	24	42	46
PFCs	764	624	704	1,014	1,021	1,227	1,308	771	777	904	1,383	1,531
SF_6	30	28	27	35	47	49	56	15	12	3	85	93
NF_3	68	40	87	151	173	250	315	5	5	60	74	82

Greenhouse Gas Category	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
	GHG Emissions (kt CO_2 eq)										
Total emissions	1,710	1,846	1,917	1,928	1,963	2,421	2,533	2,461	2,511	3,077	3,674
CO_2	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
CH_4	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
N_2O	34	35	38	24	23	129	179	231	255	263	264
HFCs	46	55	61	65	72	95	132	134	136	134	117
PFCs	1,441	1,478	1,509	1,556	1,556	1,709	1,729	1,618	1,640	2,105	2,519
SF_6	93	136	145	103	91	96	112	105	83	111	129
NF_3	97	142	165	180	221	391	381	374	397	464	645

Notation key:
IE - Included elsewhere

Integrated circuit or semiconductor

The electronics manufacturing processes utilise fluorinated compounds (FCs) for plasma etching intricate patterns on the wafers, cleaning reactor chambers, and temperature control. These processes are used in semiconductor, thin-film-transistor flat panel display (TFT-FPD), and photovoltaic (PV) manufacturing. For PV manufacturing, N_2O and NF_3 are utilised for chamber cleaning after the deposition of SiNx films.

The second highest emissions in the IPPU sector are from the 2.E. Electronics industry category, contributing 40% of the IPPU emissions. In the electronics industry, CO_2, CH_4, N_2O, HFCs, PFCs, SF_6 and NF_3 were used in the manufacturing processes. Emission control technologies are installed in some processes due to the limited utilisation efficiency during the etching and cleaning processes. CF_4, a by-product, is also formed during the etching and cleaning process. Currently, there is no report of HFCs and PFCs used as heat transfer fluids by electronics manufacturers for temperature control.

The electronics industry emits both FCs that are gases and liquid at room temperature. These gases are used in two important steps of electronics manufacturing, i.e., (i) plasma etching silicon containing materials and (ii) cleaning chemical vapour deposition (CVD) tool chamber-walls where silicon has deposited.

Emissions may vary according to the gases used in manufacturing different types of electronic devices, the process used (e.g., CVD or etch), the brand of process tool used and the implementation of emission reduction technology. The methodology to quantify the emissions can use either calculation approach or direct measurement. Under CPA, there are six emission stream types which are covered:

(i) Plasma etching thin film
(ii) Cleaning CVD tools chambers
(iii) Furnace (diffusion)
(iv) Nitride removal (etching)
(v) Cleaning of low k CVD reactors
(vi) Others

Thin-film-transistor flat panel display (TFT-FPD) or liquid crystal display (LCD) production

The utilisation of NF_3, SF_6, and CF_4 in TFT-FPD or LCD production is significant. NF_3, primarily employed as a cleaning agent, ensures the removal of residual films and contaminants without leaving damaging residues. SF_6 and CF_4, are utilised as dielectric gases in plasma etching to draw circuitry patterns and deposit thin films onto substrates.

The Dry Etch process utilises SF_6, CF_4 and other gases to generate plasma for removal of the unnecessary portion of the surface of material. During the Photo Engraving Process, a resist cover is formed on a thin film deposited substrate, and excess thin film is then removed.

Based on the 2006 IPCC Guidelines for TFT-FPD or LCD production, there are four emission stream types. This is based on the gas-specific emission factors namely PFC-14 (i.e. CF_4), NF_3 and SF_6. The last emission stream type is catered to other GHGs where default emission factors are not available.

4.6.2. Methodological issues

Table 100: Method and emission factors used for emission estimation from Electronics industry

GHG source and sink category	CO_2		CH_4		N_2O	
	Method applied	Emission Factor	Method applied	Emission Factor	Method applied	Emission Factor
2.E.1. Integrated circuit or semiconductor	T3	PS	T3	PS	T3	PS
2.E.2. TFT flat panel display	NA	NA	NA	NA	NO	NO
2.E.3. Photovoltaics	NA	NA	NA	NA	T3	PS

GHG source and sink category	HFCs		PFCs		SF_6		NF_3	
	Method applied	Emission Factor	Method applied	Emission Factor	Method applied	Emission Factor	Method applied	Emission Factor
2.E.1. Integrated circuit or semiconductor	T2a T2b T3	D, PS	T2a T2b T3	D, PS	T2a T2b T3	D, PS	T2a T2b T3	D, PS
2.E.2. TFT flat panel display	NO	NO	T3	PS	T3	PS	T3	PS
2.E.3. Photovoltaics	NO	NO	T2b	D	NO	NO	T3	PS

Notation keys:
T2a - Tier 2a, T2b - Tier 2b, T3 - Tier 3, D - IPCC Default, PS - Plant-specific, NO - Not occurring, NA - Not applicable

Integrated circuit or semiconductor

There are two types of emission estimation approach, that is the (i) calculation approach and (ii) direct measurement approach to compute the emissions from the integrated circuit or semiconductor production.

Method 1: Calculation approach

The following formula below applies to the **metered** consumption (using quantity of gas fed into the process and measured by a meter) as per 2006 IPCC Tier 2a formula:

$$E_g = FC_{g,used} \times \{(1 - C_g) \times [1 - (A_g - D_g)] \times GWP_g + B_{b,g} \times [1 - (A_{b,g} - D_{b,g})] \times GWP_{b,g}\}$$

Ie. $E_g = FC_{g,used} \times \{(1 - C_g) \times [1 - (A_g - D_g)] \times GWP_g + (B_{b,g} - GWP_{b,g})\}$

where $A_{b,g} \times D_{b,g} = 0$ by default

Non-metered consumption (using quantity of gas purchased for use in the process) is determined using the formula below:

where $FC_{g,used} = FC_{g,purchased} \times (1-h)$

Parameter	Parameter Description	Units
E_g	Emissions of FC (g)	tonne CO_2 eq
$F_{g,used}$	Quantity of FC (g) fed into the process	tonne
$FC_{g,purch}$	Quantity of FC (g) purchased	tonne
h	Fraction of gas remaining in gas cylinder (heel) after use	Fraction
$1-C_g$	Emission factor for FC (g); with C_g being the use rate of FC (g) i.e. fraction destroyed or transformed in the process	Fraction
A_g & $A_{b,g}$	Fraction of FC (g) or by-product (b) volume used with emission control technology *Note that $A_{b,g} \times D_{b,g} = 0$ by default	Fraction
D_g & $D_{b,g}$	Fraction of FC (g) or by-product (b) volume used with emission control technology *Note that $A_{b,g} \times D_{b,g} = 0$ by default	Fraction
$B_{b,g}$	Rate of creation of by-product FC (b) from FC (g) in the process	Fraction
g	Type of FC (g) ed into the process	Fraction
p	Process type i.e. emission stream type	Fraction
GWP_g & $GWP_{b,g}$	Global warming potential for FC (g) or by-product (b)	Fraction

The accuracy of estimated emissions depends on the method used. The Tier 1 method uses default values for all parameters and does not account for the use of emissions control technology. The Tier 2a method uses company-specific data on the proportion of gas used in processes with and without emissions control technology but does not distinguish between the different types of processes (i.e., etching vs CVD) and uses default values for other parameters. The Tier 2b method uses company-specific data on the proportion used in etching vs cleaning and the proportion of gas used in processes with emissions control technology but relies on default values for some or all of the other parameters. As for Tier 3 method, it would then require a complete set of process-specific values rather than defaults.

Method 2: Direct measurement approach

While direct measurement approach is possible to estimate the emissions from the integrated circuit or semiconductor production, this is currently not practised in Singapore.

Choice of activity data and emission factor

Tier 2a, Tier 2b and Tier 3 were adopted by Integrated circuit or semiconductor facilities in Singapore. Facilities have the discretion to apply either Tier 2a or Tier 2b default emission factors. For example, if there is facility-specific data on the proportion of gas used in overall processes, Tier 2a would be used while for the proportion of gas used in specific processes, Tier 2b would be used.

The Tier 2a and Tier 2b default conversion factors for (i) $1 - C_g$ i.e. emission factor for FC fed into the process; (ii) B_{CF_4}, $B_{C_2F_6}$ and $B_{C_3F_8}$ i.e. rate of creation of by-product FCs from FC in the process; and (iii) D_g, fraction of FC that is destroyed by the emission control technology, are tabulated in Table 101 and Table 102[20].

[20] Refer to the 2006 IPCC Guidelines, Volume 3, Chapter 6, Tables 6.3 and 6.6 for more details.

Table 101: Tier 2a default emission factors for fluorinated compounds from semiconductor manufacturing and default efficiency parameters for emission reduction technology[21]

Conversion factor	Type of FC fed into the process													
	Greenhouse Gases with TAR GWP									Greenhouse Gases without GWP			Non-GHGs producing FC by-products	
	CF_4	C_2F_6	CHF_3	CH_2F_2	C_3F_8	$c-C_4F_8$	NF_3	NF_3 Remote	SF_6	C_4F_6	C_5F_8	C_4F_8O	F_2	COF_2
$1-C_g$	0.9	0.6	0.4	0.1	0.4	0.1	0.2	0.02	0.2	0.1	0.1	0.1	NA	NA
B_{CF_4}	NA	0.2	0.07	0.08	0.1	0.1	0.09	0.02	NA	0.3	0.1	0.1	0.02	0.02
$B_{C_2F_6}$	NA	NA	NA	NA	NA	0.1	NA	NA	NA	0.2	0.04	NA	NA	NA
$B_{C_3F_8}$	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.04	NA	NA
D_g[22]	0.9	0.9	0.9	NA	0.9	0.9	0.95	NA	0.9	NA	NA	NA	NA	NA

Table 102: Tier 2b default emission factors for fluorinated compounds from semiconductor manufacturing

	Greenhouse Gases with TAR GWP									Greenhouse Gases without GWP			Non-GHGs producing FC by-products	
Process Gas (i)	CF_4	C_2F_6	CHF_3	CH_2F_2	C_3F_8	$c-C_4F_8$	NF_3 Remote	NF_3	SF_6	C_4F_6	C_5F_8	C_4F_8O	F_2	COF_2
Tier 2b														
Etch $1-C_g$	0.7	0.4	0.4	0.06	NA	0.2	NA	0.2	0.2	0.1	0.2	NA	NA	NA
CVD $1-C_g$	0.9	0.6	NA	NA	0.4	0.1	0.02	0.2	NA	NA	0.1	0.1	NA	NA
Etch B_{CF_4}	NA	0.4	0.07	0.08	NA	0.2	NA	NA	NA	0.3	0.2	NA	NA	NA
Etch $B_{C_2F_6}$	NA	NA	NA	NA	NA	0.2	NA	NA	NA	0.2	0.2	NA	NA	NA
CVD B_{CF_4}	NA	0.1	NA	NA	0.1	0.1	0.02	0.1	NA	NA	0.1	0.1	0.02	0.02
CVD $B_{C_2F_6}$	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CVD $B_{C_3F_8}$	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.04	NA	NA

The treatment of the gases is as follows:

i) GHG with GWP: The FC fed into the process, and the by-product emissions would need to be accounted for.

ii) GHG without GWP: For FCs that do not have GWP in the IPCC assessment report that are fed into the process, these FCs fed into the process would not need to be accounted for. Only the by-product emissions will need to be accounted for.

iii) Non-GHG producing FC by-products: The FC fed into the process is not a GHG, but it produces FC by-products. Only the by-product emissions would need to be accounted for.

For other types of GHGs, there are no default conversion factors for (i) $1 - C_g$ i.e., emission factor for fluorinated compound fed into the process; and (ii) D_g, fraction of FC that is destroyed by the emission control technology. In addition, B_{CF_4}, $B_{C_2F_6}$ and $B_{C_3F_8}$ i.e., rate of creation of by-product FCs from FC in the process, is assumed to be zero.

Thin-film-transistor flat panel display (TFT-FPD) or liquid crystal display (LCD) production

There are two approaches to estimate the emissions from TFT-FPD and LCD, i.e., the calculation and direct measurement approaches.

[21] Refer to 2006 IPCC Guidelines, Volume 3, Chapter 6, Table 6.3 for more details.
[22] Refer to the 2006 IPCC Guidelines, Volume 3, Chapter 6, pages 6.20 and 6.21 for more details.

Method 1: Calculation approach

Based on the 2006 IPCC Guidelines, the following formula is used[23]:

$$E_g = C_u \times C_d \times EF_g \times GWP_g$$

Parameter	Parameter Description	Units
E_g	Emissions of FC (g)	tonne CO_2 eq
C_u	Fraction of annual plant production capacity utilised i.e. annual capacity utilisation	Nil
C_d	Annual manufacturing design capacity, expressed in terms of m^2 substrate processed	Giga or 10^9 square metres of substrate processed, Gm^2
EF_g	Emission factor for FC (g) expressed as annual mass emissions per square metre of substrate area processed	g/m^2 substrate processed
g	Type of GHG (g)	Nil
GWP_g	Global warming potential for FC (g)	Nil

The calculation of emissions relies on a fixed set of factors:

i) a gas-specific emission factor EF_g, expressed as an average emission per unit of substrate area (e.g. TFT-FPD panel) consumed during manufacture;

ii) annual capacity utilisation (C_u, a fraction) where in most cases the facility will measure the quantity of TFT-FPD or LCD material manufactured to determine the percentage of plant production utilised; and

iii) annual manufacturing design capacity C_d, in units of giga square metres (Gm^2) of substrate processes. The product $C_u \times C_d$ is an estimate of the quantity of substrate consumed during TFT-FPD or LCD manufacture.

Method 2: Direct measurement approach

The facility is also able to directly measure and report the release of GHGs from the electronics industry should such techniques be devised.

Choice of activity data and emission factor

The activity data and emissions were extracted from CPA from 2019 onwards and from ECA from 2013 to 2018. For years prior to 2013, projection was conducted using the Manufacturing Output In Manufacturing By Industry (Computer, Electronic & Optical Products) obtained from DOS's Singstat Table Builder as the surrogate parameter. Due to data confidentiality, emissions from 2.E.2. TFT flat panel display had been aggregated with 2.E.1. Integrated circuit or semiconductor.

The default emission factors for TFT-FPD or LCD production can be found in the table below based on 2006 IPCC Guidelines, Volume 3, Chapter 6 Table 6.2.

Table 103: Default emission factors for TFT-FPD or LCD production

Emission Stream Type	FC/ square metres of substrate processed (g/m^2)
PFC-14 (CF_4)	0.5
NF_3	0.9
SF_6	4
Other GHGs	NA

4.6.3. Description of any flexibility applied

Flexibility for time series which starts from year 2000 to 2022 as described in Section 1.9. Summary of any flexibility applied had been applied throughout the report.

4.6.4. Uncertainty assessment and time series consistency

Integrated circuit or semiconductor

The uncertainty estimates for the 2.E.1. Integrated circuit or semiconductor category are estimated to be ±1% for CO_2, ±3% for CH_4, ±8% for N_2O, ±8% for HFC-23, ±182% for HFC-32, ±126% for NF_3, ±55% for PFC-116, ±55% for PFC-14, ±103% for PFC-c318 and ±96% for SF_6.

Uncertainty factors for uncertainty estimations for reporting year 2022 are from the weighted average site-specific uncertainty factors reported by individual companies and facilities through CPA.

The overall uncertainty of the emissions stream under integrated circuit or semiconductor production can vary significantly. This results from the structure of the emissions calculation and the relatively high uncertainty of each step. In particular, the high uncertainty of the 'fraction of gas destroyed or transformed in the process', and high uncertainty of the abatement effectiveness, can result in a high uncertainty for the gas released even though the actual emissions can be low due to abatement. Therefore, even though abatement helps reduce overall emissions, there is an uncertainty value tied to the default abatement conversion factor, which can increase the overall uncertainty of the emissions stream.

For non-metered consumption, the default uncertainty value for the fraction of gas remaining in the shipping container (heel) i.e. 'invoice with default heel' is 1.8%.

Uncertainty factors for uncertainty estimations for reporting year 2000 are referenced from the 2006 IPCC Guidelines. Based on the 2006 IPCC Guidelines, the default uncertainty values for the following conversion factors are tabulated as follow[24]:

Table 104: Tier 2a Default Uncertainty for Integrated circuit or semiconductor

Conversion factor	Greenhouse Gases with TAR GWP									Greenhouse Gases without GWP			Non-GHGs producing FC by-products	
	CF_4	C_2F_6	CHF_3	CH_2F_2	C_3F_8	$c\text{-}C_4F_8$	NF_3	NF_3 Remote	SF_6	C_4F_6	C_5F_8	C_4F_8O	F_2	COF_2
$1\text{-}C_g$	15	30	100	400	20	80	70	400	300	300	80	40	NA	NA
C_g[25]	135	45	66.7	44.4	13.3	8.9	17.5	8.2	75	33.3	33.3	4.4	NA	NA
B_{CF_4}	NA	90	300	200	60	100	200	200	NA	200	100	80	200	200
$B_{C_2F_6}$	NA	NA	NA	NA	NA	200	NA	NA	NA	200	200	NA	NA	NA
$B_{C_3F_8}$	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	40	NA	NA
D_g[26]	10	10	10	10	10	10	10	10	10	10	10	10	10	10

Table 105: Tier 2b Default Uncertainty for Integrated circuit or semiconductor

	Greenhouse Gases with TAR GWP									Greenhouse Gases without GWP			Non-GHGs producing FC by-products	
Process Gas (i)	CF_4	C_2F_6	CHF_3	CH_2F_2	C_3F_8	$c\text{-}C_4F_8$	NF_3 Remote	NF_3	SF_6	C_4F_6	C_5F_8	C_4F_8O	F_2	COF_2
Tier 2b														
Etch $1\text{-}C_g$	60	100	100	700	NA	200	NA	300	300	300	200	NA	NA	NA
CVD $1\text{-}C_g$	10	30	NA	NA	0.4	30	400	70	NA	NA	30	40	NA	NA
Etch B_{CF_4}	NA	200	300	200	NA	200	NA	NA	NA	200	200	NA	NA	NA
Etch $B_{C_2F_6}$	NA	NA	NA	NA	NA	200	NA	NA	NA	200	200	NA	NA	NA
CVD B_{CF_4}	NA	80	NA	NA	60	60	200	200	NA	NA	60	80	200	200
CVD $B_{C_2F_6}$	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CVD $B_{C_3F_8}$	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	40	NA	NA

The default uncertainty value for Tier 2 site-specific conversion factor: fraction of gas used with emission control technology, is assumed to be 7.5%. For other conversion factors i.e. (i) C_g i.e. emission factor for fluorinated compound fed into the process; (ii) D_g, fraction of fluorinated compound that is destroyed by the emissions control technology; and (iii) B_{CF_4}, $B_{C_2F_6}$ and $B_{C_3F_8}$ i.e. rate of creation of by-product FCs from fluorinated compound in the process, the site-specific uncertainty values are assumed to be half of that of the default uncertainty values specified in the tables above.

For other types of GHG fed into the process where no default value is specified for $1 - C_g$ i.e., fraction destroyed or transformed in the process, the Tier 2 site-specific uncertainty value for C_g is 25% and D_g is 5%. The uncertainty of a site-specific value for C_g could vary significantly from the assumed value, depending on the actual value of C_g. The uncertainty value selected therefore provides a moderate level of uncertainty. However, the facility is encouraged to provide a more accurate site-specific uncertainty value where possible. For such other types of GHGs that are fed into the process, it is assumed that there are no by-product GHG emissions generated.

[23] Refer to the 2006 IPCC Guidelines, Volume 3, Chapter 6 for more details. Note that depending on the units of the various parameters, the actual computation formula may involve unit conversion.
[24] Refer to the 2006 IPCC Guidelines, Volume 3, Chapter 6, Table 6.9 for more details

[25] Uncertainty value of Cg= (1−Cg) × uncertainty value of (1−Cg) / Cg.
[26] Refer to the 2006 IPCC Guidelines, Volume 3, Chapter 6, pages 6.21 and 6.22 for more details.

Thin-film-transistor flat panel display (TFT-FPD) or liquid crystal display (LCD) production

The 2006 IPCC Guidelines state that the uncertainty values of these emission factors are not known but are probably large due to the variability of technology across the global sector, hence the Tier 1 default uncertainty values are assumed to be at 50%. The Tier 1 site-specific uncertainty values are assumed to be one-fifth of the default uncertainty values. The significant reduction in uncertainty for site-specific emission factors assumes that the facility has a stable level of technology. The default uncertainty value for Tier 1 default site-specific conversion factor for C_u, fraction of annual plant production capacity utilised, is assumed to be 7.5%.

Table 106:Default uncertainty for TFT, TFT-FPD and LCD

Emission Stream Type	Tier 1 default uncertainty	Tier 1 site-specific uncertainty
PFC-14 (CF_4)	50%	10%
NF_3	50%	10%
SF_6	50%	10%
Other GHGs	NA	10%

4.6.5. Category-specific QA/QC and verification

Compliant with QA/QC plan and implementation as outlined in Chapter 1, Section 1.5.

4.6.6. Category-specific recalculations

According to 2006 IPCC Guidelines, the use of HFCs for solvents is categorised under 2.F. Product uses as substitutes for ODS. However, due to data confidentiality, it will be masked under PFCs instead of HFCs under 2.E. Electronics industry. Other uses of HFCs by industries in the Electronic sector will also be included under 2.E. Electronics industry. With that, the emissions from PFCs increased from 1,438 kt CO_2 eq in 2018 according to the fifth BUR to 1,729 kt CO_2 eq for the same year.

4.6.7. Category-specific planned improvements

There is no planned improvement for this category.

4.7.

Product uses as substitutes for ODS (CRT category 2.F.)

4.7.1. Category description

Early generations of ozone depleting substances like Chlorofluorocarbons (CFCs) and Hydrochlorofluorocarbons (HCFCs) are currently being phased out under the Montreal Protocol and being switched to using alternatives such as HFCs and some PFCs as components of blends. The current use of application areas in Singapore includes:

1) RAC
2) Fire Suppression System
3) Aerosols
4) Solvent
5) Foam blowing

The emission patterns from these application areas are rather complex, particularly for RAC, fire suppression system and foam blowing. This is because the HFCs and PFCs may be contained within the equipment and not emitted into the atmosphere for a long time after the HFCs and PFCs are charged into the equipment. In addition, emissions may also vary significantly across different types of equipment and among various segments of the economy. Other applications such as aerosols pose challenges in estimation as they contain a myriad of products such as perfumes, deodorants, colognes, shaving gel, room fresheners, car fresheners etc. and are mainly imported into Singapore. Hence, it is difficult to identify if the product would contain HFCs/PFCs in its composition and quantity as most products are not specifically labelled with such information. As such, depending on data availability, Tier 1 or Tier 2 methods, as provided for under 2006 IPCC Guidelines, were used to estimate the HFC and PFC emissions.

Based on the 2022 emissions estimated, the RAC application contributes to 3,973 kt CO_2 eq, that is, 98.1% of the total GHG emissions from Product uses as substitutes for ODS, followed by fire suppression system 63.89 kt CO_2 eq (1.58%), aerosols 13.06 kt CO_2 eq (0.32%) and foam blowing 0.01 kt CO_2 eq (0.0003%).

Figure 31: Total GHG emissions from Product uses as substitutes for ODS (2000 to 2022)

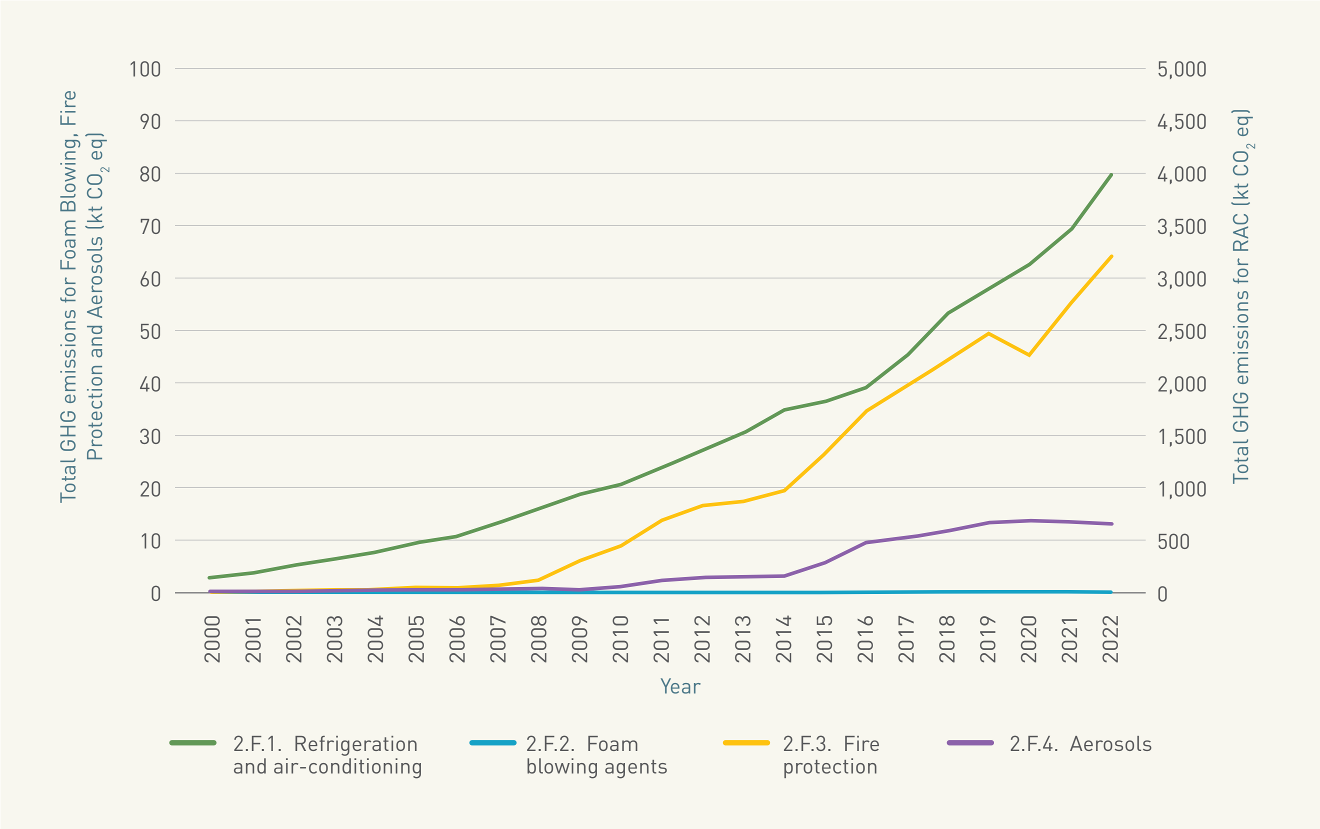


Table 107: Total GHG emissions from Product uses as substitutes for ODS (2000 to 2022)

Greenhouse Gas Category	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
	GHG Emissions (kt CO_2 eq)											
Product uses as substitutes for ODS[27]	137.47	189.14	253.15	321.88	385.03	469.27	533.33	668.04	797.02	933.39	1,041.88	1,206.60
2.F.1. Refrigeration and air-conditioning	137.16	188.71	252.60	321.23	384.07	467.92	531.87	666.04	794.01	926.69	1,031.99	1,190.70
2.F.2. Foam blowing agents	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.F.3. Fire protection	0.12	0.22	0.34	0.41	0.56	0.82	0.92	1.38	2.34	6.02	8.78	13.61
2.F.4. Aerosols	0.18	0.21	0.20	0.24	0.41	0.53	0.55	0.61	0.67	0.67	1.11	2.28

Greenhouse Gas Category	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
	GHG Emissions (kt CO_2 eq)										
Product uses as substitutes for ODS[27]	1,363.94	1,540.81	1,750.64	1,847.42	1,994.64	2,314.14	2,705.44	2,954.39	3,184.82	3,530.92	4,050.33
2.F.1. Refrigeration and air-conditioning	1,344.71	1,520.59	1,728.06	1,815.24	1,950.78	2,264.37	2,649.39	2,891.80	3,125.90	3,462.23	3,973.37
2.F.2. Foam blowing agents	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01
2.F.3. Fire protection	16.45	17.29	19.38	26.47	34.50	39.36	44.28	49.26	45.29	55.28	63.89
2.F.4. Aerosols	2.78	2.93	3.19	5.72	9.36	10.40	11.76	13.33	13.63	13.41	13.06

[27] Total emissions from 2.F. Product uses as substitutes for ODS excludes 2.F.5. Solvents to avoid double counting as 2.F.5. Solvents has been reported in 2.E.1. Integrated circuit or semiconductor.

Refrigeration and air-conditioning

Based on 2006 IPCC Guidelines, there are six sub-applications under the RAC systems. Further details on the six sub-applications present in Singapore are as follows:

a) Commercial refrigeration, including equipment in food establishments and refrigeration systems in supermarkets;
b) Domestic refrigeration, which covers mainly household refrigerators;
c) Industrial refrigeration, including refrigeration systems used in cold storages in warehouses, refrigeration systems in food, refineries, petrochemical and other manufacturing industries;
d) Transport refrigeration, including refrigeration systems used in refrigerated trucks, reefers and containers;
e) Mobile air-conditioning, including systems used in land transport vehicles and trains; and
f) Stationary air-conditioning, including household air-conditioning systems, VRF and chiller systems.

Based on the 2022 HFC emissions estimates, the stationary air-conditioning sub-application contributes to 1,931 kt CO_2 eq, that is 48.60% of the total HFC emissions for RAC systems, followed by commercial refrigeration 1,257 kt CO_2 eq (31.62%), industrial refrigeration 490 kt CO_2 eq (12.34%), mobile air-conditioning 279 kt CO_2 eq (7.02%) and transport refrigeration 12.19 kt CO_2 eq (0.31%).

Figure 32: Total GHG emissions from RAC (2000 to 2022)

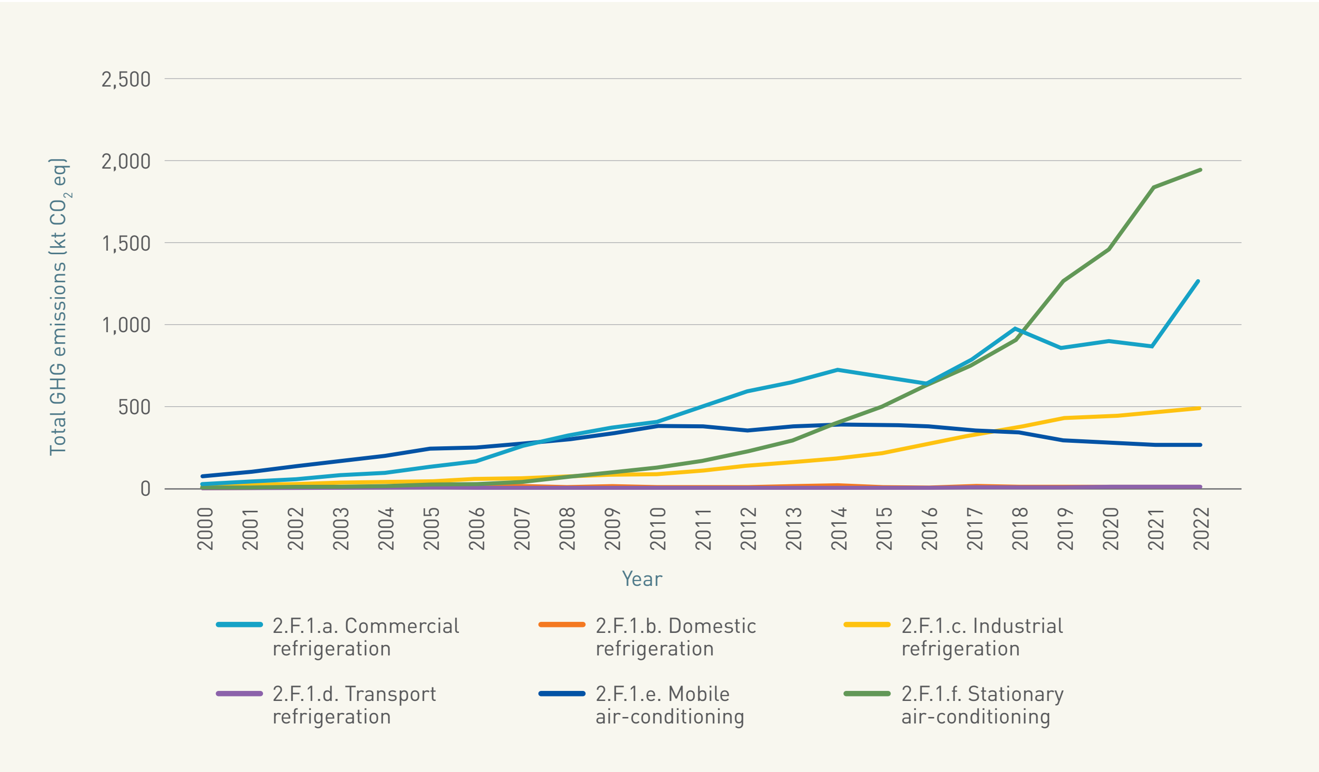


Table 108: Total GHG emissions from RAC (2000 to 2022)

Greenhouse Gas Category	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
	GHG Emissions (kt CO_2 eq)											
2.F.1. Refrigeration and air-conditioning	137	189	253	321	384	468	532	666	794	927	1,032	1,191
2.F.1.a. Commercial refrigeration	26	43	62	81	104	137	170	257	319	372	407	501
2.F.1.b. Domestic refrigeration	4	6	8	6	8	8	9	14	12	13	9	11
2.F.1.c. Industrial refrigeration	20	26	30	39	44	51	59	64	77	91	89	115
2.F.1.d. Transport refrigeration	1	1	2	2	2	3	2	5	5	5	5	5
2.F.1.e. Mobile air-conditioning	80	102	138	177	206	244	261	284	309	343	392	387
2.F.1.f. Stationary air-conditioning	7	10	12	16	19	25	31	43	73	102	131	171

Greenhouse Gas Category	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
	GHG Emissions (kt CO_2 eq)										
2.F.1. Refrigeration and air-conditioning	1,345	1,521	1,728	1,815	1,951	2,264	2,649	2,892	3,126	3,462	3,973
2.F.1.a. Commercial refrigeration	595	651	727	682	637	790	980	866	909	877	1,257
2.F.1.b. Domestic refrigeration	11	13	14	9	9	13	16	12	10	6	4
2.F.1.c. Industrial refrigeration	140	165	188	219	272	326	374	433	444	463	490
2.F.1.d. Transport refrigeration	5	5	5	6	11	8	10	11	12	13	12
2.F.1.e. Mobile air-conditioning	366	385	395	396	388	369	353	307	294	276	279
2.F.1.f. Stationary air-conditioning	228	301	399	503	633	758	917	1,263	1,456	1,826	1,931

The refrigerants containing HFCs and PFCs currently used for RAC systems are summarised in Table 109 below.

Table 109: Refrigerants used in RAC systems in Singapore

Sub-applications	Refrigerants
Commercial refrigeration	HFC-134a, R-404a, R-507a, R-410a, HFC-134, HFC-143a
Domestic refrigeration	HFC-134a, HFC-152a
Industrial refrigeration	HFC-134a, R-404a, R-407c, R-507a
Transport refrigeration	HFC-134a, R-404a, R-408a
Mobile air-conditioning	HFC-134a, HFO-1234yf, HFC-152a, R-407c
Stationary air-conditioning	R-410a, R-407c, HFC-32, R-450a, R-410a, R-507a, HFO-1234ze, R-404a, R-407c, R-514a, HFO-1336mzz, HFC-143a

Foam Blowing Agent

There are two types of applications that use foam blowing agent, that is, the open-cell foam and closed-cell foam. Emissions from open-cell foam usually occur during the manufacturing process while small amount of emissions from closed-cell foam occur during the manufacturing process and majority of the emissions occur at end-of-life (EOL). So far, there is no known open-cell foam manufacturing in Singapore.

Fire Suppression System

The fire suppression sub-application consists of two different types – fixed (flooding) and portable (streaming) equipment. The fixed systems, which may contain HFCs or other types of fire suppressants like nitrogen, argon, carbon dioxide or powder, are those designed to automatically dispense the fire suppressant when an alarm is triggered. It is common that such systems remain charged during their lifetime. The HFCs currently used in fixed fire suppression systems in Singapore are HFC-23 and HFC-227ea.

Based on market survey, there is no known report of HFCs or PFCs use for portable fire suppression systems, possibly due to cheaper alternatives such as dry chemical, carbon dioxide and water that are readily available.

Aerosols

According to 2006 IPCC Guidelines, there are five main sub-applications of aerosols, namely metered dosed inhalers (MDIs); personal care products such as deodorants, shaving cream etc.; household products such as air fresheners, fabric cleaners etc.; industrial products such as cleaning sprays, lubricants; and other general products such as tyre inflators etc.. There is no known manufacturing of aerosol within the country.

The HFCs currently used as propellants in MDIs are HFC-134a and HFC-227ea.

Solvents (non-aerosol)

There are four main sub-applications for solvent according to 2006 IPCC Guidelines, which include (i) Precision cleaning, (ii) Electronics cleaning, (iii) Metal cleaning, and (iv) Deposition applications. For solvents used, due to data confidentiality, the HFC emissions from this subcategory is reported in 2.E. Electronics Industry.

4.7.2. Methodological issues

Table 110: Method and emission factors used for emission estimation for Product uses as substitutes for ODS

GHG source and sink category	HFCs	
	Method applied	Emission Factor
2.F.1. Refrigeration and air-conditioning	T2a, T2b	D, CS
2.F.2. Foam blowing agents	T2a	D
2.F.3. Fire protection	T1a	D
2.F.4. Aerosols	T2a	D
2.F.5. Solvents	T2a	PS

Notation keys:
T1a - Tier 1a, T2a - Tier 2a, T2b - Tier 2b, D - IPCC Default, CS - Country-specific, PS - Plant-specific

Under the 2006 IPCC Guidelines, there are two tiers that were used – Tier 1 and Tier 2. The Tier 2 method estimates emissions at a disaggregated level, and is recommended for applications that are identified as a "Key Category" through the KCA; whereas under Tier 1, emissions estimation is carried out at an aggregated level.

Out of the six applications, RAC has been identified as a key category based on a study conducted earlier in 2018. On 1 January 2019, Singapore implemented licensing controls on the HFCs regulated under the Kigali Amendment of the Montreal Protocol. The licensing regime has enabled Singapore to collect more accurate import and export trade data on HFCs. With the new licensing condition, Singapore has been working to develop a Tier 2 estimate of HFC emissions inventory where the HFC emissions is now included in the NID.

Time series projection

As historical equipment data prior to 2019 for some sub-applications are not available, according to 2006 IPCC guidelines for time series consistency, surrogate data is an alternative splicing method, and this would be implemented using the following equation.

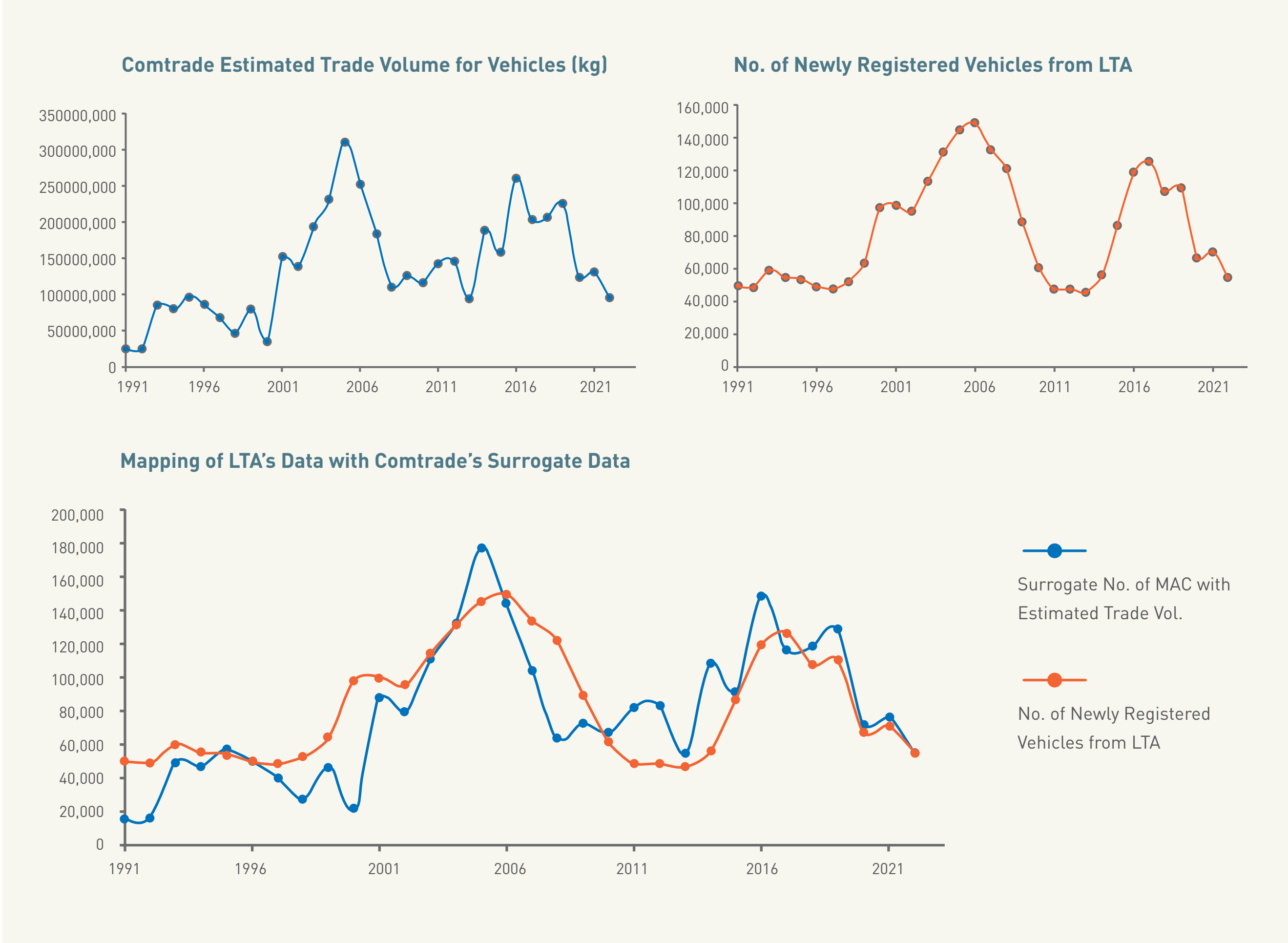
$$y_t = \frac{y_0}{S_0} \times S_t$$

where:
y_0 and y_t are the emission-related data in years 0 and t respectively
s_t and s_0 are the surrogate data in years 0 and t respectively

Singapore employs the ASEAN Harmonised Tariff Nomenclature (AHTN), an 8-digit code system, to classify trade goods. This system is derived from the 6-digit level Harmonised System (HS) codes recommended by the World Customs Organisation (WCO). The first six digits of both systems are identical. Prior to the adoption of HS codes in 1989, the Standard International Trade Classification (SITC) system was commonly used. Trade data pertaining to Singapore can be accessed from the United Nations Comtrade database, categorised by HS codes from 1989 to 2022 and SITC Rev. 2 codes from 1976 to 2000.

By utilising Comtrade, import and export data for each specific good are extracted using the identified HS codes and SITC codes. The trend in the trade volume serves as surrogate data for the historical market trend of relevant goods, which is used to estimate backward emissions projection. To validate the use of the Comtrade data as an indicator of market trends, comparison to a sub-application was conducted where there was robust data on the actual market: mobile air-conditioning. See Figure 33 below. Land Transport Authority (LTA) has historical data on car registration that can be used to compare with Comtrade trade volume.

Figure 33: Mapping of trade volume from Comtrade database to LTA newly registered vehicles



Reference year for mapping: 2022

To derive the backwards projection for both EOL and operating emissions preceding the year of available data up to 1990, the following quantities are used:

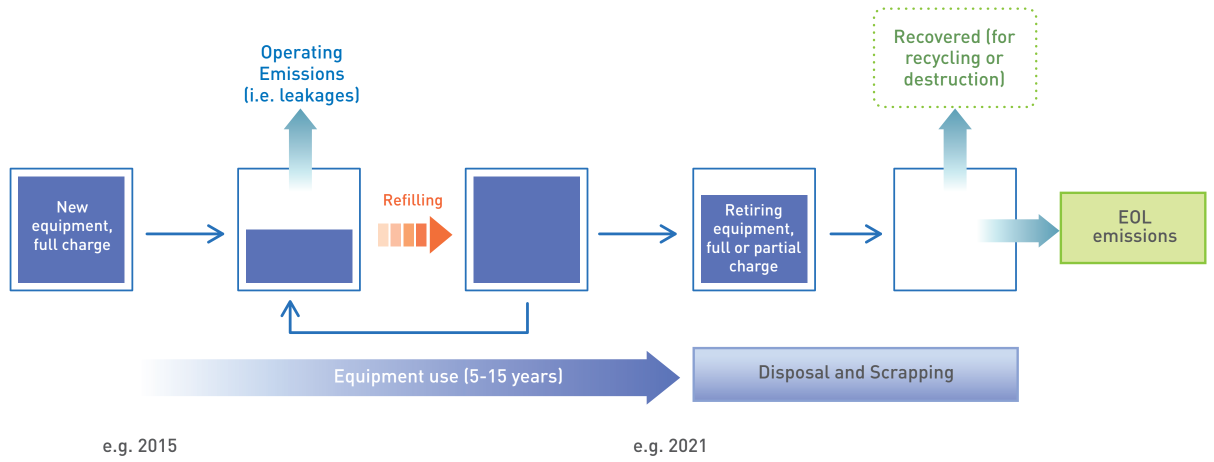
a) Projected total quantity of HFCs and related chemicals;
b) Proportion of each HFCs and related chemical (as described in the previous paragraph);
c) GWP of each chemical;
d) Average lifespan of equipment (from survey data, LTA data or default IPCC values); and
e) Rate of leakage (from default IPCC values).

To obtain the EOL emissions, the projected total quantity of chemicals in a particular year (a) is distributed over the proportion of each chemical (b) to obtain the projected quantity of each chemical. The quantity of each chemical is then multiplied by its GWP (c) to obtain the emissions in CO_2 eq. The emissions from each chemical are summed up, and this total emissions value is then assigned to the appropriate year according to the equipment lifespan.

On the operation emissions, this involves summing up the initial charges of all equipment actively in service during their operating lifetimes to estimate the bank of emissions and the chemical leakage rate obtained from IPCC default emission factor.

Refrigeration and air-conditioning

Figure 34: An illustration of emissions from RAC and fire suppression application



There are two approaches that could be used to estimate the emissions from RAC systems within Tier 2. They are Tier 2a (Emission factor approach) which calculates emissions at equipment level, and Tier 2b (Mass balance approach) which calculates emissions based on refrigerant sales data. As Singapore moved towards using Tier 2 to estimate the emissions from RAC systems, Tier 2a approach was adopted. In sub-applications where national statistics were not available, Tier 2b approach was used.

Tier 2a (Emission Factor approach)

Using the following equation for Tier 2a methodology from IPCC Guidelines at the sub-application level.

$$Emissions_{reporting\ year} = Manufacturing\ Emissions_{reporting\ year} + Operation\ Emissions_{reporting\ year} + Disposal\ Emissions_{reporting\ year}$$

where
$Manufacturing\ Emissions_{reporting\ year}$ is assumed to be zero as equipment under the sub-applications considered is imported;
$Operation\ Emissions_{reporting\ year}$ is a result of leakage from the equipment throughout its lifetime;
$Disposal\ Emissions_{reporting\ year}$ is a result of disposal of equipment upon its EOL

$Operation\ Emissions_{reporting\ year}$ = Bankreporting year × (Emission Factor/100)

$$Bank_{reporting\ year} = \sum_{j=t_0}^{t\,=\,reporting\ year} Charged\ quantity\ of\ HFC_i\ in\ each\ equipment_j \times Number\ of\ equipment_j$$

where
i represents HFC/HFC-blend number;
t_0 = reporting year- equipment lifetime+1 for both domestic refrigeration and domestic air-conditioning; reporting year inclusive.

$$Disposal\ Emissions_{reporting\ year} = M_{reporting\ year\text{-}d} \times \left(1 - \frac{Recovery\ efficiency}{100}\right) \times p$$

where
$M_{reporting\ year\text{-}d}$ is the total amount of refrigerant charged for all equipment under a given sub-application;
p represents residual charge of refrigerant in the equipment being disposed of expressed in % of initial charge.

Tier 2b (Mass balance approach)

$$Emissions_{Total,\ reporting\ year}\ (in\ tonnes\ CO_{2\ eq}) = (Servicing\ of\ equipment\ for\ local\ use_{reporting\ year} + Direct\ utilisation_{reporting\ year}) \times GWP_i$$

where
i represents HFC/HFC-blend number.
$Servicing\ of\ equipment\ for\ local\ use_{reporting\ year}$ could be used for applications such as RAC and Fire suppression; and
$Direct\ utilisation_{reporting\ year}$ could be used for applications such as foam blowing, aerosols and solvents due to the nature of the use for these applications.

Solvents (non-aerosols)

For solvents, the emissions could be estimated using calculation approach. While the use of HFCs and PFCs is typically emitted within the two years of initial use[28], for ease of reporting under the CPA, all HFCs and PFCs from solvent applications are assumed to be emitted in the form of a net usage during the reporting period (i.e. within the year of use). This net usage amount would have to be determined by the facility e.g. the total amount that is used in the application less any amount disposed of via a third-party vendor and/or any amount destroyed or recovered during the reporting period. Thereafter, the quantity of HFCs and PFCs emitted is derived based on the mass content of the applicable solvent used during the reporting period.

$$E_g = Q_g \times GWP_g$$

Parameter	Parameter Description	Units
E_g	Emissions of GHG (g) i.e. HFCs or PFCs	tonne CO_2 eq
Q_g	Quantity of HFCs or PFCs solvent (g) emitted	tonne
g	Type of GHG (g) i.e. HFCs or PFCs	Nil
GWP_g	Global warming potential for GHG (g)	Nil

Choice of activity data and emissions factors

National statistics were available for sub-applications such as domestic refrigeration, mobile air-conditioning, transport refrigeration and part of the stationary air-conditioning systems. The list of national statistics can be summarised in Table 111. For sub-applications that are without national statistics, a survey has been conducted to obtain the current year's data using either Tier 2a or Tier 2b methodology.

Table 111: National statistics used for RAC systems

Sub-applications	National statistics
Domestic refrigeration	Survey on Sales of Electrical Appliances (SSEA) collected under the Statistics Act and ECA
Stationary air-conditioning[29]	SSEA collected under the Statistics Act and ECA
Mobile air-conditioning	Singapore Land Transport (Statistics)
Transport refrigeration	Singapore Land Transport (Statistics)
Commercial refrigeration	Licensed Food Establishments (Statistics) under Sale of Food Act, Wholesome Meat and Fish Act, and Environmental Public Health Act

The emission factor and lifetime of each sub-application under the RAC systems can be summarised in the table below. For emission factor for EOL emissions, it is assumed that all equipment is fully charged, that is, 100% of initial charge remaining.

Table 112: Emission factor and lifetime for RAC systems

Sub-applications	Emission factor (Operation Emission)	Lifespan (years)
Commercial refrigeration	15.1%	7
Domestic refrigeration	0.5%	7
Industrial refrigeration	25%	9
Transport refrigeration	50%	10
Mobile air-conditioning[30]	20%	10 to 30
Stationary air-conditioning[31]	10 to 15%	7 to 15

[28] Refer to the 2006 IPCC Guidelines, Volume 3, Chapter 7, pages 7.23 to 7.27.
[29] For stationary air-conditioning with national statistics, it includes household air-conditioning and VRFs.
[30] For Mobile air-conditioning, the lifetime for trains is estimated to the 30 years whereas for all other vehicles is estimated to be 10 years.
[31] For stationary air-conditioning, it includes household air-conditioning, VRFs and chillers.

Foam Blowing Agent

A voluntary survey was conducted with companies dealing with foam blowing agent where activity data were collected to compute the HFC emissions from foam blowing activities. On the estimation of emissions for closed-cell foam, we assumed an IPCC default of 20 years with operating emission rate at 4.5% of initial charge per year, with additional first year emission rate of 10% of initial charge.

Fire Protection

Information such as HFC type and the quantity used for fire protection systems were collected from fire protection system plans provided by Singapore Civil Defence Force (SCDF). These plans were submitted by qualified persons who declared full compliance with the Fire Code and the Fire Safety Act. The estimation of emissions for fire protection systems is similar to that of RAC systems where both Tier 2a and Tier 2b methodology could be used to estimate its emissions. For Tier 2a estimation, the country-specific lifetime for fixed fire suppression system is 15 years while IPCC operating emission rate at 3% was used.

Aerosols

As there is no known manufacturing of aerosols within the country, the emissions from aerosols were estimated based on the sales data of pharmaceutical companies for MDIs in Singapore. The main methodology used to estimate emissions from MDIs is the emission factor approach. The operating emissions are calculated based on a leakage rate of 50 percent of the cumulative total charge of all MDIs introduced within the previous two years. Consequently, the assumed value for the EOL emissions of MDIs is zero.

Solvents (non-aerosols)

The activity data and emissions were extracted from CPA from 2019 onwards and from ECA from 2013 to 2018. For years prior to 2013, projection was conducted using the Manufacturing Output In Manufacturing By Industry (Computer, Electronic & Optical Products) obtained from DOS's Singstat Table Builder as the surrogate parameter as the solvent was mainly used in the electronics industry. Due to data confidentiality, emissions from 2.F.5. Solvents had been aggregated with 2.E.1. Integrated circuit or semiconductor.

4.7.3. Description of any flexibility applied

Flexibility for time series which starts from year 2000 to 2022 as described in Section 1.9. Summary of any flexibility applied had been applied throughout the report.

4.7.4. Uncertainty assessment and time series consistency

For product uses as substitutes for ODS (Category 2.F.), the uncertainty estimates were calculated using Approach 2 – Monte Carlo Simulation (MCS). Approach 2 involves generating random samples of data for each parameter involved in the calculations. For example, in the context of HFC appliances, when calculating the total charge of a specific equipment model in a given year, N instances of initial charge were multiplied by N instances of equipment sales for that year, considering their respective distributions. The resulting array of potential total charges created a distribution, from which the mean and uncertainty could be determined.

The probability distribution function used for MCS is assumed to be a normal distribution function. The assumption of a normal distribution for survey data is also recommended by the IPCC Good Practice Guidance and Uncertainty Management in National GHG Inventories. While a lognormal distribution is another alternative suggested in the IPCC Good Practice Guidance for cases where the standard deviation is considerably larger than the mean, all values of a lognormal distribution are positive and hence it removes the possibility of having a negative portion of the distribution. However, further processing of lognormal distributions presents challenges that are not trivial. For instance, it can invalidate the application of IPCC approach 1 in uncertainty propagation. With the consideration that majority of the categories are using Approach 1 – Error Propagation to calculate uncertainty estimates, for this set of MCS, normal distribution would be assumed, and the truncated form of the distribution would be used for uncertainty estimations.

The iteration number implemented for MCS as N = 1000, with the randomness instance of the MCS fixed at 0, and the uncertainty coverage factor fixed at 1.96 as the uncertainty estimates are computed within a 95% confidence interval. The activity data collated from the surveys were used to calculate the uncertainty estimates using a Python script.

Table 113 shows the uncertainty values used calculated for each application for base year and reporting year 2022 using MCS. The uncertainty values have been rounded up to the next whole number for a modest estimation of uncertainty.

Table 113: Uncertainty values calculated for each application for base year and reporting year 2022 using MCS

Categories	Subcategories	Uncertainty
2.F. Product uses as substitutes for ODS	2.F.1.a. Commercial refrigeration	±1%
	2.F.1.b. Domestic refrigeration	±3%
	2.F.1.c. Industrial refrigeration	±10%
	2.F.1.d. Transport refrigeration	±21%
	2.F.1.e. Mobile air-conditioning	±100%
	2.F.1.f. Stationary air-conditioning	±130%
2.F.2. Foam blowing agents	2.F.2.a. Closed cells	±49%
2.F.3. Fire protection	2.F.3. Fire protection	±68%
2.F.4. Aerosols	2.F.4.a. Metered dose inhalers (MDI)	±63%

Solvents (non-aerosols)

As the activity data and emissions data for 2.F.5. Solvents are included under 2.E.1, uncertainty assessment is not performed for this subcategory.

4.7.5. Category-specific QA/QC and verification

As emissions calculations are dependent on data submitted by various stakeholders such as importers/exporters, servicing companies, pharmaceutical companies and equipment manufacturers etc., quality control checks are performed upon receipt of the data.

The QC activities carried out to assess and maintain the quality of the data and information submitted can be found in Table 114.

Table 114: Activities undertaken in Quality Control for Product uses as substitutes for ODS

Category	QC activity	Remarks
Unit	To ensure unit consistency (e.g. quantity of HFCs is reported in kg in questionnaire)	To reduce input error in unit conversion
Data labels	To ensure values are input in the correct sub-application category (e.g., follow up with companies if HFCs are found to be used in unique sub-applications)	To reduce input error which will jeopardise the effort in understanding HFCs consumption across various sub-applications.
Data values	To ensure the data values input by the companies are within tolerance limit set internally (i.e. 5% tolerance on the lower limit of purchases made by First-point-of-sales (FPOS) companies reported in the EPMA data)	To reduce the likelihood of under-reporting of data values
Completeness	To ensure surveys are correctly and completely filled.	To reduce the intensity of outliers in data submissions

4.7.6. Category-specific recalculations

In the fifth BUR, HFC emissions of 376 kt CO2 eq (largely from regulated industrial facilities) were reported. As part of Singapore's continual improvement efforts to meet the TACCC principles and BTR requirements for national GHG inventory reporting, Singapore developed an economy-wide Tier 2 estimate of HFC emissions from all ODS applications occurring in Singapore (such as commercial refrigeration, mobile air-conditioning, industrial refrigeration, domestic refrigeration, transport refrigeration, stationary air-conditioning).

With the availability of more comprehensive data, Singapore's HFC emissions are now updated to be 2,705 kt CO_2 eq (for 2018) in this NID2024, of which 2,649 kt CO_2 eq is attributed to HFC emissions from RAC. Projection was also conducted to ensure consistency in the time series.

4.7.7. Category-specific planned improvements

There is no planned improvement for this category.

4.8. Other product manufacture and use (CRT category 2.G.)

4.8.1. Category description

This section estimates the SF_6, PFCs and N_2O emissions from electrical equipment, semiconductor and flat panel display manufacturing, which have been reported in Section 4.5., 2.E. Electronics Industry, particle accelerator, 'adiabatic' applications, sound-proof windows, heat transfer fluids in commercial and consumer applications, cosmetics and medical applications etc. On the heat transfer fluids application, there is no known use of PFCs as heat transfer fluids have been reported. Only data on SF_6 used in electrical equipment such as gas insulated switchgear and substations (GIS), gas circuit breakers (GCB), high voltage gas insulated lines (GIL), outdoor gas-insulated instrument transformer and other equipment have been collected under the CPA.

Based on the 2022 emissions estimated, 2.G. Other product manufacture and use contributes to 25.74 kt CO_2 eq, that is, 0.04% of the total GHG emissions in Singapore.

Table 115: Total GHG emissions from Other product manufacture and use (2000 to 2022)

Greenhouse Gas Category	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
	GHG Emissions (kt CO_2 eq)											
2.G. Other product manufacture and use	2.57	2.29	2.20	2.15	2.48	2.58	2.87	3.05	3.14	2.63	2.50	2.51

Greenhouse Gas Category	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
	GHG Emissions (kt CO_2 eq)										
2.G. Other product manufacture and use	2.61	2.61	34.92	1.06	3.74	4.37	15.37	15.37	7.79	20.57	25.74

Electrical equipment

SF_6 is used in electrical equipment such as GIS, GCB, GIL, outdoor gas insulated instrument transformer and other equipment.

There are 12 emission stream types for the use of SF_6 in electrical equipment. The emission stream types are grouped into manufacture, use/installation and disposal, and further divided by the type of electrical equipment as listed below.

i) Use - Sealed Pressure[32] (MV Switchgear)
ii) Use - Closed Pressure[33] (HV Switchgear)
iii) Use - Gas Insulated Transformers
iv) Use - Others
v) Manufacture - Sealed Pressure (MV Switchgear)
vi) Manufacture - Closed Pressure (HV Switchgear)
vii) Manufacture - Gas Insulated Transformers
viii) Manufacture - Others
ix) Disposal - Sealed Pressure (MV Switchgear)
x) Disposal - Closed Pressure (HV Switchgear)
xi) Disposal - Gas Insulated Transformers
xii) Disposal - Others

SF_6 and PFCs from other product use

SF_6 within the country has been used in university and research operated particle accelerators. It is generally used as an insulating gas contained in high voltage equipment and operated within a vessel at a pressure exceeding atmospheric pressure. The charges within the accelerator, according to 2006 IPCC Guidelines, can range from five kg to over 10,000 kg. However, the typical charges are between 500 to 3,000 kg. When the equipment requires maintenance, the SF_6 is transferred into storage tanks where losses through slow leaks occur typically during gas recovery and transfer, when pressure relief valves are actuated[34].

N_2O from product uses

According to 2006 IPCC Guidelines, the larger sources that uses N_2O for its applications are for medical applications such as for anaesthetic use, analgesic use, veterinary use, and propellant in aerosol products such as for blowing of cream into foam in the whipped cream canister. Currently, emissions from this category are not estimated.

[32] Sealed pressure systems are defined as equipment that do not require any refilling with gas during its lifetime and which generally contain less than 5kg of gas per functional unit.
[33] Closed pressure systems are defined as equipment that require refilling with gas during its lifetime and which generally contain between 5 and ~100 kg of gas per functional unit.
[34] Refer to the 2006 IPCC Guidelines, Volume 3, Chapter 8, Page 8.26.

4.8.2. Methodological issues

Table 116: Method and emission factors used for emission estimation for Other product manufacture and use

GHG source and sink category	SF_6	
	Method applied	Emission Factor
2.G.1. Electrical equipment	T3	PS
2.G.2. SF_6 and PFCs from other product use	T2	PS

Notation keys:
T2 - Tier 2, T3 - Tier 3, PS - Plant-specific

Electrical equipment

Under CPA, calculation approach is used to estimate emissions of SF_6. Based on 2006 IPCC Guidelines, the following formula has been used.

Total Emissions = Manufacturing Emissions + Equipment Installation Emissions + Equipment Use

Emissions + Equipment Disposal Emissions

Equipment use and installation emissions

The facility using electrical equipment containing SF_6 is required to report emissions due to:

- Losses during filling of new equipment (installation); and
- Leakage from installed equipment.

The calculation approach uses the following formula:

$$E_{SF_6} = E_{SF_6,install} + E_{SF_6,usage}$$

The emissions from filling of new equipment can be derived from the difference between the quantity of SF_6 used to fill the new equipment and the capacity of the new equipment:

$$E_{SF_6,install} = (Q_{t,SF_6} - Cap_{t,New}) \times GWP_{SF_6}$$

The emissions from use of installed equipment is determined based on the following formula:

$$E_{SF_6,Use} = (Cap_{t,Stock} \times EF_{t,Stock}) \times GWP_{SF_6}$$

The usage leakage rate for equipment use includes emissions due to leakage, servicing and maintenance as well as failures. As the leakage rate for equipment use is difficult to measure, an alternative approach is to report the quantity of SF_6 used to top up the installed equipment. In this case, the leakage rate for equipment use would be 1 (i.e. quantity of SF_6 topped up equals to leakage quantity).

Parameter	Parameter Description	Units
E_{SF_6}	Emissions of SF_6	tonne CO_2 eq
$E_{SF_6,install}$	Emissions of SF_6 from filling of new equipment	tonne CO_2 eq
$E_{SF_6,Use}$	Emissions of SF_6 from use of installed equipment	tonne CO_2 eq
$Cap_{t,New}$	Capacity of new equipment (t)	tonne SF_6
Q_{t,SF_6}	Quantity of SF_6 used to fill new equipment (t)	tonne SF_6
$Cap_{t,Stock}$	Capacity of installed equipment (t)	tonne SF_6
$EF_{t,Stock}$	Usage leakage rate for equipment (t) during use	Factor
t	Type of equipment (i.e.: sealed-pressure, closed-pressure, gas-insulated transformers, other)	Nil
GWP_{SF_6}	Global warming potential for SF_6	Nil

Depending on the approach for quantifying the activity data, the facility is required to specify either or both of the following:

i) SF_6 capacity of electrical equipment (new and/or installed)
ii) Quantity of SF_6 used to top up installed equipment and/or fill new equipment.

Manufacturing emissions

The facility which manufactures electrical equipment containing SF_6 is required to report the emissions due to losses during filling of the equipment.

Based on the 2006 IPCC Guidelines, calculation approach uses the following formula:

$$E_{SF_6} = Q_t \times EF_t \times GWP_{SF_6}$$

Parameter	Parameter Description	Units
E_{SF_6}	Emissions of SF_6	tonne CO_2 eq
Q_t	Emissions of SF_6 used to fill equipment by (t)	tonne SF_6
EF_t	Manufacture emission rate for equipment (t) during filling	Factor
t	Type of equipment (i.e.: sealed-pressure, closed-pressure, gas-insulated transformers, other)	Nil
GWP_{SF_6}	Global warming potential for SF_6	Nil

The facility using a site-specific manufacture emissions rate can derive it from the quantity of SF_6 used to fill the equipment compared to the capacity of the equipment:

$$EF_t = \frac{Q_t - Cap_t}{Q_t}$$

where Cap_t is the capacity of the equipment of type (t).

Equipment disposal emissions

The facility which disposes of electrical equipment that contains SF_6 must either:

i) provide evidence to NEA that the recycling company engaged to dispose of equipment will manage the SF_6 gas contained in the equipment in an approved manner; or

ii) report emissions due to SF_6 remaining in the disposed equipment and not captured for recycling or destruction.

The IPCC method uses the following formula:

$$E_{SF_6} = (Cap_t \times EF_t) \times GWP_{SF_6}$$

Parameter	Parameter Description	Units
E_{SF_6}	Emissions of SF_6	tonne CO_2 eq
Cap_t	SF_6 capacity of equipment (t)	tonne SF_6
EF_t	Fraction of SF_6 remaining (not captured for recycling or destruction) at disposal for equipment (t)	Factor
t	Type of equipment (i.e.: sealed-pressure, closed-pressure, gas-insulated transformers, other)	Nil
GWP_{SF_6}	Global warming potential for SF_6	Nil

The facility using a site-specific fraction of SF_6 remaining in the disposed equipment can derive it from the quantity of SF_6 released from the equipment and the capacity of the equipment:

$$EF_t = \frac{Cap_t - Q_t}{Cap_t}$$

where Q_t is the quantity of SF_6 not captured for recycling from equipment of type (t) as measured by the change in weight of the equipment after the removal of the gas.

Choice of activity data and emission factor

The activity data and emissions were extracted from CPA from 2019 onwards and emissions from ECA from 2013 to 2018. However, there was no activity data prior to year 2018. For years prior to 2013, projection was conducted using the Manufacturing Output In Manufacturing By Industry (Electrical Equipment) obtained from DOS's Singstat Table Builder as the surrogate parameter.

The default IPCC conversion factors[35] for SF_6 in electrical equipment are shown in Table 117. The conversion factors were obtained based on the regional values for Japan[36].

Table 117: Tier 1 default conversion factors for use of SF_6 in electrical equipment

Equipment type	Manufacture emissions rate	Usage leakage rate	Fraction remaining at disposal
Sealed Pressure (MV Switchgear)	0.29	0.007	0.95
Closed Pressure (HV Switchgear)	0.29	0.007	0.95
Gas Insulated Transformers	0.29	0.007	0.95
Others	Not available	Not available	Not available

SF_6 and PFCs from other product use

To compute the SF_6 emissions from university and research particle accelerator, the following formula from 2006 IPCC Guidelines can be adopted.

Total Emissions = SF_6 university and research particle accelerator Emission Factor × Σ Individual Accelerator Charges

where SF_6 university and research particle accelerator Emission Factor = 0.07, the average annual university and research particle accelerator emissions rate as a fraction of the total charge.

Individual User Accelerator Charges = SF_6 contained within each university and research accelerator.

Choice of activity data and emission factor

The activity data and emissions were provided for from 1998 onwards. Instead of using the default emission factor of 7 percent, plant-specific emission factor was used. However, due to data confidentiality, emissions from 2.G.2. SF_6 and PFCs from other product use had been aggregated with 2.G.1. Electrical equipment.

4.8.3. Description of any flexibility applied

Flexibility for time series which starts from year 2000 to 2022 as described in Section 1.9. Summary of any flexibility applied had been applied throughout the report.

[35] Refer to the 2006 IPCC Guidelines, Volume 3, Chapter 8, Tables 8.2 to 8.4.
[36] Based on data reported by the Federation of Electric Power Companies (FEPC) and the Japan Electrical Manufacturers' Association (JEMA) (FEPC and JEMA, 2004). These organisations did not distinguish among equipment types in reporting average emissions factors. The factors are therefore intended to be applied to all equipment types, including sealed pressure systems, closed pressure systems and gas-insulated transformers.

4.8.4. Uncertainty assessment and time series consistency

Electrical equipment

The uncertainty estimates for the 2.G.1. Integrated circuit or semiconductor category are estimated to be ±1% for SF_6. Uncertainty factors for uncertainty estimations for reporting year 2022 are from the weighted average site-specific uncertainty factors reported by individual companies and facilities through CPA.

Uncertainty factors for uncertainty estimations for base year 2000 references the default uncertainty factors from the 2006 IPCC Guidelines. The default uncertainty factors[37] for SF_6 in electrical equipment are shown in the table below. The conversion factors were obtained based on the regional values for Japan. The default uncertainty values for the fraction remaining were not provided by IPCC. An uncertainty of 5% has been assumed based on the default factor of 95%.

The default uncertainty for Tier 1 site-specific conversion factors is half or one-third of the default for the manufacturing emission rates due to the ability of the facility to measure actual loss for the facility.

The uncertainty will remain relatively high as it is based on the comparison between losses and gas used. It may be lower than 10%, however facilities would need to justify a lower value. The site-specific uncertainty for fraction remaining at disposal is equal to the default (5%) as facilities may not have any control over the life span of equipment and leakage over the period.

Table 118: Tier 1 default uncertainty values for use of SF_6 in electrical equipment

Equipment type	Manufacture emissions rate		Usage leakage rate		Fraction remaining at disposal	
	Tier 1 default uncertainty	Tier 1 site-specific uncertainty	Tier 1 default uncertainty	Tier 1 site-specific uncertainty	Tier 1 default uncertainty	Tier 1 site-specific uncertainty
Sealed Pressure (MV Switchgear)	20%	10%	20%	10%	5%	5%
Closed Pressure (HV Switchgear)	30%	10%	30%	10%	5%	5%
Gas Insulated Transformers	30%	10%	30%	10%	5%	5%
Others	NA	10%	NA	10%	NA	5%

4.8.5. Category-specific QA/QC and verification

Compliant with QA/QC plan and implementation as outlined in Chapter 1, Section 1.5.

4.8.6. Category-specific recalculations

There is no recalculation for this category.

4.8.7. Category-specific planned improvements

Emissions from other uses of SF_6, PFCs and N_2O for other applications and use are currently not known and further study needs to be conducted to determine if the activity occurs in Singapore.

[37] Refer to the 2006 IPCC Guidelines, Volume 3, Chapter 8, Table 8.5.

4.9. Other (CRT category 2.H.)

4.9.1. Category description

For this category, it reports all other emissions stream not reported in other IPPU categories. It contains emissions mainly from the food and beverage industry, fugitive, flares, vents from biomedical industry, general manufacturing industry and other forms of emissions from refineries, petrochemical, chemical, electronics and waste industry. These emissions are reported under the CPA.

Based on the 2022 emissions estimated, 2.H. Other contributes to 21.35 kt CO_2 eq, that is, 0.04% of the total GHG emissions in Singapore.

Table 119: Total GHG emissions from Others not specified in other IPPU categories (2000 to 2022)

Greenhouse Gas Category	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
	GHG Emissions (kt CO_2 eq)											
2.H. Other	9.44	8.08	8.62	9.05	11.13	12.90	14.36	15.33	16.34	13.40	15.92	17.28
2.H.1. Pulp and paper	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2.H.2. Food and beverages industry	IE, NO	IE, NO	IE, NO	IE, NO	IE, NO	IE, NO	IE, NO	IE, NO	IE, NO	IE, NO	IE, NO	IE, NO
2.H.3. Other (please specify)	9.44	8.08	8.62	9.05	11.13	12.9	14.36	15.33	16.34	13.40	15.92	17.28

Greenhouse Gas Category	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
	GHG Emissions (kt CO_2 eq)										
2.H. Other	17.57	17.14	16.90	17.98	19.52	34.35	36.73	31.53	23.43	24.02	21.35
2.H.1. Pulp and paper	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2.H.2. Food and beverages industry	IE, NO	IE, NO	IE, NO	IE, NO	IE, NO	IE, NO	IE, NO	IE, NO	IE, NO	IE, NO	IE, NO
2.H.3. Other (please specify)	17.57	17.14	16.90	17.98	19.52	34.35	36.73	31.53	23.43	24.02	21.35

Notation keys:
NO - Not occurring, IE - Included elsewhere

4.9.2. Methodological issues

Table 120: Method and emission factors used for emission estimation in Others not specified in other IPPU categories

GHG source and sink category	CO_2		CH_4		N_2O	
	Method applied	Emission Factor	Method applied	Emission Factor	Method applied	Emission Factor
2.H.2. Food and beverages industry	T3	PS	NO	NO	NO	NO
2.H.3. Other	T3	PS	T3	PS	T3	PS

Notation keys:
T3 - Tier 3, PS - Plant-specific, NO - Not occurring

Facilities reporting under CPA could use three different approaches to estimate the emissions. They are namely the (i) calculation approach, (ii) material balance approach and (iii) direct measurement approach. As facilities that report under this category account for a wide spectrum of different emission stream, the facilities will have to produce supporting documents to the verifiers to ensure proper accounting and estimation of the emissions stream.

Method 1: Calculation approach

The facility may identify a calculation formula that can be used to estimate emissions. The formula will include activity data and emission factors.

The facility can use site-specific emission factors if the facility can demonstrate that the site-specific conversion factor is appropriate and leads to a more accurate and representative quantification of its emissions. Such site-specific factors must be justified by supporting documents/data and will be subject to verifier's approval. These conversion factors can be derived from:

a) Reputable literature, industry guidelines or headquarters' guidelines and reports;

b) Historical measurement and analysis; or

c) Actual measurement and analysis performed during a reporting period. The facility will specify the measurement approach and analysis technique to be used. The derived emission factors can be calculated from the analysis of materials or process performance during the reporting period.

Method 2: Material balance approach

Material balance can be used if CO_2 emissions are released, and carbon is contained in a process feedstock as well as in a product or waste stream, that is, the difference in the quantity of carbon measured entering and exiting a process. It requires the quantification of the flow (activity data) of each input, output, waste stream and the carbon content (material property) of each stream. The total carbon measured in the output and waste streams is deducted from the total carbon in the input stream to identify the carbon lost to the atmosphere as CO_2.

Site-specific CO_2 emission factors are then calculated by emissions per unit of the main product for the process activity.

Material balance uses the following formula to calculate the CO_2 emissions and CO_2 emission factor:

$$E_{CO_2} = [\sum (Qf_i \times CCF_i) - \{\sum_j (QP_j \times CCP_j) + \sum_k (QS_k \times CCS_k) + \sum_l (QW_l \times CCW_l)\}] \times \frac{44}{12}$$

$$EF_{p,CO_2} = EF_{CO_2} / Q_p$$

Parameter	Parameter Description	Units
E_{CO_2}	Emissions of CO_2	tonne CO_2
QF_i	Annual quantity of feedstock (i) consumed for the production of primary product and other secondary products and waste streams	tonne
CCF_i	Carbon content of feedstock (i)	% or ratio
QP_j	Annual quantity of primary product (j), produced	tonne
CCP_j	Carbon content of primary product (j)	% or ratio
QS_k	Annual quantity of secondary product (k), produced	tonne
CCS_k	Carbon content of secondary product (j)	% or ratio
QW_l	Annual quantity of waste stream (l) resulting from the production process	tonne
CCW_l	Carbon content of waste stream (l)	% or ratio
Q_p	Quantity of primary product produced for sub-process type (p)	tonne
p	Sub-process type	
EF_{p,CO_2}	Emission factor for CO_2 and primary product using sub-process	tonne CO_2/tonne

Method 3: Direct measurement approach

Direct measurement can be used if the GHG emissions are measured directly within a constrained exhaust system. It involves the direct measurement of emissions at a point of emissions release, usually an exhaust stack or other ducting that allows measurement. The exhaust gas flow rate and the concentration of the GHG being measured are used to quantify the emissions over a sample period. The samples are then aggregated across the reporting period. The facility is required to report the final GHG emissions.

Direct measurement of GHG emissions is most commonly used in conjunction with other emissions monitoring such as sulphur oxide (SOx) emissions in power stations and IPPU emissions where direct measurement of emissions are the only option for measuring the emissions from a particular plant. The measurement of N_2O emissions from the production of various acids such as adipic and nitric acid are examples of IPPU emissions requiring direct measurement when abatement technology is used to reduce N_2O emissions. The performance of the abatement can vary from plant to plant and over time and cannot be accurately estimated from emission factors.

Direct measurement can be conducted continuously or periodically:

i) For **Continuous Emissions Monitoring System (CEMS)**, the measurement instrument is normally permanently installed and expected to operate continuously. CEMS is usually the preferred method where the measurement instrument is already required for other purposes.

ii) For **Periodic Emissions Monitoring System (PEMS)**, it measures the emissions over a defined time period together with an activity data to determine an emission factor for the facility. The emission factor is then multiplied by the activity value over the whole reporting period to calculate the annual emissions to be reported. The PEMS must operate over a sufficient period to obtain a representative profile of all operating modes of the plant.

Choice of activity data and emission factor

The activity data and emissions consist of data from 2.H.2. Food and beverages industry, 2.H.3 Others (CO_2 from the use of fire protection, and CO_2, 2.H.3 Others (CH_4 and N_2O emissions from flares, vents, other processes in manufacturing industries). The activity data and emissions were extracted from CPA from 2019 onwards and emissions from ECA from 2013 to 2018. For years prior to 2013, projection was conducted using the Manufacturing Output In Manufacturing By Industry (Total Manufacturing) obtained from DOS's Singstat Table Builder as the surrogate parameter. The emission factor and methodology applied for flares, vents and fugitive emissions are consistent across all IPPU activities as per Section 3.3.2.2.

Due to data confidentiality, CO_2 emissions from 2.H.2 Food and beverages industry, CH_4 and N_2O emissions from 2.H.3 Others (which includes emissions from flares, vents, and other processes in manufacturing industries) had been aggregated and reported as CO_2 emissions under 2.H.3 Others.

4.9.3. Description of any flexibility applied

Flexibility for time series which starts from year 2000 to 2022 as described in Section 1.9. Summary of any flexibility applied had been applied throughout the report.

4.9.4. Uncertainty assessment and time series consistency

The uncertainty values for 2.H.3. Other is estimated to be ±4% for CO_2. Uncertainty estimation for this subcategory is calculated using Approach 1 – Propagation of Error. Uncertainty factors for reporting year 2022 is calculated from the weighted average of site-specific uncertainty factors reported by respective companies and facilities through CPA.

Since CPA came into effect only from 2019 onwards, uncertainty estimates for base year 2000 uses default uncertainty factors referenced from 2006 IPCC Guidelines (Volume 2 Chapter 4.2.2.7.2). As flares, vents and fugitive emissions for non-energy processes are included under this subcategory, the uncertainty estimation makes use of their corresponding uncertainty factors to provide a conservative estimate.

Table 121: Uncertainty factors for uncertainty estimates for base year 2000 for Others not specified in other IPPU categories

Uncertainty Parameters	CO_2
Activity Data	17%
Emission factor	75%

4.9.5. Category-specific QA/QC and verification

Compliant with QA/QC plan and implementation as outlined in Chapter 1, Section 1.5.

4.9.6. Category-specific recalculations

Previously the report of emissions from flaring and venting for all industries were reported under 1.B.2. Oil, Natural Gas and other emissions from energy production. In this NID, the emissions from flaring and venting apart from oil industries would be reported in the relevant category such as chemical industries in the IPPU sector.

4.9.7. Category-specific planned improvements

There is no planned improvement for this category.

Chapter 5

AGRICULTURE (CRT SECTOR 3)

5.1.

Overview of the sector and background information

5.1.1. Description of the agriculture industry in Singapore

The small agriculture sector only occupies about 1% of land in Singapore and mainly produces eggs, food fish and leafy vegetables for local consumption to supplement our imports of these items. Some quail eggs are produced, and a small number of dairy cattle and goats are reared for milk for local consumption.

5.1.2. Overview of emissions and activity data in the sector

The emissions from the agriculture sector for the reporting year 2022 were estimated to be 8.04 kt CO_2 eq, contributing to only 0.01% of Singapore's total GHG inventory. 2022 emissions were 15% higher compared to emissions in 2000.

The emission sources comprise CH_4 from 3.A. Enteric Fermentation, CH_4 and N_2O from 3.B. Manure Management, N_2O from 3.D. Agricultural soils (direct and indirect N_2O emissions from managed soils), CO_2 from 3.G. Liming, and CO_2 from 3.H. Urea Application. 3.B. Manure management is the largest contributor to emissions, followed by 3.D. Agricultural soils.

3.C. Rice Cultivation, 3.E. Prescribed Burning of Savannahs and 3.F. Field burning of agricultural residues do not occur in Singapore. Due to the focus on growing leafy vegetables in Singapore, crop residues were minimal and mainly comprised vegetable trimmings which were incinerated in waste-to-energy plants. Emissions have been accounted for under the Energy sector and the volume of crop residues was accounted for under horticultural waste. Due to the types of crops grown and soil conditions, farmers typically rely more on NPK fertilisers which contain low to no carbon and do not need to use fertilisers rich in other elements. Hence emissions from category 3.I. Other carbon-containing fertilisers were likely to be insignificant and have not been estimated.

For reporting, activity data and emissions for all livestock categories have been combined, due to data confidentiality issues given the small number of livestock farms in Singapore.

Table 122: GHG Emissions from Agriculture sector in 2022

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	CO_2	CH_4	N_2O
	(kt)		
3. Total agriculture	0.07	0.10	0.02
3.A. Enteric fermentation		0.02	
Option A:			
3.A.1.a. Dairy cattle		0.02	
3.A.1.b. Non-dairy cattle*		IE	
Option B (country-specific):			
3.A.1.a. Other			
3.A.2. Sheep		NO	
3.A.3. Swine		NO	
3.A.4. Other livestock (goats)*		IE	
3.B. Manure management		0.09	0.01
3.B.1. Cattle*		IE	IE
Option A:			
3.B.1.a. Dairy cattle*		IE	IE
3.B.1.b. Non-dairy cattle*		IE	IE
Option B (country-specific):			
3.B.1.a. Other			

3.B.2. Sheep		NO	NO
3.B.3. Swine		NO	NO
3.B.4. Other livestock (goats)*		IE	IE
3.B.4. Other livestock (poultry)		0.09	0.01
3.B.4. Other livestock (quail)*		IE	IE
3.B.5. Indirect N_2O emissions			NE
3.C. Rice cultivation		NO	
3.D. Agricultural soils			0.01
3.D.1. Direct N_2O emissions from managed soils			0.01
3.D.1.a. Inorganic N fertilisers			0.00
3.D.1.b. Organic N fertilisers			0.01
3.D.1.c. Urine and dung deposited by grazing animals			NO
3.D.1.d. Crop residues			NO
3.D.1.e. Mineralisation/immobilisation associated with loss/gain of soil organic matter			0.00
3.D.1.f. Cultivation of organic soils (i.e. histosols)			NO
3.D.1.g. Other			NO
3.D.2. Indirect N_2O emissions from managed soils			0.01
3.E. Prescribed burning of savannahs		NO	NO
3.F. Field burning of agricultural residues		NO	NO
3.G. Liming	0.07		
3.H. Urea application	0.00		
3.I. Other carbon-containing fertilisers	NE		

Notation keys:
NO - Not occurring, IE - Included elsewhere, NE - Not estimated

* *For reporting, emissions for all livestock categories have been combined due to data confidentiality issues given the small number of livestock farms in Singapore.*

The activity data used to derive the emissions estimates were obtained from census data and customised surveys. A considerable amount of effort was spent to collect data required from farms for reporting in the BTR and emissions were insignificant. As the agriculture sector is not a key category, emissions were estimated using the Tier 1 approach, with default emission factors from the 2006 IPCC Guidelines.

Table 123: Method and emission factors used for emission estimation in Agriculture sector

Greenhouse Gas Source and Sink Categories	CO_2		CH_4		N_2O	
	Method Applied	Emission Factor	Method Applied	Emission Factor	Method Applied	Emission Factor
3 AGRICULTURE, FORESTRY AND OTHER LAND USE						
3.A. Enteric fermentation			T1	D		
3.B. Manure management			T1	D	T1	D
3.C. Rice cultivation			NO	NO	NO	NO
3.D. Agricultural soils					T1	D
3.D.1. Direct N_2O emissions from managed soils					T1	D
3.D.2. Indirect N_2O emissions from manure management					T1	D
3.E. Prescribed burning of savannahs			NO	NO	NO	NO
3.F. Field burning of agricultural residues			NO	NO	NO	NO
3.G. Liming	T1	D				
3.H. Urea application	T1	D				
3.I. Other carbon-containing fertilisers	NE	NE				

Notation keys:
T1 - Tier 1, D - IPCC Default, NO - Not occurring, NE - Not estimated

5.1.2.1. Livestock population characterisation

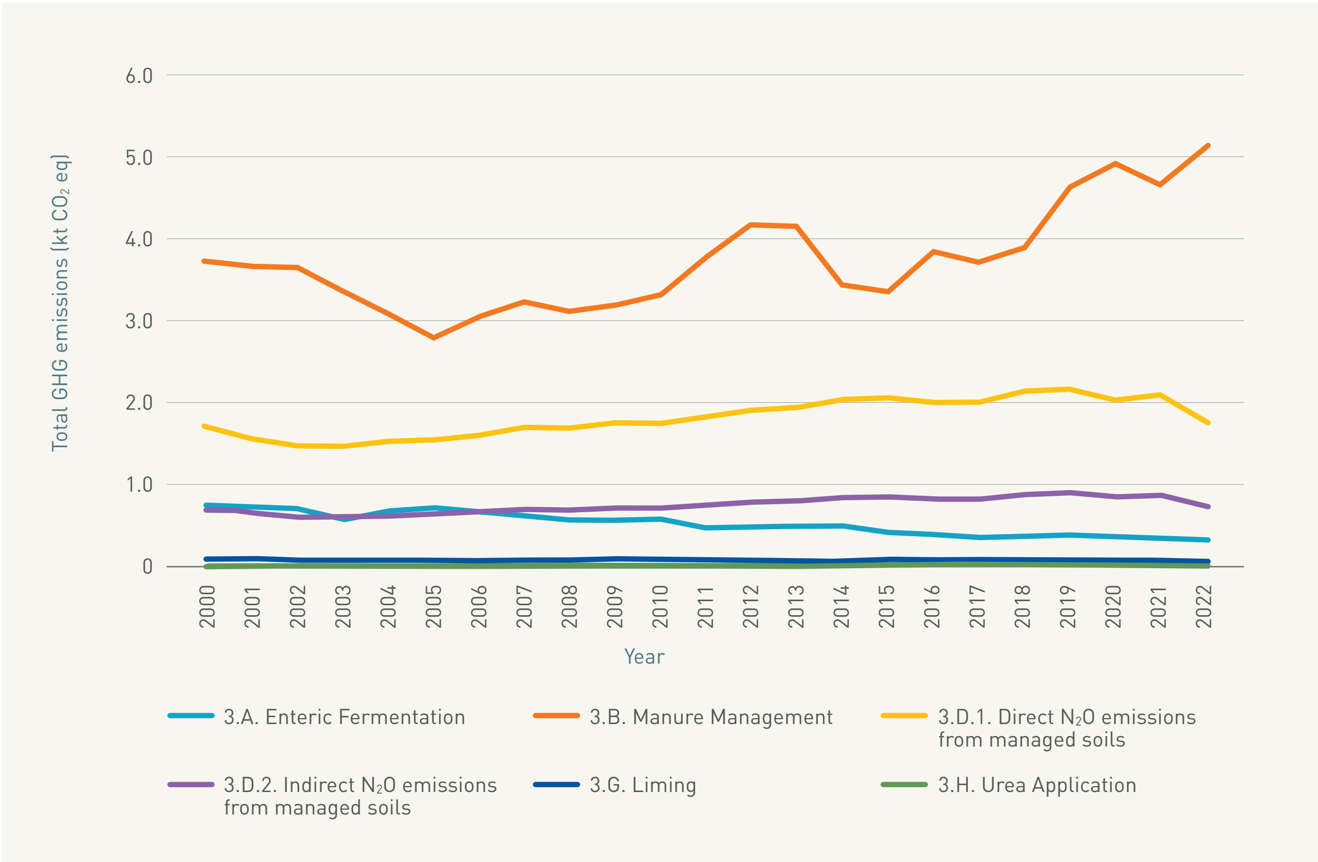
As none of the Agriculture categories are key categories, a Tier 1 methodology and basic characterisation was applied. Cattle have been divided into dairy cattle and other cattle (or non-dairy cattle), and the other livestock categories are goats, poultry (layers) and quails. Dairy cattle are defined as mature cows that have calved at least once and are used principally for milk production, while other cattle are defined as all other cattle in Singapore, including those used for other purposes such as religious purposes.

As the livestock in Singapore are raised for eggs and milk, and not meat, they are static animal populations. Due to the small number and size of livestock farms in Singapore, a census is conducted every year for all the farms to determine the annual population of the different species. Livestock farms report population figures regularly each year. Livestock population numbers have not been reported in the NID due to data confidentiality issues given the small number of livestock farms in Singapore. Population size has remained roughly constant throughout the time series and comprises a few million animals, majority of which are layers.

5.1.3. Trends in emissions and activity data

Agriculture GHG emissions have remained roughly constant across the time series.

Figure 35: GHG Emissions from Agriculture sector from 2000 to 2022 (kt CO_2 eq)



5.2.

Enteric fermentation (CRT category 3.A.)

5.2.1. Category description

Enteric fermentation is a digestive process in herbivores that releases CH_4 as a by-product. In ruminant livestock, enteric fermentation occurs more extensively in their digestive system, releasing more CH_4. For poultry, there are no emissions inventory methods in the 2006 IPCC Guidelines.

Enteric fermentation contributed 0.34 kt CO_2 eq emissions in 2022, which is 0.0006% of Singapore's total 2022 emissions and 4.22% of agriculture emissions.

Table 124: CH_4 Emissions from Enteric fermentation from 2000 to 2022 (kt)

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	CH_4 (kt)											
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
3.A. Enteric fermentation	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.03	0.02
Option A:												
3.A.1.a. Dairy cattle	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.03	0.02
3.A.1.b. Non-dairy cattle*	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
3.A.2. Sheep	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
3.A.3. Swine	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
3.A.4. Other livestock (goats)*	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	CH_4 (kt)										
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
3.A. Enteric fermentation	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Option A:											
3.A.1.a. Dairy cattle	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
3.A.1.b. Non-dairy cattle*	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
3.A.2. Sheep	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
3.A.3. Swine	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
3.A.4. Other livestock (goats)*	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE

Notation keys:
NO - Not occurring, IE - Included elsewhere

* *Emissions for dairy cattle, other cattle and goats have been combined under dairy cattle for reporting due to data confidentiality issues given the small number of livestock farms in Singapore.*

5.2.2. Methodological issues

Emissions from enteric fermentation were estimated using Tier 1 methodology. Default emission factors for annual methane emissions per head of livestock were obtained from Tables 10.10 and 10.11 of the 2006 IPCC Guidelines. Equation 10.19 was used to estimate the CH_4 emissions using the livestock population (Section 5.1.2.1.) and the default emission factors. The emission factor for dairy cattle for Eastern Europe was used as the average milk production of dairy cattle in Singapore most closely resembled the average milk production assumed for the default Eastern Europe emission factor. Data on milk production are reported by the farms every year. Dairy cattle were also fed both forage and grain, similar to the feed assumed for the default Eastern Europe emission factor. The other cattle population include multi-purpose cows, bulls and young, and resemble the regional characteristics of Asia. Hence, the emission factor for Asia was used for other cattle.

5.2.3. Description of any flexibility applied

Flexibility for time series which starts from year 2000 to 2022 as described in Section 1.9. Summary of any flexibility applied had been applied throughout the report.

5.2.4. Uncertainty assessment and time series consistency

Uncertainty assessment will be reported in Annex II: Uncertainty Assessment.

5.2.5. Category-specific QA/QC and verification

QA/QC conducted as per Section 1.5 Brief general description of QA/QC plan and implementation.

5.2.6. Category-specific recalculations

A review conducted in late 2023 – early 2024 on the suitability of the default emission factors used found that the average milk production and feed for dairy cattle in Singapore more closely resembled the average milk production assumed for the Eastern Europe default emission factor. Hence, recalculations were conducted throughout the time series to replace the emission factor used for CH_4 emissions from dairy cattle enteric fermentation from the Asia default emission factor to the Eastern Europe emission factor.

The recalculations resulted in an increase in emissions.

5.2.7. Category-specific planned improvements

There are no category-specific planned improvements that will be conducted this year for this source category.

5.3. Manure management (CRT category 3.B.)

5.3.1. Category description

CH_4 and N_2O emissions result from the management of livestock manure in different manure management systems. Manure management contributed 0.09 kt of CH_4 emissions and 0.01 kt of N_2O emissions in 2022, which are 0.009% of Singapore's total 2022 emissions and 64% of agriculture emissions.

Table 125: CH_4 and N_2O emissions from Manure management from 2000 to 2022 (kt)

	GREENHOUSE GAS SOURCE AND SINK CATEGORIES	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
CH_4 (kt)	**3.B. Manure management**	0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06
	3.B.1. Cattle*	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
	Option A:												
	3.B.1.a. Dairy cattle*	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
	3.B.1.b. Non-dairy cattle*	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
	3.B.2. Sheep	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
	3.B.3. Swine	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
	3.B.4. Other livestock (goats)*	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
	3.B.4. Other livestock (poultry)	0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06
	3.B.4. Other livestock (quail)*	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
N_2O (kt)	**3.B. Manure management**	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	3.B.1. Cattle*	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
	Option A:												
	3.B.1.a. Dairy cattle*	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
	3.B.1.b. Non-dairy cattle*	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
	3.B.2. Sheep	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
	3.B.3. Swine	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
	3.B.4. Other livestock (goats)*	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
	3.B.4. Other livestock (poultry)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	3.B.4. Other livestock (quail)*	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
	3.B.5. Indirect N_2O emissions	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE

	GREENHOUSE GAS SOURCE AND SINK CATEGORIES	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
CH_4 (kt)	**3.B. Manure management**	0.07	0.07	0.06	0.06	0.07	0.07	0.07	0.08	0.09	0.08	0.09
	3.B.1. Cattle*	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
	Option A:											
	3.B.1.a. Dairy cattle*	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
	3.B.1.b. Non-dairy cattle*	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
	3.B.2. Sheep	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
	3.B.3. Swine	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
	3.B.4. Other livestock (goat)*	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
	3.B.4. Other livestock (poultry)	0.07	0.07	0.06	0.06	0.07	0.07	0.07	0.08	0.09	0.08	0.09
	3.B.4. Other livestock (quail)*	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
N_2O (kt)	**3.B. Manure management**	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	3.B.1. Cattle*	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
	Option A:											
	3.B.1.a. Dairy cattle*	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
	3.B.1.b. Non-dairy cattle*	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
	3.B.2. Sheep	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
	3.B.3. Swine	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
	3.B.4. Other livestock (goat)*	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
	3.B.4. Other livestock (poultry)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	3.B.4. Other livestock (quail)*	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
	3.B.5. Indirect N_2O emissions	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE

Notation keys:
NO - Not occurring, IE - Included elsewhere, NE - Not estimated
**Emissions for all livestock categories have been combined under poultry due to data confidentiality issues given the small number of livestock farms*

5.3.2. Methodological issues

Given that there are very few livestock farms in Singapore, SFA is familiar with the manure management systems (MMS) used in each farm. MMS for all livestock categories have been combined for reporting due to data confidentiality issues given the small number of livestock farms in Singapore. Emissions estimates were derived separately for each livestock category and MMS. MMS distribution is reassessed annually. The same emission factors have been used across the time series except where changes in farming practices, i.e. changes in MMS, have resulted in different proportions of manure being allocated to the different emission factors for the different MMS. Farmers have started turning more to anaerobic digestion over the years and the emission factors have been adjusted accordingly.

Table 126: Types of manure management system used for livestock in Singapore

Livestock	Type of manure management system used
• Dairy cattle • Other cattle • Goats • Poultry • Quails	• Anaerobic digestion • Liquid/slurry • Composting • Drying • Uncovered anaerobic lagoon

Default typical animal mass values from the 2006 IPCC Guidelines Tables 10A-4, 10A-5 and for Asia were used for dairy cattle and other cattle, and Table 10A-9 for developed countries for goats and poultry given Singapore's focus on urban agriculture. Typical animal mass values for quail were estimated from a survey of farms conducted in 2020.

5.3.2.1. CH_4 emissions from manure management

CH_4 emissions from manure management were estimated using Tier 1 methodology. Equation 10.22 was used to estimate the CH_4 emissions using the livestock population (Section 5.1.2.1.) and default emission factors and parameters from the 2006 IPCC Guidelines.

As the Manure Management System Usage (MS%) characteristics assumed for the different regions in Tables 10A-4 and 10A-5 for the default emission factors in Table 10.14 do not correspond closely with that of Singapore's characteristics for dairy cattle and other cattle, adjustments were made to the default emission factor for Asia which was used in the fifth BUR. Equation 10.23 was used with the Bo, VS and MCF values in Tables 10A-4 – 10A-5 and country-specific MS%. MS% used aligns with the MMS distribution used for the estimation of N_2O emissions from manure management. Insufficient data was available to assess the assumptions behind the default Bo, MCF and VS values provided in the 2006 IPCC Guidelines so Asia values were used given that Singapore is located in Asia.

Default emission factors for annual methane emissions per head of livestock were obtained from Table 10.15 for goats and poultry. Given Singapore's focus on urban agriculture, the default emission factors for developed countries for warm (>25°C) temperatures were used for goats and poultry, specifically the one for layers (dry) for poultry. Temperature data have been obtained from data published by the Meteorological Service Singapore (MSS). No default emission factors are available in the 2006 IPCC Guidelines for quails. An approximate emission factor was derived by scaling the default poultry layer (dry) emission factor using the ratio of the weights of the quails and layer hens raised to the 0.75 power as suggested by the 2006 IPCC Guidelines Vol. 4 Chapter 10 Section 10.2.4. The approximate estimated emissions from CH_4 emissions from manure management from quail was found to contribute less than 1% of total agriculture emissions in 2022. There are no plans to develop country-specific emissions factors for quails.

5.3.2.2. Direct N_2O emissions from manure management

Direct N_2O emissions from manure management were estimated using Tier 1 methodology. Equation 10.30 was used to estimate the annual N excretion per livestock category using the livestock population (Section 5.1.2.1.) and the default N excretion rates for Asia from the 2006 IPCC Guidelines Table 10.19. As was done for CH_4 emissions from manure management, an approximate N excretion rate was derived for quails by scaling the poultry hen default N excretion rate using the ratio of the weights of the quail and poultry hen to the 0.75 power. The approximate estimated emissions from N_2O emissions from manure management from quail were found to contribute less than 0.2% of total agriculture emissions in 2022. There are no plans to develop a country-specific N excretion rate for quails. Equation 10.25 was then applied to multiply the amount of N managed in each MMS by their default emission factors in Table 10.21. Digestate from anaerobic digestion further underwent composting. As data on this process were not available, a maximum estimate of 0.69 kt CO_2 eq N_2O emissions was derived by applying the default emission factor for composting (higher as compared to the emission factor for anaerobic digestion) to the initial volume of manure sent for anaerobic digestion. As this value is less than 0.002% of Singapore's 2022 total emissions, it has been deemed insignificant and was not estimated.

After processing in the MMS, the manure is used as fertiliser for agriculture, landscaping or gardening, or treated as waste (reported under the energy sector if incinerated at WtE plants and reported under the waste sector if no energy generation is involved).

5.3.2.3. Indirect N_2O emissions from manure management

As default $Frac_{GasMS}$ values are not available in the 2006 IPCC Guidelines for the MMS used in Singapore, a maximum estimate of 3.15 kt CO_2 eq was derived assuming the highest value in Table 10.22 for all the MMS and Equation 10.26. As this is less than 0.006% of Singapore's total emissions in 2022, the value is insignificant in accordance with paragraph 32, annex to decision 18/CMA.1 and is reported as 'NE'.

5.3.3. Description of any flexibility applied

Flexibility for time series which starts from year 2000 to 2022 as described in Section 1.9. Summary of any flexibility applied had been applied throughout the report.

5.3.4. Uncertainty assessment and time series consistency

Uncertainty assessment will be reported in Annex II: Uncertainty Assessment.

5.3.5. Category-specific QA/QC and verification

QA/QC conducted as per Section 1.5 Brief general description of QA/QC plan and implementation.

5.3.6. Category-specific recalculations

A review conducted in late 2023 – early 2024 on the suitability of the default emission factors used found that the MS% characteristics assumed for the different regions in Table 10A-4 and 10A-5 for the default emission factors in Table 10.14 do not correspond closely with that of Singapore's characteristics for dairy cattle and other cattle. Adjustments were made to the emission factors to more closely capture the situation in Singapore as described in Section 5.3.2.1., and the same adjusted emission factors were used for the entire time series.

Due to the availability of more granular data regarding the MMS in the poultry farms, minority management practices have also been considered in the emissions estimates instead of only the main management practice used in each farm.

The recalculations resulted in a decrease in emissions.

5.3.7. Category-specific planned improvements

There are no category-specific planned improvements that will be conducted this year for this source category.

5.4. Agricultural soils (CRT category 3.D.)

5.4.1. Category description

Direct N_2O emissions occur with N additions to agricultural soils. Nitrification oxidises ammonium to nitrate, and denitrification reduces nitrate to nitrogen gas, releasing N_2O as one of the intermediates during denitrification. Land-use change on mineral soils also leads to direct N_2O emissions. Indirect N_2O emissions result when N added to the soils also undergo volatilisation, leaching and runoff.

Direct N_2O emissions from managed soils contributed 0.01 kt emissions in 2022, which is 0.003% of Singapore's total 2022 emissions and 22% of agriculture emissions. Indirect N_2O emissions from managed soils contributed 0.01 kt emissions in 2022, which is 0.002% of Singapore's total 2022 emissions and 10% of agriculture emissions.

Table 127: Direct N_2O emissions from managed soils from 2000 to 2022 (kt)

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	N_2O (kt)											
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
3.D. Agricultural soils	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
3.D.1. Direct N_2O emissions from managed soils	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
3.D.1.a. Inorganic N fertilisers	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.D.1.b. Organic N fertilisers	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
3.D.1.c. Urine and dung deposited by grazing animals	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
3.D.1.d. Crop residues	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
3.D.1.e. Mineralisation/ immobilisation associated with loss/gain of soil organic matter	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.D.1.f. Cultivation of organic soils (i.e. histosols)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
3.D.1.g. Other	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
3.D.2. Indirect N_2O emissions from managed soils	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	N_2O (kt)										
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
3.D. Agricultural soils	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
3.D.1. Direct N_2O emissions from managed soils	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
3.D.1.a. Inorganic N fertilisers	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.D.1.b. Organic N fertilisers	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
3.D.1.c. Urine and dung deposited by grazing animals	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
3.D.1.d. Crop residues	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
3.D.1.e. Mineralisation/ immobilisation associated with loss/gain of soil organic matter	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.D.1.f. Cultivation of organic soils (i.e. histosols)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
3.D.1.g. Other	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
3.D.2. Indirect N_2O emissions from managed soils	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

Notation key:
NO - Not occurring

5.4.2. Methodological issues

Direct and indirect N_2O emissions from managed soils were estimated using Tier 1 methodology.

Farms report production volumes regularly each year. The rate of application of inorganic N fertilisers, including urea fertilisers, and organic N fertilisers per kg of produce, as well as the N content of the fertilisers applied, were estimated from a survey of farms conducted in 2020. The total amount of inorganic and organic N fertilisers applied to the soil was estimated through multiplying production volumes with the fertiliser application rates. Activity data on fertiliser application can be found in the appended CRT tables.

Direct N_2O emissions from managed soils from 3.D.1.e. Mineralisation/immobilisation associated with loss/gain of soil organic matter were estimated using a different methodology as described in Section 6.5.2.2.

5.4.2.1. Direct N_2O emissions from managed soils

Equation 11.1 was used to multiply the annual amount of N applied by the default emission factor for N additions from mineral fertilisers, organic amendments and crop residues found in Table 11.1 of the 2006 IPCC Guidelines.

5.4.2.2. Indirect N_2O emissions from managed soils

Equation 11.9 was used to estimate the N_2O emissions from the atmospheric deposition of N volatilised from managed soils. Default values for $Frac_{GASF}$, $Frac_{GASM}$, and the emission factor for N volatilisation and re-deposition from Table 11.3 of the 2006 IPCC Guidelines were used. Equation 11.10 was used to estimate the N_2O emissions from leaching/runoff. Default values for $Frac_{LEACH-(H)}$ and the emission factor for leaching/runoff from Table 11.3 of the 2006 IPCC Guidelines were used.

5.4.3. Description of any flexibility applied

Flexibility for time series which starts from year 2000 to 2022 as described in Section 1.9. Summary of any flexibility applied had been applied throughout the report.

5.4.4. Uncertainty assessment and time series consistency

Uncertainty assessment will be reported in Annex II: Uncertainty Assessment.

5.4.5. Category-specific QA/QC and verification

QA/QC conducted as per Section 1.5 Brief general description of QA/QC plan and implementation.

5.4.6. Category-specific recalculations

There are no category-specific recalculations conducted this year for this source category.

5.4.7. Category-specific planned improvements

A future survey of farms is planned for every few years to review the rate of application of inorganic N fertilisers, including urea fertilisers and organic N fertilisers per kg of produce.

5.5.
Liming (CRT category 3.G.)

5.5.1. Category description

Liming of agricultural soils to improve soil pH results in the release of CO_2. Liming contributed 0.07 kt emissions in 2022, which is 0.001% of Singapore's total 2022 emissions and 0.83% of agriculture emissions.

Table 128: CO_2 emissions from liming of agricultural soils from 2000 to 2022 (kt)

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	CO_2 (kt)											
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
3.G. Liming	0.11	0.11	0.10	0.09	0.09	0.09	0.10	0.09	0.10	0.11	0.10	0.10

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	CO_2 (kt)										
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
3.G. Liming	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.09	0.10	0.09	0.07

5.5.2. Methodological issues

CO_2 emissions from liming were estimated using Tier 1 methodology.

SFA holds data on the area of land licensed for agriculture. The rate of application of limestone/dolomite per m^2 was estimated from a survey of farms conducted in 2020. Total amount of limestone/dolomite applied to the soil was estimated through multiplying licensed agricultural land area with the limestone/dolomite application rates. All the limestone/dolomite used was considered to be dolomite and the default emission factor of 0.13 tonne of C (tonne of dolomite)$^{-1}$ for dolomite from the 2006 IPCC Guidelines was used with Equation 11.12 to estimate the CO_2 emissions from liming. As data on the breakdown between limestone and dolomite were not available, for a more conservative estimate all the limestone/dolomite was assumed to be dolomite as it has the higher emission factor. Activity data on dolomite application can be found in the appended CRT tables.

5.5.3. Description of any flexibility applied

Flexibility for time series which starts from year 2000 to 2022 as described in Section 1.9. Summary of any flexibility applied had been applied throughout the report.

5.5.4. Uncertainty assessment and time series consistency

Uncertainty assessment will be reported in Annex II: Uncertainty Assessment.

5.5.5. Category-specific QA/QC and verification

QA/QC conducted as per Section 1.5 Brief general description of QA/QC plan and implementation.

5.5.6. Category-specific recalculations

There are no category-specific recalculations conducted this year for this source category.

5.5.7. Category-specific planned improvements

A future survey of farms is planned for every few years to review the rate of application of limestone/dolomite.

5.6.
Urea application (CRT category 3.H.)

5.6.1. Category description

The addition of urea fertilisers to agricultural soils results in the release of CO_2. Urea application contributed 0.00 kt emissions in 2022, which is 0.00000% of Singapore's total 2022 emissions and 0.001% of agriculture emissions.

Table 129: CO_2 emissions from urea application to agricultural soils from 2000 to 2022 (kt)

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	CO_2 (kt)											
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
3.H. Urea application	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	CO_2 (kt)										
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
3.H. Urea application	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

5.6.2. Methodological issues

CO_2 emissions from urea application were estimated using Tier 1 methodology.

Farms report production volumes regularly each year. The rate of application of urea fertilisers per kg of produce was estimated from a survey of farms conducted in 2020. The total amount of urea fertilisers applied to the soil was estimated by multiplying production volumes with the urea fertiliser application rates.

The default emission factor of 0.20 tonne of C (tonne of urea)$^{-1}$ for carbon emissions from urea application from the 2006 IPCC Guidelines was used with Equation 11.13 to estimate the CO_2 emissions from urea application.

5.6.3. Description of any flexibility applied

Flexibility for time series which starts from year 2000 to 2022 as described in Section 1.9. Summary of any flexibility applied had been applied throughout the report.

5.6.4. Uncertainty assessment and time series consistency

Uncertainty assessment will be reported in Annex II: Uncertainty Assessment.

5.6.5. Category-specific QA/QC and verification

QA/QC conducted as per Section 1.5 Brief general description of QA/QC plan and implementation.

5.6.6. Category-specific recalculations

There are no category-specific recalculations conducted this year for this source category.

5.6.7. Category-specific planned improvements

A future survey of farms is planned for every few years to review the rate of application of urea fertilisers.

Chapter 6

LAND USE, LAND-USE CHANGE AND FORESTRY (CRT SECTOR 4)

6.1. Overview of the sector

Singapore is an island city-state located in Southeast Asia, at the southern tip of the Malay peninsula, consisting of a single main island and small offshore islands. All of Singapore's territory falls within the Tropical Wet climate region and the Tropical Rainforest ecological zone. All land in Singapore is considered managed land and consists primarily of low-activity clay soil. The landscape in Singapore is heavily urbanised, but with extensive and intensive greening within the urban fabric. This greenery includes urban parks, streetscapes and nature reserves.

Singapore maintains a system to capture emissions and removals from the LULUCF sector, in accordance with the 2006 IPCC Guidelines on LULUCF. The estimation and reporting of the GHG emissions and removals are carried out for all land use and land-use change categories and assessed for all five carbon pools. The main land-use categories *(Forest Land, Cropland, Wetlands and Settlements)* are further subdivided into subcategories relevant to Singapore's national circumstances and assessed for their respective contributions to the emissions and removals.

6.1.1. Emissions trends

In 2022, the LULUCF net source amounted to 38.12 kt CO_2 eq, of which 7.31 kt CO_2 eq are direct and indirect N_2O emissions associated with carbon losses in mineral soil due to land-use changes and conversions.

The most important land-use categories for the LULUCF net carbon sink/source in Singapore are *Forest Land* and *Settlements*. Forest land has been a rather stable net sink of carbon which is mainly due to net carbon accumulation of biomass in the category *Forest Land remaining Forest Land* as well as net carbon accumulation in biomass and soil in land use changes to *Forest Land*.

The net emissions in *Settlements* category are due to land-use changes from *Forest Land to Settlements*, and conversions within *Settlements* subcategories that led to a loss of tree cover within the category. The annual net emissions trend in the *Settlement* category fluctuated throughout the time series, peaking between 2013 and 2017. These peaks were caused by high land-use change (LUC) rates of *Forest Land to Settlements*.

Cropland and *Wetlands* have only a marginal contribution to the area of Singapore, and thus contribute minimally to the LULUCF GHG inventory.

The total land area of Singapore has continuously increased over the last few decades due to land reclamation from the sea. Emissions and removals from these reclaimed areas were estimated by categorising these lands into appropriate land-use categories after reclamation and development. In addition, losses of land to the sea also occurs in Singapore due to construction activities. For these land losses, emissions were also calculated (although not covered by any IPCC approach) and reported under the category *Other (Sea)* (not to be confused with the category *Other Land*, which does not occur in Singapore). Figure 36 indicates the minor contribution of the land losses to the overall GHG inventory of the LULUCF sector in Singapore.

Figure 36: GHG Emissions from LULUCF sector (kt CO_2 eq)

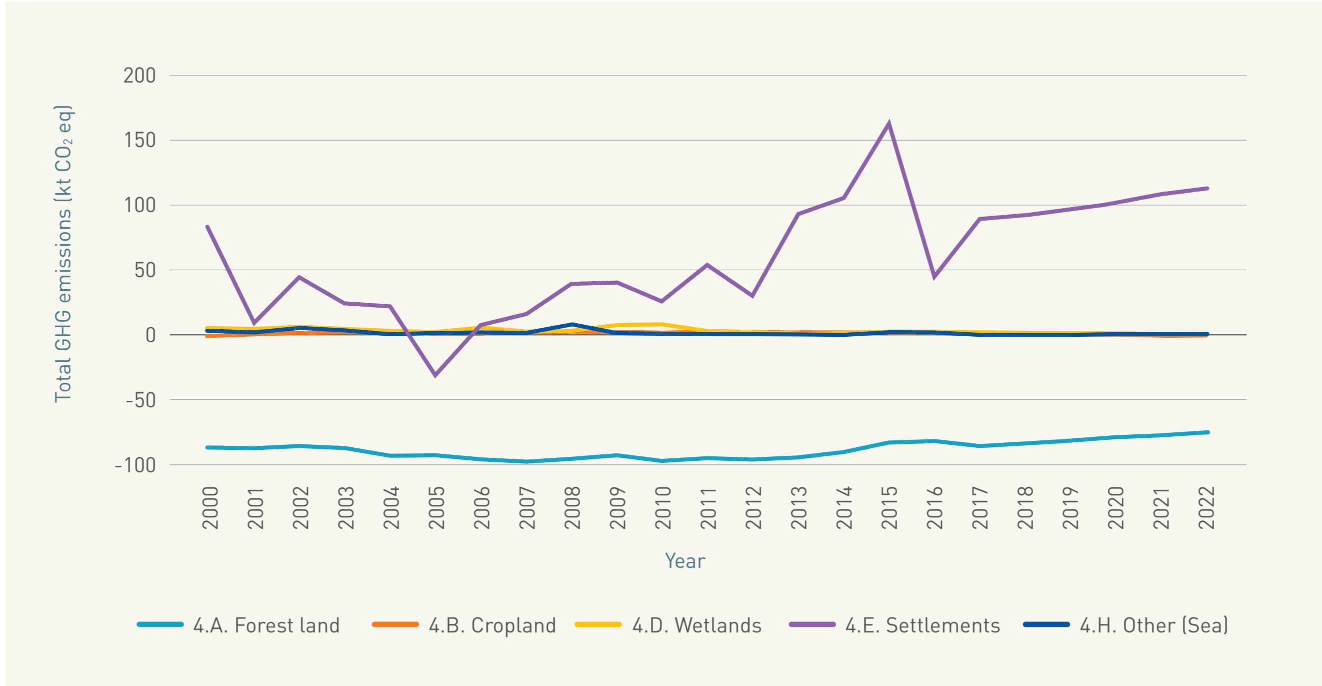


Table 130: Total GHG emissions from LULUCF land-use categories (2000 to 2022)

Greenhouse Gas Category	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
	GHG Emissions (kt CO_2 eq)											
4. Total LULUCF	1.97	-72.81	-29.88	-54.53	-64.67	-120.49	-81.72	-76.81	-43.22	-41.35	-63.25	-36.80
4.A. Forest Land	-86.97	-87.69	-86.10	-87.51	-93.17	-93.10	-96.44	-97.67	-95.71	-93.44	-97.48	-95.03
4.B. Cropland	-0.25	0.52	1.16	1.89	2.62	0.36	1.01	1.74	2.47	3.20	0.75	1.37
4.C. Grassland	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
4.D. Wetlands	4.71	4.57	5.53	4.58	3.68	2.71	5.94	2.56	3.05	7.59	8.04	3.17
4.E. Settlements	81.98	8.47	43.83	23.71	21.56	-31.50	6.67	15.50	38.51	39.46	24.89	53.12
4.F. Other Land	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
4.G. Harvested wood products	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
4.H. Other (Sea)	2.50	1.33	5.70	2.80	0.65	1.04	1.11	1.06	8.46	1.83	0.56	0.56

Greenhouse Gas Category	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
	GHG Emissions (kt CO_2 eq)										
4. Total LULUCF	-62.83	0.56	17.39	85.32	-33.80	5.40	10.29	16.42	23.59	31.28	38.12
4.A. Forest Land	-96.19	-94.93	-90.74	-83.51	-82.35	-86.13	-83.98	-81.98	-79.35	-77.60	-75.70
4.B. Cropland	1.99	2.61	2.59	2.66	1.52	0.82	0.34	-0.13	-0.20	-0.56	-0.59
4.C. Grassland	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
4.D. Wetlands	1.80	0.87	0.98	1.66	1.67	1.95	1.96	1.88	1.87	1.84	1.81
4.E. Settlements	29.01	92.01	104.56	162.60	44.00	88.77	91.96	96.64	101.27	107.59	112.59
4.F. Other Land	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
4.G. Harvested wood products	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
4.H. Other (Sea)	0.56	0.00	0.00	1.91	1.36	0.00	0.00	0.00	0.00	0.00	0.00

Notation key:
NO - Not occurring

The biomass and soil carbon pools contribute the most to the estimates. This reflects the dynamics in Singapore's *Settlements* category in the last couple of decades, which led to losses in the soil carbon pool due to infrastructure construction (an increase in sealed areas) and a decrease in biomass (e.g., when *Forest Land* is cleared for development). The other carbon pools (dead wood and litter) only have a minor contribution to carbon stocks.

6.1.2. Methodology

The LULUCF approaches for BTR 2024 follow the 2006 IPCC Guidelines for National GHG Inventories and the 2013 Supplement to the 2006 IPCC Guidelines for National GHG Inventories: Wetlands (Wetlands Supplement).

Estimating and reporting of the GHG emissions was carried out for all land-use categories that exist in Singapore *(Forest Land, Cropland, Wetlands and Settlements)* and for all land-use change and conversion between and within these categories. In addition, GHG emissions due to land losses to the sea (reported in *Other (Sea)*) were estimated.

It should be noted that the category *Other (Sea)* is used for reporting emissions due to land conversions to the sea. Such area of land loss to the sea does not represent land in any of the six land-use categories and was not added and reported under the areas of any of the land-use categories. The area increases and GHG emissions/removals associated with land reclamation from the sea are reported under the land-use (change) category that represents the final land-use of the reclaimed land.

The main land-use categories were further stratified into subcategories, which represent different land-use, management, ecological conditions, carbon stocks or carbon stock changes. The land use conversion areas, as well as the emissions and removals for all these subcategories, were separately assessed (see specific sections on the LULUCF categories). The annual LULUCF emissions and removals of the time series between 2000 and 2022 were estimated. For all land-use change and conversion subcategories, the IPCC approach of estimating emissions and removals in all pools for a transition period of 20 years was applied. All five carbon pools (above-ground biomass, below-ground biomass, dead wood, litter and soil) were assessed.

The land use and land-use change matrix for Singapore was assessed using IPCC Approach 3 on land representation, based on a wall-to-wall mapping using satellite images. The emission factors of all pools from significant subcategories were estimated with Tier 2/3 approaches and based on country-specific data, namely, the biomass, dead wood, litter and soil carbon stocks and stock changes of *Forest Land* and *Settlements* subcategories. These stocks and stock changes were measured in the field by conducting a tree biomass and soil inventory and estimated through modelling approaches. Furthermore, they were complemented by data from the literature on country-specific carbon stocks in mangroves and lawns within urban areas. Biomass and soil carbon stocks of *Cropland* were estimated based on IPCC default values (i.e., Tier 1) due to the insignificant area share of this land-use category in Singapore (less than 1%).

6.1.2.1. Activity Data

Wall-to-wall assessments of the land use and land use conversions in Singapore are performed, where all lands in Singapore are classified into respective IPCC land-use categories and subcategories using satellite image features and on-the-ground knowledge. High and Very High Resolution images taken from SPOT and later Pléiades satellites were used for these mapping purposes.

Land use and land-use change mapping is based on satellite images with different spatial resolutions, according to their availability within the mapping period. Land use maps were produced for 1973, every year from 1989 to 2017 (except 1992). From 1989 to 2015, SPOT satellite images with spatial resolutions from 5 m to 20 m were used.

Subsequently, from 2015 to 2017, Very High Resolution (0.5 m) satellite imagery from the Pléiades satellite constellation was used. Land use and land-use changes before 1990 were assessed with reference to a land use map derived from Landsat data, and used for determining the land cover changes for the 20-year time period. Where needed (i.e., when SPOT data were affected by cloud cover), additional information was derived from Landsat images with 30 m resolutions.

In order to bridge the gap between the use of satellite images of different spatial resolutions, two overlap years (2014 and 2015) were mapped with images from both SPOT and Pléiades satellites. This enabled comparability between the two approaches and allowed the transfer of more generalised data from historic mapping to the more detailed approach used in Very High Resolution satellite imagery.

The satellite images were pre-processed (geometrically and radiometrically adjusted, cloud-masked, and mosaicked) before land cover and land use mapping using object-based image segmentation based on spectral and 3D information. The mapped areas were assessed according to the land-use categories and subcategories defined for Singapore.

The land-use change and conversion areas between each of these subcategories were derived from the change in land use maps between the mapped years. In addition, the land gains due to land reclamation and the land losses to the sea were monitored. Interpolations and extrapolations were carried out for the years in between without data, and for years beyond without data, respectively. Gap-filling processes were carried out if necessary (e.g., for areas covered by clouds) and artificial land use changes due to artefacts in classification rather than actual conversions were corrected using a smoothing procedure which corrected land-use changes and conversions exceeding 10 years. Furthermore, area statistics were used to adjust the area estimates for categories and years with low resolution (i.e., in *Cropland* category and *mangrove forest* subcategory).

To derive a complete GHG inventory time series starting from 1990 to 2022 that includes the 20-year transition period, gap filling for years without satellite imagery data was done either through backwards projections, interpolations or forward projections. The historical land use and land-use changes from 1971 were estimated based on land use maps derived from Landsat data, and this was used for the 20-year transition time period before 1990.

Between 1973 and 1989, annual LUCs were calculated by dividing the sum of LUCs by the number of years for this period. For the years 1971 to 1972, the same annual LUCs were used to calculate the areas backwards from 1973. For 1992, there was no suitable data available from the SPOT satellite, thus the LUCs between 1991 and 1993 were distributed over two years. For 2018 to 2022, the annual LUCs from the most recent available LUC dataset (i.e., 2017) was used. The time series will be updated when new land use data from more recent satellite images are available.

6.1.2.2. Emission factors

Methodological details on emission factors are provided in the respective sections for each of the land-use categories. All carbon pools are defined according to the 2006 IPCC Guidelines and the definitions are consistently applied across the entire time series.

6.1.3. Quality Assurance and Quality Control

The assessments of the activity data and emission factors for Singapore include various QA/QC steps.

The following QA/QC elements were carried out during the generation of LULUCF emissions and removals estimates.

Input data:

- Check that all references are clearly made
- Check that all assumptions are documented
- Check that all correct values are used (e.g., check for transcription errors, etc.)
- Check input data for completeness
- Check for the plausibility of the activity data and their trend
- Comparison of the used activity data with those from other statistics
- Check for the consistency and completeness of the area trend for Singapore
- Check for plausibility of the emission factors as well as the related input data and their trends
- Compare used emission factors and underlying input data with those of other data sources

Estimations:

- Check calculations units
- Check that all estimates are clearly documented
- Check the correctness of all equations in the estimate files
- Check the correctness of all interim results
- Check the correctness of all data and results transfer
- Check plausibility of results (e.g. time series, order of magnitude, etc.)

These checks are implemented as independent "four-eyes" controls. A clear version management and protection of the files against changes helps to prevent unintended changes and ensure the reproducibility of the results in the estimate process.

6.1.4. Uncertainty Assessment

See Annex II.

6.1.5. Completeness

A complete time series of emissions and removals in the LULUCF sector of Singapore was estimated for the years between 2000 to 2022. GHG emissions and removals from LULUCF were calculated for the total area of Singapore, for all land use, land-use change and conversion subcategories and for all five carbon pools (i.e., above-ground and below-ground biomass, dead wood, litter and soil). In addition, estimates on the GHG emissions due to the loss of land to the sea from construction activities were carried out and are included in the reported total emissions for LULUCF.

The LULUCF inventory includes all relevant GHG that occur in Singapore: CO_2 emissions and CO_2 removals due to carbon stock changes in the five pools and N_2O emissions associated with C losses in mineral soil due to land use changes and conversions. CH_4 emissions are NO.

6.1.6. Planned improvements

Currently the following improvements are planned:

- Refine emission factor for *Forest Land* and *Settlements* using data from Singapore's third National Forest Inventory and updated YASSO model runs;
- Improve transparency of reporting regarding the occurrence of organic soils and report areas of unmanaged organic soils (e.g., swamp forests);
- Investigate if the historical area trend of mangroves in Singapore has to be adjusted based on recent studies and new remote sensing data;
- Update time series with activity data from more recent satellite images;
- Include information on verification activities of Tier 3 methods.

6.2.

Land-use definitions and the land representation approach(es) used and their correspondence to the land use, land-use change and forestry categories

The following definitions of the land-use categories were defined and consistently applied across the whole time series. All land in Singapore is considered managed land.

6.2.1. Forest Land

Forest Land in Singapore is defined as any vegetation dominated by trees having the potential to grow to at least 5 m, having the potential for a canopy cover of at least 30%, and having an area of not less than 0.5 ha, and a minimum width of 20 m. The minimum area and height of trees for this definition is consistent with the Food and Agriculture Organisation (FAO)'s definition of Forest. However, it should be noted that due to Singapore's circumstances, tree-covered areas that meet this definition can also be considered *Forest Land* in the inventory if they are able to meet other criteria detailed in Table 131. The definition of *Forest Land* differs from FAO's definition in that a higher minimum canopy cover of 30% is used and it can include lands primarily used for urban lands.

Treeless areas within forest land and *infrastructure within forest land* are subcategories accounted for under *Forest Land*. Additionally, mangrove forests are accounted for under *Forest Land*. All soils in mangrove forests are considered organic soils.

Table 131: Definition and subcategories under Forest Land in Singapore

IPCC land-use category	Forest Land subcategory	Description
Forest Land	Stocked forest areas	Ranging from early regrowth to mature/ primary stand conditions; potential to grow to at least 5 m, having the potential for canopy cover of at least 30 % Minimum size of 0.5 ha (outside Settlements) or 5 ha within Settlements Minimum width of 20 m *Areas from 0.5-5 ha within urban areas are included in subcategory *tree-covered areas in Settlements*
	Treeless areas within forest land	Includes areas (up to 1 ha) with grass, with or without bushes
	Infrastructure within forest land	Buildings, huts, roads, landings, bare soil, etc.
	Mangrove forest	Coastal forests dominated by mangrove species

6.2.2. Cropland

Cropland in Singapore consists of a mosaic of different cultivated vegetation, including annual and perennial crops, solitary trees and trees growing in clusters. In addition, the areas are interspersed with various types of infrastructure such as roads and buildings.

Abandoned areas of *perennial cropland* which are in the transition to forests and meet the definition are categorised as *Forest Land*.

Table 132: Definition and subcategories under Cropland in Singapore

IPCC land-use category	Cropland subcategory	Description
Cropland	Perennial cropland	Fruit trees/shrubs, tree nursery, horticulture
	Annual cropland	With or without solitary trees
	Infrastructure within cropland	Non-cultivated, buildings, shades, huts, roads, landings, etc.

6.2.3. Wetlands

This category includes all inland areas permanently covered by water, such as natural streams, rivers and other natural/ semi-natural water bodies and waterways as well as man-made water reservoirs, quarry ponds and canals. All such areas are considered as flooded land. Peatlands undergoing extraction do not exist in Singapore. Mangroves do not fall under this category but under *Forest Land*.

6.2.4. Grassland

Singapore does not have any land in the *Grassland* category, as per definition in the 2006 IPCC Guidelines. Also, agricultural grasslands do not occur. Lawns and grass patches are located in between infrastructure, areas with tree cover and in parks. Such areas are accounted for under *Forest Land* and under *Settlements*, depending on the location of these areas.

6.2.5. Settlements

Settlements includes all developed land, including human settlements of any size and lands used for transportation and other infrastructure, unless they are already included in other categories. For mapping green space and vegetation within Singapore's urban environment, a basic distinction between areas in *Settlements* of different vegetation density was determined. For carbon monitoring purposes the vegetated areas were classified based on the level of tree cover that was assessed through a combination of remote sensing and field sampling. The details of the approach are described in Section 6.1.2.

Table 133: Definition and subcategories under Settlements in Singapore

IPCC land-use category	Settlements subcategory	Description
Settlements	Tree-covered areas in settlements	Within settlement land with crown cover >30%, minimum area of 0.25 ha and minimum width 20 m, as far as not defined as Forest Land. Includes park lands, tree-stocked areas within streetscape, golf courses. cemeteries, residential areas
	Other vegetated areas in settlements	All other vegetated areas within settlement areas not belonging in tree-covered area in Settlements.
	Sealed/ unvegetated areas in settlements	All areas without any vegetation, infrastructure like buildings, roads, landings, bare soil, cased ponds and swimming pools, etc.

6.2.6. Other Land

This category includes bare soil, rock and all land areas that do not fall into any of the other categories. Currently, this category does not occur in Singapore.

6.2.7. Other (Sea)

Land-use changes to *Other (Sea)* were detected in the subcategories *Forest Land* to *Other (Sea)* and *Settlements* to *Other (Sea)*. For the latter, an analysis of the satellite images suggests that such areas are the result of tide and annual changes of flooded parts during the process of land reclamation. Consequently, emissions were only estimated for *Forest Land* to *Other (Sea)*.

6.3.

Country-specific approaches

6.3.1. Information on approaches used for representing land areas and on land-use databases used for the inventory preparation

Data for the land use matrices were derived by the National Parks Board of Singapore (NParks) using satellite images (more details in Section 6.1.2.). Additionally, mangrove extent areas were based on inputs from subject matter experts, and the total land area of Singapore for any given year was obtained from the Singapore Land Authority (SLA).

Singapore's total land area changes over time due to land reclamation efforts. In 2022, the land area is 734.3 km^2. Instead of keeping the most recent land area unchanged across the historical time series, these gradual increments in land area would be reflected in Singapore's reporting tables under land-use categories which represent their final land use after development. In addition, land conversions to the sea and the related emissions are reported under the category *Other (Sea)* for completeness and accuracy because such conversions represent a loss of land which belonged previously to Singapore's area. Thus, the sum of areas from all land-use categories for an inventory year is equal to the official total land area, as reported by SLA, for that year. Within the *Other (Sea)*, only emissions due to land conversions to *Other (Sea)* in the year of conversion are reported. For areas of land reclamation from the sea, carbon stock changes are reported in the following years after land reclamation when the reclaimed land is then categorised according to its appropriate final land use category. This ensures an accurate and consistent representation of Singapore's dynamic land use and GHG emissions and removals throughout the time series.

6.3.2. Information on approaches used for natural disturbances

Singapore does not track natural disturbances because their effects have been negligible so far.

6.3.3. Information on approaches used for reporting harvested wood products

There is no commercial timber harvest in Singapore.

6.4.

Forest Land (CRT Category 4.A.)

6.4.1. Description

The *Forest Land* category includes emissions and removals estimations for all four subcategories (*stocked forest areas, treeless areas within forest land, infrastructure within forest land* and *mangrove forest*), including all remaining categories and conversions between or land-use changes to these subcategories. The calculations cover the time series from 2000 to 2022 for all subcategories and carbon pools.

The net removals of *Forest Land* in 2022 amount to -75.70 kt CO_2 eq. This category represents the largest sink subcategory of the total LULUCF sector of Singapore.

Figure 37: Total GHG emissions from Forest Land (2000 to 2022)

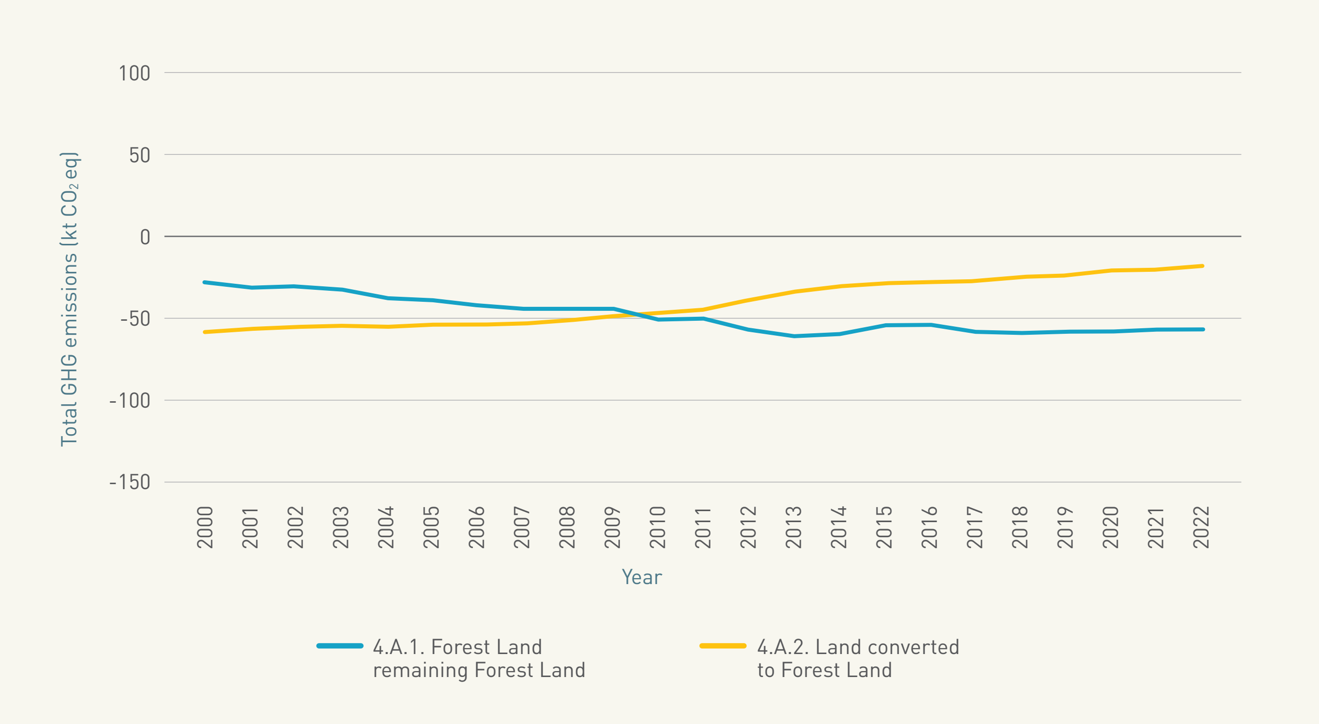


Table 134: Total GHG emissions from Forest Land (2000 to 2022)

Greenhouse Gas Category	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
	GHG Emissions (kt CO_2 eq)											
4.A. Forest Land	-86.97	-87.69	-86.10	-87.51	-93.17	-93.10	-96.44	-97.67	-95.71	-93.44	-97.48	-95.03
4.A.1. Forest Land remaining Forest Land	-28.50	-31.17	-30.58	-33.05	-38.05	-39.24	-42.35	-44.14	-44.33	-44.34	-50.76	-50.20
4.A.2. Land converted to Forest Land	-58.47	-56.52	-55.52	-54.46	-55.12	-53.87	-54.09	-53.53	-51.38	-49.10	-46.72	-44.84

Greenhouse Gas Category	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
	GHG Emissions (kt CO_2 eq)										
4.A. Forest Land	-96.19	-94.93	-90.74	-83.51	-82.35	-86.13	-83.98	-81.98	-79.35	-77.60	-75.70
4.A.1. Forest Land remaining Forest Land	-56.94	-61.13	-59.86	-54.30	-54.13	-58.71	-58.88	-58.17	-58.24	-57.26	-57.23
4.A.2. Land converted to Forest Land	-39.24	-33.80	-30.89	-29.21	-28.22	-27.42	-25.10	-23.81	-21.11	-20.34	-18.46

6.4.2. Methodological issues

6.4.2.1. Field inventory for AGB, dead wood, litter and soil

In 2015, in order to derive country-specific emission factors for the carbon stocks of *Forest Land* and *Settlements*, a field inventory was established for Singapore. Parameters for estimating the above-ground biomass (AGB) representing all woody plant species (i.e., diameter at breast height (DBH) and species of trees, palms and bamboo) were assessed for all inventory plots. In addition, litter and mineral soil samples were taken to analyse bulk density and carbon content to derive carbon stocks for litter and soil in land-use subcategories *stocked forest areas in forest land* and *tree-covered areas in settlements*, as well as nitrogen content for deriving the C:N ratios for N_2O calculations.

The carbon stocks and carbon stock changes were assessed and monitored by employing a combination of

- Permanent terrestrial inventory; supported by
- Remote sensing of all land uses, land-use changes and conversions in Singapore.

In the first phase of setting up the monitoring system, permanent field inventory plots were established. The permanent inventory field plots were established on a systematic sampling grid (north-south/east-west) that covers the entire area of Singapore, including its islands. The distance between grid intersections is 900 m, thus resulting in a square grid layout. Permanent field inventory plots were established at each grid intersection within the subcategories *stocked forest areas in forest land* and *tree-covered areas in settlements.*

The inventories in *Forest Land* and *Settlements* differ with regards to the intensity of sampling (i.e., higher density in *Settlements*). For *Forest Land (stocked forest areas)*, there were 59 plots, and for *Settlements (tree-covered areas)* 65 plots were recorded. In 2020, all plots were re-measured. The main purpose of these re-measurements was to update the diameter increments used in the AGB growth model.

The processing of the inventory data involved the following main steps:

- Transfer of the plot and tree data to a database including plausibility checks and correction of wrong data.
- Calculations of AGB for each individual tree measured in the field with the pan-tropical allometric biomass model from Chave et al. (2014) with DBH and species-specific wood density as input parameters.
- When comparing this with local AGB models for street trees in Singapore from Ngo and Lum (2018), it was found that the equations developed for tropical forests substantially overestimated street tree AGB. A local AGB model was developed for five genera of trees commonly found in the subcategory *tree-covered area in settlements (Garcinia, Khaya, Peltophorum, Samanea,* and *Syzygium)*. For all other species in *tree-covered area in settlements,* the AGB was generated with the Chave et al. (2014) model.
- The below-ground biomass was estimated with a typical root-to-shoot ratio (0.201) for Singapore's conditions derived from Kenzo et al. (2009).
- Default C contents from the 2006 IPCC Guidelines were applied (0.47 t C/t biomass).
- Biomass of standing dead trees is estimated with the same biomass model. However, in the event that standing dead trees were assessed in the field as being partially decayed, their biomass is reduced by 15%. Since no tree species were recorded for dead trees, the wood density for these trees was set to 0.5 t/m³ by default.
- Lying dead wood is processed for biomass using the mid-diameter, length and the average wood density of 0.5 t/m³.
- Conversion of single tree data to per hectare values separately for *stocked forest areas in forest land* and *tree-covered areas in settlements*.

The total biomass carbon stocks in *stocked forest areas in forest land* are presented in Table 136; those of *tree-covered areas in settlements* in Table 149. This field inventory also includes the monitoring of carbon stocks in litter and soils. The basic approach to monitoring the carbon stock changes in litter and soil of the remaining *stocked forest areas in forest land* and *tree-covered areas in settlements* subcategories was to apply soil models calibrated to the local conditions in Singapore. To this end, the terrestrial inventory also obtained data on litter and mineral soil carbon stocks at selected plots during the first measurement of the inventory in *Forest Land*. The data were used for calibrating soil carbon models and acted as a baseline for litter and mineral soil carbon stock changes at related land-use changes. In addition, a soil monitoring system consisting of 10 permanent plots for repeated re-measurement was established for purposes of detecting the carbon variation in forest soils and of model verification in the long-term.

6.4.2.1.1. Growth models for estimating changes of AGB and dead wood

A forest growth model has been developed for *stocked forest area* to estimate carbon stock changes over time. The model was designed as an individual tree growth model applying diameter growth and mortality rates on an annual basis. For application in carbon accounting, the growth model was used in a reverse mode by starting with the trees measured in the field inventory in 2020 modelling reverse diameter growth, recruitment (i.e., loss of trees in the lowest diameter class) and mortality. The main features of the model include:

- All trees recorded on the plots measured in the *stocked forest areas* were included in the modelling process.
- Reverse diameter growth (i.e., shrinkage) was based on locally observed diameter increments from long-term monitoring plots (8 to 16 years) in the Central Catchment Nature Reserve and Bukit Timah Nature Reserve. The reverse growth rates for individual wood density and diameter classes were applied to each inventory tree.
- In 2020, for all plots in subcategory *stocked forest areas* were re-measured and the data indicated a different growth of trees compared to values from growth rates recorded in 2015. For this reason, a model simulation was run with each of the two datasets and the average growth rate of both simulations was taken for the land use changes and conversions to *stocked forest areas*.

- Once a tree has shrunk in its DBH below 5 cm (i.e., lower diameter limit), the tree was removed from the model data, representing the reverse recruitment component (Note: in a growth model recruitment represents young trees and regeneration growing into the lowest diameter class).
- Reverse mortality was modelled by bringing to life a specific number of trees per year within the diameter classes based on long-term, non-catastrophic mortality rates commonly found in regenerating natural forests in the region (Ong and Kleine, 1995). It is assumed that the wood density distribution of the new trees is approximately the same as of the living trees. Their actual diameters were randomly selected within a diameter class.
- Applying the above process to all trees on an annual basis generates inventory data for each year (2020 to 1990). These inventory data of the past are further processed to generate the annual AGB values.

  The following considerations were taken into account for generating the final annual stand parameters.
- Each living tree in the sample plots was processed for its biomass using the Chave et al. (2014) biomass model representing the same approach used for deriving biomass in the 2020 inventory.
- Each standing dead tree was processed for its basal area. The ratio of the total basal area of standing dead trees to the total basal area of standing living trees in 2020 was used to estimate the total AGB of standing dead trees from the AGB of the standing living trees for any other year in the simulation.
- Two thirds of the standing dead trees were assessed in the field as being partially decayed. In order to account for this, the tree biomass of these trees has been reduced by 15 percent. Since no tree species were recorded for dead trees, the wood density for these trees was set to 0.5 t/m³ by default; and
- Lying dead wood was processed for biomass using the mid-diameter, length and the average wood density of 0.5 t/m³.

Results for *stocked forest areas remaining stocked forest areas* are shown in Table 135 (biomass) and Table 137 (dead wood).

For the period 2020-2022 a projection was added by calculating the percent change from 2019 to 2020 and adding this to the 2020 value to obtain the value for the year 2021 and the same was done for 2018 to 2020 to estimate the year 2022.

6.4.2.1.2. Land-use change to stocked forest

Inventory data from young forests were used to estimate the growth of the AGB at an early stage of the succession. Since forests in Singapore are strictly protected for the purpose of nature conservation and recreation, among other things, it was assumed that the accumulation of AGB is undisturbed at least by human interventions over the period of 20 years.

The estimation of the annual biomass growth over a period of 20 years was based on a very young forest stand found among the inventory plots showing an initial biomass of only below 2 t/ha. This stand consists exclusively of smaller trees (i.e., below 10 cm DBH) and at this stage was identified as forest by satellite imagery. Applying the growth model for *stocked forest areas remaining stocked forest areas* as explained previously resulted in an average annual AGB growth presented in Table 135.

6.4.2.1.3. Soil and litter carbon stocks

The stock of soil organic carbon (SOC) as a baseline for reporting on soil carbon can be determined by a soil inventory. In 2015, a soil carbon inventory was carried out in the land-use subcategories *stocked forest areas in forest land* and *tree-covered areas in settlements* in Singapore. There were 30 soils plots in the land-use subcategory *tree-stocked areas in forest land*, and seven soils plots in the land-use subcategory *tree-covered areas in settlements*, that were sampled and analysed for assessing SOC stocks. Within the 30 soil plots in *stocked forest areas*, 10 permanent soil plots were selected with a specific, more detailed sampling design. The reason for this was to gain an insight into the variation of the soil properties and to use these plots for long-term calibration for the applied soil carbon model and to improve the performance of the soil carbon model. For the latter reason, it is planned to repeat the soil sampling and soil analysis in these permanent plots every 10 years. To improve the baseline of SOC stocks, the number of plots in the land-use subcategory *tree-covered areas in settlements* has been increased by adding soil data from 20 existing plots from previous investigations by NParks. Temporal changes in SOC stocks, however, cannot be assessed by repeating the soil inventory due to the large variation of soil carbon in the field. This soil inventory was therefore only carried out once.

According to the 2006 IPCC Guidelines, carbon stocks were assessed for the two carbon pools, litter and mineral soil. The litter fraction comprised all dead organic material, independent of the stage of decomposition with a diameter smaller than 2 cm. For land-use changes between land-use categories and subcategories of *Forest Land* and *Settlements*, a soil depth of up to 50 cm was used. For *Cropland*, the default soil carbon stock from the 2006 IPCC Guidelines was used and this is only available for up to 30 cm soil depth. Therefore, for the calculation of carbon stock changes in mineral soil for land-use changes from and to *Cropland*, the carbon stocks for *Forest Land* and *Settlements* were also calculated up to 30 cm. Total mean SOC stocks and standard deviations were calculated by pooling the results of soil sample plots in each land use category. In addition, the ratio SOC/total nitrogen (C/N ratio) was calculated accordingly to be used to estimate N_2O emissions from soils due to carbon losses as a result of land-use changes.

6.4.2.1.4. Simulation of soil and litter carbon stock changes

SOC changes are usually assessed by using soil carbon models. Singapore uses the internationally recognised and proven soil model YASSO. YASSO is an intentionally simple soil carbon simulation model. The user supplies air temperature and precipitation, as climate parameters, the quantity of the above- and below-ground influx of C to the soil, and information on the chemical quality of

the incoming organic matter. The organic matter enters the soil as above-ground and below-ground litter. In the decomposition module, it is divided into four chemical fractions (lignin, cellulose, sugar, waxes) and is either emitted as CO_2 or converted into stable soil organic matter. As output, YASSO returns a time series of the total soil SOC pool, which is divided into carbon in woody matter (branches, coarse roots, stems, etc.), non-woody matter and the acid-, water-, ethanol- and insoluble fractions, and changes in the soil carbon pool and heterotrophic soil respiration. The model does not distinguish between soil horizons and does not explicitly state a soil depth but refers to the ''total soil organic carbon pool''.

Main features of YASSO20

In the fifth BUR, the model YASSO07 was used, but since then an updated version YASSO20 became available and was used in the evaluation of SOC changes in Singapore for the first BTR. This latest version of YASSO shows a better temperature input representation and calibration approach. The updated version also incorporates a more powerful and comprehensive dataset with 18,000 litter decomposition and SOC measurements including values for tropical and subtropical regions. The calibration of YASSO20 with multiple datasets leads to a better model performance.

Input Parameters

Tree biomass data were collected in the forest inventory. The AGB inventory data were re-formatted so that every tree with its morphology characteristics, such as stem DBH, and height (h), forms an individual record. Accordingly, each individual tree releases organic matter into the soil from different tree compartment, i.e., foliage, fine roots, branches, coarse roots, stems and stumps. The above-ground and below-ground litter transfer to the soil is calculated from carbon stock of these respective tree compartments and from turnover time (longevity) of carbon in these tree compartments. A combination of the biomass functions that have been published by Kenzo et al. (2009) and Chave et al (2014) was used. For consistency with the AGB inventory, the function of Chave et al. (2014) was used to calculate the AGB. The functions of Kenzo et al. (2009) were used to calculate the total biomass (i.e., sum of above-ground and below-ground biomass), and the biomass of the compartments: coarse roots, fine roots, leaves, and stem wood. In the equations, the measured or simulated DBH was used as input parameter. Stem biomass, leaf biomass, and fine-root (small roots) biomass were calculated directly. Branch biomass was calculated as the difference between total AGB and leaves and stems. Coarse root biomass was calculated as the difference between total root biomass and small roots. The percentage of the biomass in individual compartments as a fraction of the total biomass was calculated and the percentages were applied on the biomass estimate based on Chave et al. (2014) to ensure the consistency with the AGB simulations. The estimation of the carbon flux from the individual tree compartments to the soil required the definition of turnover rates. The assumed data for the turnover rates of organic matter ranges from one year (leaves, fine roots) to four years (branches and coarse roots).

The chemical characteristics of the incoming litter fall require a particular chemical fractionation scheme distinguishing acid-soluble, water-soluble, ethanol-soluble and insoluble organic substances ("AWENH"). The chemical characteristics are required for all tree compartments (stem, branch, leaf, fine root, coarse root) of all tree species. The chemical fractionation of organic matter has not been done yet for the tree species in Singapore. Therefore, values from different databases were taken and averaged.

Climate data from seven stations across Singapore were taken from Meteorological Service Singapore (MSS). To accommodate a representative climate file for YASSO, the data were aggregated to one climate data set for all of Singapore.

6.4.2.2. Carbon stocks and stock changes in Forest Land

In the following section, the results of the field inventory and the AGB and soil modelling, as used for the emissions/removals estimations, are presented by pool.

Biomass

Table 135 shows the carbon stock gains of the categories *Forest Land remaining Forest Land* and land-use changes to *Forest Land* for above and below-ground biomass. It is estimated that net carbon accumulation only takes places in *stocked forest areas remaining stocked forest areas*, which was simulated for AGB with the forest growth model from Ong and Kleine (1995) and amounts to 0.78 t C/ha/yr. The below-ground biomass gains for trees in stocked forest land (0.16 t C/ha/yr) was estimated with a typical root-to-shoot ratio (0.201) for Singapore's conditions derived on basis of Kenzo et al. (2009).

For the other *Forest Land* remaining subcategories *(treeless areas within forest land remaining; infrastructure within forest land remaining; mangrove forests remaining)*, it was assumed that no net carbon stock increase occurs. Regarding *remaining mangrove forest*, it was assumed that processes of biomass carbon gains due to increment and biomass carbon losses due to mortality are in balance. The IPCC (2014) default growth rates for mangroves, which were applied for land-use change and conversion areas to mangroves, lead after the transition period of 20 years to carbon stocks in a magnitude which was measured with field research for Singapore's mangroves (Friess et al. 2015, see Table 136). Therefore, it is reasonable that no further biomass carbon stock gains for these remaining mangroves are assumed.

When land is changed/converted to *stocked forest areas,* the biomass gains from the young forest simulation are applied (see section 6.4.2.1.2.). The biomass carbon stocks increase by 0.10 t C/ha/yr in AGB over the transition period of 20 years. In the Table 135, the ground biomass gains for land changed/converted to stocked forest land were again estimated with the AGB gains and the root-to-shoot ratio on basis of Kenzo et al. (2009). In *treeless areas within forest land* only low vegetation (annual grass biomass) occurs, therefore when land is changed/converted to this subcategory, this biomass (0.68 t C/ha/yr in AGB, 0.29 t C/ha/yr in BGB) is reported as annual carbon stock gain in the year of land-use change. These values for grass biomass were taken from measurements in lawns of Singapore from Ng et al. (2015).

In the case of LUC/conversion to *mangrove forest,* the AGB increases by an IPCC default factor of 4.46 t C/ha/yr, BGB increases by an IPCC default factor of 2.19 t C/ha/yr, both across the transition period of 20 years (Table 4.4., 2013 Wetlands Supplement).

Table 135: Forest Land – net carbon stock changes from biomass

Remaining category	Carbon stock gains AGB (t C/ha/yr)	Carbon stock gains BGB (t C/ha/yr)	Total carbon stock gains living biomass (t C/ha/yr)	Source:
Stocked forest areas	0.78	0.16	0.93	Updated modelling based on field measurements 2020
Treeless areas within forest land	0.00	0.00	0.00	
Infrastructure within forest land	0.00	0.00	0.00	
Mangrove forest	0.00	0.00	0.00	
Land-use change or conversion category				
Stocked forest areas	0.10	0.02	0.12	Updated modelling based on field measurements 2020
Treeless areas within forest land	0.00	0.00	0.00	
Infrastructure within forest land	0.00	0.00	0.00	
Mangrove forest	4.46	2.19	6.65	2013 Wetlands Supplement, table 4.4

For all land-use changes from *Forest Land* subcategories to other land categories, the total biomass carbon stock in the individual *Forest Land* subcategories is of interest (Table 136), as this was lost in the year of land-use change. The AGB stock for stocked forest (73.09 t C/ha) was derived from the AGB field inventory. The BGB stock for trees in *stocked forest areas* (14.68 t C/ha) was estimated with a typical root-to-shoot ratio (0.201) for Singapore's conditions derived on basis of Kenzo et al. (2009). The country-specific biomass carbon stock for *treeless areas within forest land* (0.68 t C/ha AGB, 0.29 t C/ha BGB) was provided in a study from Ng et al. (2015) which investigated low vegetation biomass in grass and lawn patches in Singapore.

For *mangrove forest*, country-specific biomass carbon stocks are available from a study carried out in Singapore by Friess et al. (2015). The weighted mean of the results of this study was calculated to be 136.93 t C/ha AGB and 47.25 t C/ha BGB.

Table 136: Forest Land - biomass carbon stocks

Remaining category	Carbon stock AGB (t C/ha)	Carbon stock BGB (t C/ha)	Total carbon stock living biomass (t C/ha)	Source:
Stocked forest areas	73.09	14.68	87.78	Updated based on field measurements 2020
Treeless areas within forest land	0.68	0.29	0.97	Ng et al. 2015 (used for low vegetation carbon stocks)
Infrastructure within forest land	0.00	0.00	0.00	
Mangrove forest	136.93	47.25	184.19	Friess et al. (2015)

Dead wood

In Singapore dead wood is only present in *stocked forest areas*. This carbon stock was measured in the field inventory (Table 138). The annual carbon stock change of dead wood in *stocked forest areas remaining stocked forest areas* was simulated with the forest growth model as described in Chapter 6, Section 6.4.2.1 (see Table 137). In the case of *stocked forest areas remaining stocked forest areas*, the dead wood carbon stock increases by 0.05 t C/ha/yr. When *stocked forest areas* is changed or converted to another subcategory, the dead wood stock of 4.82 t C/ha is lost in the year of conversion.

Table 137: Forest Land - net carbon stock changes from dead wood

Remaining category	Dead wood gains (t C/ha/yr)	Source:
Stocked forest areas	0.05	Updated modelling based on field measurements 2020

Table 138: Forest Land – dead wood carbon stocks

Category	Dead wood carbon stock (t C/ha)	Source:
Stocked forest areas	4.82	Updated based on field measurements 2020

Litter and soil

As described in Chapter 6, Section 6.4.2.1.3, the mineral soil and litter carbon stocks of *stocked forest areas* were measured in the field inventory in 2015 and updated by additional measurements in 2017 (litter: 6.79 t C/ha, 0-50cm: 74.61 t C/ha). In addition, it was assumed that the mineral soil carbon stock of *treeless areas within forest land* is the same as for the unsealed part of *tree-covered areas in settlements* (0-50 cm: 44.8 t C/ha).

For the soil carbon stocks of *mangrove forest* in Singapore, Friess et al. (2015) provides a country-specific value (weighted mean down to 1 m: 307.4 t C/ha). It is assumed that the soil carbon stock of *infrastructure within forest land* is zero. These litter and soil carbon stocks (Table 139) were used to calculate the annual stock change rate in litter mineral soil for the 20 years transition period in cases of land-use changes and conversion between, from and to these *Forest Land* subcategories (together with the stocks of the previous or following land use subcategories). The only exception is for mangrove forests, where, in line with the 2013 IPCC Wetlands Supplement, the full soil carbon stocks are reported as a loss in the year of land-use change and conversion from *mangrove forest* to other subcategories.

Table 139: Forest Land - litter and soil carbon stocks

Category	Mean soil carbon stock (0-50 cm) (t C/ha)	Mean soil carbon stock (0-30 cm) (t C/ha)	Mean litter carbon stock (t C/ha)	Source:
Stocked forest areas	74.61	53.39	6.79	Field measurements
Treeless areas within forest land	44.84	32.82	0	Field measurements
Infrastructure within forest land	0	0	0	
Mangrove forest	307.40	307.40	0	Friess et al. (2015)

Table 140 provides the annual soil carbon stock changes for *stocked forest areas remaining stocked forest areas* (0.55 t C/ha/yr) including litter which has been simulated with the YASSO20 model (see Chapter 6, Section 6.4.2.1.4). For remaining mangroves resulting from land-use changes/conversions to this subcategory after finalisation of the transition period of 20 years, the 2013 Wetlands Supplement proposes to assume the same further soil carbon stock change rate as for the transition period until the typical soil carbon stock is approached (1.62 t C/ha/yr). For the other remaining *Forest Land* subcategories it is assumed that the soil carbon stocks do not change. The soil carbon stock change when land is changed/converted to *mangrove forest* is a default value (1.62 t C/ha/yr) provided in the 2013 Wetlands Supplement. It should be noted that mangroves are not drained in Singapore. In cases of conversions of *mangrove forest* to a different land-use category (e.g., *Settlements*), it is assumed that all carbon stocks of mangroves are lost in the year of land-use change.

Table 140: Forest Land - net carbon stock changes from soil

Remaining category	Mean soil carbon stock change (t C/ha/yr)	Mean litter carbon stock change (t C/ha/yr)	Source:
Stocked forest areas	0.55	IE (in soil)	Updated with new YASSO20 and new AGB field data from 2020
Treeless areas within forest land	0	0	
Infrastructure within forest land	0	0	
Mangrove forest (only for those remaining mangroves resulting from land-use changes to mangroves after the transition period)	1.62	0	2013 Wetlands Supplement, Table 4.12
Land-use change/conversion category			
LUC to mangrove forest	1.62	0	2013 Wetlands Supplement, Table 4.12

6.4.2.3. Forest Land remaining Forest Land

This category comprises the estimation of net emissions/removals for *stocked forest areas remaining stocked forest areas* and the conversions between the *Forest Land* subcategories. The calculations use country-specific emission factors and are in line with the Tier 3 methodology according to the 2006 IPCC Guidelines. Conversions between *stocked forest areas* and *mangrove forest* are considered unlikely and the minor changes in areas are due to an artefact of mapping due to difficulties in the assessment of boundaries. Therefore, no carbon stock changes were estimated for these conversion categories.

Biomass

Other *Forest Land* subcategories converted to *stocked forest areas* were calculated over the 20-year transition period as if a non-*Forest Land* category is changed to *stocked forest areas*. If *stocked forest areas* was converted to other *Forest Land* subcategories, the complete biomass carbon stock of *stocked forest areas* would be reported as loss in the year of conversion and multiplied by the annual conversion area. The same methodology applies to land-use changes/conversions with *mangrove forests*.

For *infrastructure within forest land* converted to another *Forest Land* subcategory, a carbon loss of the low vegetation biomass has to be reported. On the other hand, when a *Forest Land* subcategory is converted to *infrastructure within forest lan*d, this low vegetation carbon stock would be reported as a gain in the year of conversion. In both cases, the annual conversion area is considered in the calculation.

Dead wood

Dead wood only occurs in *stocked forest areas*. A loss of the complete dead wood pool would be reported in the year of conversion of *stocked forest areas* to another *Forest Land* subcategory and was calculated with the annual conversion area.

Litter and soil

For *stocked forest areas remaining stocked forest areas*, the soil carbon stock changes were simulated in a model and the annual net change amount to 0.55 t C/ha.

Soil carbon stock changes for land conversions among the *Forest Land* subcategories were calculated by applying equation 2.25 of the 2006 IPCC Guidelines. The soil and litter carbon stock of the *Forest Land* subcategory before conversion was subtracted from the carbon stock of the new *Forest Land* subcategory which was then divided by IPCC default time period for transition between the SOC stocks (20 years).

Once a *mangrove forest* is converted, the soil carbon stock is reported as a loss in the year of conversion (and is calculated with the annual conversion area). When other *Forest Land* subcategories are converted to *mangrove forest,* the annual soil carbon stock increase according to Table 140 is reported over the transition period of 20 years and beyond until the typical soil carbon stock of *mangrove forest* is reached.

6.4.2.4. Land converted to Forest Land

Cropland changed to Forest Land

This category includes land-use changes from *Cropland* subcategories to *Forest Land* subcategories.

Biomass

When *perennial cropland* is changed to *stocked forest areas*, it is assumed that the perennial crops are not harvested but continue to grow. This is a typical practice in Singapore of the past and can be identified by the tree species composition in the forests. As a result, no biomass carbon loss would be reported at time of land-use changes, and only the increase in biomass carbon stocks was calculated over a period of 20 years. For the land-use changes of *perennial croplan*d to other *Forest Land* subcategories, the complete biomass carbon stock of *perennial cropland* (30.13 t C/ha, Table 144) was lost in the year of conversion. For *annual cropland* changed to *Forest Land*, the same methodology applies (loss of 6.11 t C/ha). In cases of *Cropland* converted to *treeless areas within forest land*, an annual gain of low vegetation biomass has to be reported.

Dead wood

This pool is only reported when *Cropland* is changed to *stocked forest areas*. Thereby, the dead wood carbon pool increases by 0.051 t C/ha over the transition period of 20 years (see Table 137).

Litter

As for dead wood, litter is only reported in *Cropland* changed to *stocked forest areas*. The annual increase of litter amounts to 0.34 t C/ha over the 20-year transition period.

Soil

Soil carbon stock changes are calculated by applying equation 2.25 of the 2006 IPCC Guidelines. The carbon stock of the category before land-use change was subtracted from the carbon stock of the new land-use category (see Table 139), which was then divided by IPCC default time period for transition between the SOC stocks (20 years). However, for the land-use change to mangroves, the IPCC default soil C stock change factor from Table 4.12 of the 2013 Wetlands Supplement was applied to calculate the soil carbon stock change.

Wetlands changed to Forest Land

In all these land-use changes subcategories, no carbon stock losses occur as no carbon stocks are assumed to be present in *Wetlands* (flooded lands) due to lack of information in the literature and IPCC guidelines.

Biomass

For *Wetlands* changed to *stocked forest areas* and *mangrove forest*, the carbon stock gains in biomass as provided in Table 135 are reported over the transition period of 20 years. In category *Wetlands* converted to *treeless areas within forest land*, the annual biomass gain of low vegetation is reported (see also Table 135).

Dead wood

For *Wetlands* changed to *stocked forest areas*, an increase of dead wood was reported over the 20-year transition period (see Table 137). In the other categories, dead wood is NO.

Litter

Litter is only reported in *Wetlands* converted to *stocked forest areas*. The annual increase of litter amounted to 0.34 t C/ha over the 20-year transition period.

Soil

The carbon stock of the category before land-use changes (0 t C/ha) was subtracted from the carbon stock of the new land-use category, which was then divided by IPCC default time period for transition between the SOC stocks (20 years). However, for the land-use change to *mangrove forest*, the IPCC default factor from Table 4.12 of the 2013 Wetlands Supplement was applied to calculate the soil carbon stock change.

Settlements changed to Forest Land

Biomass

Tree-covered areas in settlements to *stocked forest areas*:

As per the definition, *tree-covered areas in settlements* areas consist of patches and clusters of trees below 0.5 ha in size usually surrounded and interspersed by urban infrastructure such as buildings, roads, and other open spaces. Through remote sensing, a significant increase in *stocked forest area* can be observed. This increase is partly caused by an increase of crown cover within *tree-covered settlement* areas (e.g., open space is overgrown with trees) – and thus such areas become *stocked forest areas*. Since these new stocked forest areas are made up of older trees in patches (classified before under *tree-covered areas in settlements*), they do not represent very young forests but rather retain the characteristics of *tree-covered areas in settlement*. Therefore, it is assumed that the biomass stocks will not increase in such areas in the transition period of 20 years to *stocked forest areas*.

Other vegetated areas in settlements converted to *stocked forest areas*:

As in the previous case, it is assumed that it is more likely that other vegetated areas converted into *stocked forest areas* have similar carbon stock characteristics as *tree-covered areas in settlements* than those of *stocked forest areas*. For this reason, the carbon stock change in this land-use change subcategory was calculated as a carbon stock change to *tree-covered areas in settlements* (see Chapter 6, Section 6.8.2.2).

Sealed/unvegetated areas in settlements converted to *stocked forest areas*:

This carbon stock change is similar to the conversion of *sealed/unvegetated areas in settlements* to *tree-covered areas in settlements*. Therefore, the carbon stock changes in this category was calculated as a carbon stock change to *tree-covered areas in settlements.*

For *Settlements* subcategories converted to *treeless areas in forest land* and to *infrastructure within forest land* no carbon stock changes were estimated. An analysis of such mapped areas showed that these are frequently classification changes due to neighbourhood effects and land-use class definitions, but without any significant land cover change. Therefore, it can be assumed that there is no carbon stock change at such land-use changes areas.

Other vegetated areas and sealed areas converted to mangroves

In both these categories, the tree biomass and the low vegetation of the *Settlements* subcategories were accounted as a carbon loss, whereby annual carbon stock gains were estimated for *mangrove forest* over a transition period of 20 years based on the default emission factor from the 2013 Wetlands Supplement, Table 4.4.

Dead wood

Dead wood is only present in *stocked forest areas*. As mentioned previously, all land-use changes from *Settlements* to *stocked forest areas* are either deemed to be zero or calculated as conversion to *tree-covered areas in settlements*. Therefore, no carbon stock change in dead wood was reported.

Litter

Litter was reported in the *Settlements* subcategory *tree-covered areas in settlements* only. As all land-use changes from *Settlements* to *stocked forest areas* were calculated as a land-use change to *tree-covered areas in settlements*, a net carbon stock increase in litter was reported over a transition period of 20 years (0.15 t C/ha, Table 150).

Soil

The carbon stock of the category before land-use change (Table 151) was subtracted from the carbon stock of the new land-use category, which was then divided by IPCC default time period for transition between the SOC stocks (20 years). However, all land-use changes from *Settlements* subcategories to *stocked forest areas* were calculated as a land-use change to *tree-covered areas in settlements*, so this was also applied to soil carbon stocks.

For the *Settlements* subcategories *(other vegetated areas in settlements and sealed/unvegetated areas in settlements)* converted to *mangrove forest*, the mineral soil of the *settlements* subcategories was reported as carbon loss. On the other hand, the annual soil carbon stock increase of organic soil was reported over the transition period of 20 years and beyond until the typical soil carbon stock of *mangrove forest* is reached.

Land reclamation from sea to Forest Land

The land reclamation from *Other (Sea)* to *Forest Land* is reported in all *Forest Land* subcategories. In all the reported categories, no carbon stock losses occur as no carbon stocks is assumed to be present in the sea due to lack of information in the literature and IPCC guidelines.

Biomass

For sea converted to *stocked forest areas* and *mangrove forest*, the carbon stock gains in biomass as provided in Table 135 are reported over the transition period of 20 years. In the category *Other (Sea)* converted to *treeless areas within forest land*, the annual biomass gain of low vegetation is reported (see also Table 135).

Dead wood

For *Other (Sea)* converted to *stocked forest areas,* an increase of dead wood is reported over the 20-year transition period. In the other categories, dead wood is NO.

Litter

Litter is only reported in *Other (Sea)* converted to *stocked forest areas*. The annual increase of litter amounts to 0.365 t C/ha over the 20-year transition period.

Soil

The carbon stock of the category before land-use change (0 t C/ha) was subtracted from the carbon stock of the new land-use category, which was then divided by IPCC default time period for transition between the SOC stocks (20 years). However, for the change from sea to *mangrove forest* the IPCC default factor from Table 4.12 of the 2013 Wetlands Supplement was applied to calculate the soil carbon stock change.

Direct N_2O emissions from LUC/conversion to/within Forest Land subcategories

In accordance with the 2006 IPCC Guidelines, N_2O emissions from mineral soils at land-use changes and conversion areas to *Forest Land* have to be reported in cases of a net carbon loss in the mineral soil. For Singapore, these emissions occur in the following subcategories:

Conversions within *Forest Land* subcategories with soil carbon stock losses

Land-use changes from some *Cropland* subcategories to some *Forest Land* subcategories

The direct N_2O emissions were estimated based on a Tier 1 method (Eq 11.8 Ch.11 of the 2006 IPCC Guidelines). A default emission factor of 0.01 kg N_2O-N/kg N was used (2006 IPCC Guidelines, Chapter 11, Table 11.1).

The C/N ratios are provided in the following table:

Table 141: C/N ratio of soil organic matter

Category	C/N ratio	Source:
Stocked forest areas	17.88	Field measurements
Treeless areas within forest land	16.49	Field measurements
Other vegetated areas in settlements	16.49	Field measurements
Tree-covered areas in settlements	16.49	Field measurements
Sealed/unvegetated areas in settlements	16.49	Field measurements
Perennial cropland	15	Default C/N ratio (2006 IPCC Guidelines, eq. 11.8)
Annual cropland	10	Default C/N ratio (2006 IPCC Guidelines, eq. 11.8)

Indirect N_2O emissions from land-use change/conversion to/within Forest Land subcategories

In addition to the direct N_2O emissions from mineralised soil nitrogen, indirect N_2O emissions occur due to the mineralised N which is leached from the soil. The 2006 IPCC Guidelines provide the following tier 1 methodology in Chapter 11:

$$N_2O - N = F_{SOM} \times Frac_{LEACH} \times EF_5 \text{ (eq.11.10)}$$

Where

- N_2O-N = annual amount of N_2O-N produced from leaching and runoff of N additions to managed soils, kg yr^{-1}
- F_{SOM} = the net annual amount of N mineralised in mineral soil associated with loss of soil C from soil organic matter as a result of changes in land use or management, kg N yr^{-1}
- $Frac_{LEACH}$ = 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 per kg of N additions

$Frac_{LEACH}$ is a default factor (0.3) of Table 11.3 of the 2006 IPCC Guidelines. EF_5 (0.0075) is provided in this Table 11.3 as well.

6.4.2.5. Wildfires

Uncontrolled (wildfires) and managed (prescribed) fires, according to 2006 IPCC Guidelines, does not occur in any of the land categories in Singapore due to the specific conditions of Singapore being dominated by the urban environment.

6.4.3. Uncertainty assessment and time series consistency

See Annex II.

6.4.4. Description of any flexibility applied

Flexibility for time series which starts from year 2000 to 2022 as described in Section 1.9. Summary of any flexibility applied had been applied throughout the report.

6.4.5. Category-specific QA/QC and verification

The implemented steps of QA/QC were compiled in Chapter 6, Section 6.1.3.

6.4.6. Category-specific recalculations

See Chapter 8, Section 8.3.

6.4.7. Category-specific planned improvements

See Chapter 6, Section 6.1.6.

6.5. Cropland (CRT Category 4.B.)

6.5.1. Description

The *Cropland* category includes emissions/removals estimations for *Cropland remaining Cropland* and land-use changes to *Cropland*. The calculations cover the time series from 2000 to 2020 for all subcategories and carbon pools.

In 2022, the total net removals from *Cropland* amounted to 0.59 kt CO_2 eq. A marginal share (0.001 kt CO_2 eq) of the emissions is from direct and indirect N_2O emissions from mineral soil associated with carbon losses due to land-use changes/conversions.

Figure 38: Total GHG emissions from Cropland (2000 to 2022)

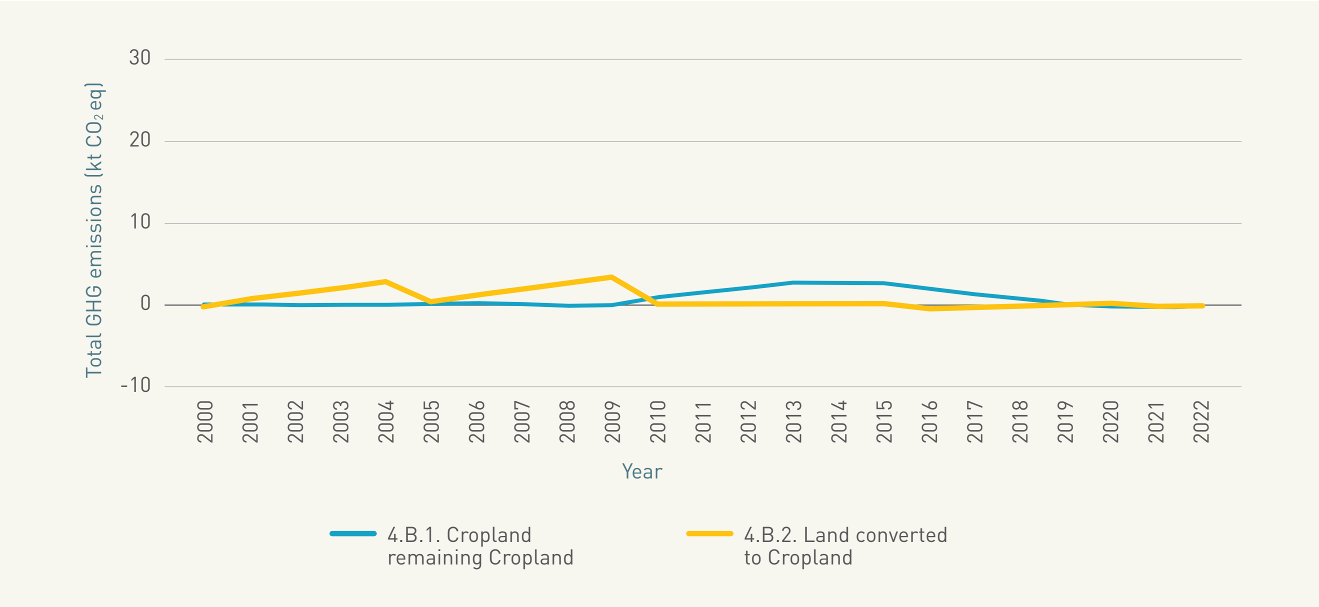


Table 142: Total GHG emissions from Cropland (2000 to 2022)

Greenhouse Gas Category	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
	GHG Emissions (kt CO_2 eq)											
4.B. Cropland	-0.25	0.52	1.16	1.89	2.62	0.36	1.01	1.74	2.47	3.20	0.75	1.37
4.B.1. Cropland remaining Cropland	-0.02	-0.04	-0.06	-0.09	-0.11	0.02	0.00	-0.03	-0.05	-0.07	0.70	1.32
4.B.2. Land converted to Cropland	-0.23	0.56	1.22	1.98	2.73	0.34	1.01	1.77	2.52	3.28	0.05	0.05

Greenhouse Gas Category	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
	GHG Emissions (kt CO_2 eq)										
4.B. Cropland	1.99	2.61	2.59	2.66	1.52	0.82	0.34	-0.13	-0.20	-0.56	-0.59
4.B.1. Cropland remaining Cropland	1.94	2.57	2.57	2.57	2.03	1.22	0.61	0.01	-0.20	-0.33	-0.30
4.B.2. Land converted to Cropland	0.05	0.05	0.02	0.09	-0.51	-0.40	-0.27	-0.14	-0.01	-0.23	-0.29

6.5.2. Methodological issues

6.5.2.1. AGB, dead wood, litter and soil

Biomass

According to the 2006 IPCC Guidelines, the change in biomass of the remaining categories is only estimated for *perennial cropland*. For *annual cropland*, it assumed that the annual increase of biomass stocks equals the biomass losses from harvest and mortality. Therefore, the net accumulation of carbon stocks from annual biomass is zero. Likewise, for *infrastructure within cropland*, it is assumed that no biomass is present. In addition, perennial crops which were planted in the past are assumed to have completed the rotation cycle after 5 years and need to be replaced. This loss (50 t C/ha) of perennial above-ground biomass is reported as well.

Table 143: Cropland - net carbon stock changes from biomass

Remaining category	Carbon stock gains AGB (t C/ha/yr)	Carbon stock gains BGB (t C/ha/yr)	Total carbon stock gains living biomass (t C/ha/yr)	Source:
Perennial cropland	10.00	2.05[38]	12.05	2006 IPCC Guidelines, Table 5.1
Annual cropland[39]	5.00	1.11[40]	6.11	C stock at maturity according to 2006 IPCC Guidelines, Table. 5.9
Infrastructure within cropland	0	0	0	

For the calculation of land-use changes to *Cropland* and conversions to the *Cropland* subcategories, it is assumed that the *perennial cropland* accumulates biomass carbon in a 20-year transition period. As in the remaining category, perennial crops that were planted in the past and completed the rotation cycle after 5 years need to be subtracted as an emission. This biomass loss is estimated to amount to 50 t C/ha/yr according to the 2006 IPCC Guidelines (see Table 144).

When there are land-use changes and conversions to *annual cropland*, it is assumed that there is immediate establishment of biomass, thus in the year in which an area is changed/converted to *annual cropland,* the total annual biomass carbon stock is considered as a gain. There is no continuous increase as in the *perennial cropland* and therefore it is calculated with the annual area.

In cases of a land-use change/conversion from single *Cropland* subcategories, the carbon stocks presented in Table 144 are lost in the year of land-use changes/conversion. If *perennial cropland* is converted to any land, it will be assumed that the average carbon stock of the perennial crops is lost (25 t C/ha), instead of the complete (possible) carbon stock of 50 t C/ha at the end of the rotation period. Only if *perennial cropland* is converted to *annual cropland,* the complete carbon stock of 50 t C/ha will be lost because it is assumed that due to economic reasons the farmer will only clear perennial crops when they have reached maturity.

The 2006 IPCC Guidelines only provide AGB default stocks for perennial and annual crops. For this reason, a root-to-shoot ratio (R/S) from literature was applied to estimate the below-ground biomass stocks and gains in *Cropland*:

- *Perennial cropland*: R/S = 0.205 (Mokany et al. (2005))
- *Annual cropland*: R/S= 0.222 (Umweltbundesamt, 2015)

Table 144: Cropland - biomass carbon stocks

Category	Carbon stock AGB (t C/ha)	Carbon stock BGB (t C/ha)	Total carbon stock living biomass (t C/ha)	Source:
Perennial crops at maturity (for remaining category, land-use change to perennial cropland and conversion from perennial to annual cropland	50.00	10.25	60.25	Carbon stock at maturity according to 2006 IPCC Guidelines, Table 5.1
Perennial crops lost at land-use changes from perennial cropland to other land-use categories	25.00	5.13	30.13	Average carbon stock according to 2006 IPCC Guidelines, Table 5.1
Annual crops (only accounted for land-use change/conversion areas to and from annual cropland in the year of land-use change)	5.00	1.11	6.11	Carbon stock at maturity according to 2006 IPCC Guidelines, Table. 5.9
Infrastructure within cropland	0	0	0	

[38] Mokany et al.(2005)
[39] This is only accounted for land-use change areas to annual cropland in the year of change.
[40] Umweltbundesamt 2015

Dead wood

Dead wood occurs in land-use changes from *Forest Land* to *Cropland*. It is assumed that the stock of dead wood would be lost immediately in the year of conversion. The value is presented in Table 138.

Litter

Litter occurs in land-use changes from *Forest Land* and some *Settlements* subcategories (*tree-covered areas in settlements*) to *Cropland*. It is also assumed that the stock will be lost completely in the year of conversion. The values can be found in Table 139 (litter in *Forest Land*) as well as Table 151 (litter in *Settlements*).

Soil

The share of *Cropland* in Singapore's area is comparably low, and it is assumed that cropland management practices did not change last few years. Therefore, the carbon stock changes of mineral soils of *annual cropland remaining annual cropland* and *perennial cropland remaining perennial cropland* are estimated to be zero.

However, in order to calculate the soil carbon stock changes in land-use changes/conversions from, to and within *Cropland*, it is necessary to estimate soil carbon stocks for *Cropland*. They are estimated based on default reference soil carbon stocks as provided for low activity clay (LAC)[41] soils in Table 2.3 of the 2006 IPCC Guidelines. According to the soil inventory, LAC soils are typical for Singapore. By applying the default management factors from Table 5.5 of the 2006 IPCC Guidelines for tropical conditions and equation 2.25 of the 2006 IPCC Guidelines, the soil carbon stocks for *annual cropland* and *perennial cropland* were estimated from the reference soil carbon stocks (Table 145):

Table 145: Cropland - relative carbon stock change factors (F_{LU}, F_{MG}, and F_I) and soil carbon stock

Category	Default reference soil C stock (LAC soils) (t C/ha)	Land use (F_{LU})	Tillage (F_{MG})	Input (F_I)	Mean soil CSC (0-30 cm) (t C/ ha)	Source:
Perennial cropland	60	1	1	1.11	66.60	Management factors from Table 5.5. 2006 IPCC Guidelines, default C stock from Table 2.3. 2006 IPCC Guidelines
Annual cropland	60	0.48	1	1.11	31.97	Management factors from Table 5.5. 2006 IPCC Guidelines, default C stock from Table 2.3. 2006 IPCC Guidelines
Infrastructure within cropland					0	

6.5.2.2. Cropland remaining Cropland

This section includes methodological descriptions for the category *Cropland remaining Cropland* and its carbon pools, which comprises the following subcategories:

- *Perennial cropland remaining perennial cropland*
- *Annual cropland remaining annual cropland*
- *Infrastructure within cropland remaining infrastructure within cropland*

Conversions between these three subcategories

The conversions between these three *Cropland* subcategories are estimated with the IPCC approach for land-use changes between the main categories but with the related areas and emissions factors of these *Cropland* subcategories.

Biomass

The carbon stock change of *perennial cropland* biomass is calculated based on the Tier 1 method as provided in the 2006 IPCC Guidelines, Ch. 5.2.1.1. The default method estimates carbon stock changes from annual rates of biomass gains and losses.

The area of *perennial cropland* is multiplied by the biomass accumulation from growth (see Table 144). To calculate the losses, the area of harvested cropland is multiplied by the carbon stock at the end of the rotation period. A default harvest cycle of five years has been considered for this calculation (see Table 5.1 of the 2006 IPCC Guidelines).

Dead wood

The Tier 1 method assumes that dead wood is not present in *Cropland remaining Cropland*.

Litter

The Tier 1 method assumes that litter is not present in *Cropland remaining Cropland*.

Soil

The carbon stock changes are estimated to be zero as no change in management practices is assumed.

[41]Soils with low activity clay (LAC) minerals are highly weathered soils, dominated by 1:1 clay minerals and amorphous iron and aluminium oxides (in WRB classification includes Acrisols, Lixisols, Nitisols, Ferralsols, Durisols; in USDA classification includes Ultisols, Oxisols, acidic Alfisols).

6.5.2.3. Land converted to Cropland

Forest Land converted to Cropland

This category includes all land-use changes from *Forest Land* to *Cropland* for all carbon pools.

Biomass

The annual carbon stock losses in biomass were calculated by multiplying the annual area of *Forest Land* that was cleared for *Cropland* by the carbon stock in *Forest Land* biomass before land-use change. In the case of a land-use change to *perennial cropland*, the carbon stocks from cleared perennial crops which were planted 5 years ago and have reached maturity are considered as carbon stock losses across the land-use change transition period of 20 years.

The carbon stock increase in *annual cropland* biomass after land-use change was calculated by multiplying the annual area of land-use change to *annual cropland* by the annual carbon stock gain. In cases of a conversion to *perennial cropland* the land-use change area of 20 years in transition was multiplied by the annual carbon stock gains in biomass.

Dead wood

In cases of a land-use change from *stocked forest areas* to *Cropland* the carbon stock of dead wood is lost in the year of conversion.

Litter

In cases of a land-use change from *stocked forest areas* and *tree-covered areas in settlements* to *Cropland,* the carbon stock of litter is lost in the year of land-use change.

Soil

The annual carbon stock changes in mineral soils were calculated by applying the methods described in Chapter 2.3.3 of the 2006 IPCC Guidelines. The carbon stock of the category before land-use change was subtracted from the carbon stock of the new land-use category, which was then divided by IPCC default time period for transition between the SOC stocks (20 years).

Land-use change from *mangrove forest* to *Cropland* subcategories are considered as very unlikely for ecological reasons. The negligible areas for which such land-use changes were assessed are assumed to be mapping artefacts and therefore no carbon stock changes were estimated for them. The same applies for the minor land-use change areas infrastructure in *Forest Land* to *perennial cropland*.

Wetlands changed to Cropland

Biomass

The carbon stock increase in *annual cropland* biomass after land-use change is calculated by multiplying the annual area of land-use change to *annual cropland* by the annual carbon stock gain. In case of a conversion to *perennial cropland*, the land-use change area of 20 years in transition was multiplied by the annual carbon stock gains in biomass. In the case of a land-use change to *perennial cropland*, in addition, the carbon stocks from cleared *perennial cropland* which were planted five years ago and have reached maturity were considered as carbon stock losses across the land-use change transition period of 20 years.

Dead wood

This carbon pool does not occur in this land-use change category.

Litter

This carbon pool does not occur in this land-use change category.

Soil

Soil carbon stock changes were calculated by applying the methods described in Chapter 2.3.3.1 of the 2006 IPCC Guidelines. The carbon stock of the category before conversion (0 t C/ha) was subtracted from the carbon stock of the new land-use category, which was then divided by IPCC default time period for transition between the SOC stocks (20 years).

Settlements converted to Cropland

In this category for all possible land-use change from *Settlement* subcategories to *Cropland* subcategories emissions/removals were reported, except for the three *Settlements* subcategories converted to *Infrastructure within cropland* which were considered as reclassification of unchanged land due to definitional issues.

Biomass

The annual carbon stock losses in biomass were calculated by multiplying the annual area of *Settlements* that were changed to *Cropland* by the carbon stock of the perennial and low vegetation biomass of the *Settlement* subcategory. In the case of a land-use change to *perennial cropland*, in addition, the carbon stocks from cleared perennial crops which were planted five years ago and have reached maturity were considered as carbon stock losses across the land-use change transition period of 20 years.

The carbon stock increase in *annual cropland* biomass after land-use change was calculated by multiplying the annual area of land-use change to *annual cropland* by the annual carbon stock gain (see Table 143). In cases of a conversion to *perennial cropland* the land-use change area of 20 years in transition was multiplied by the annual carbon stock gains in biomass (see Table 143).

Dead wood

Dead wood does not occur in this category.

Litter

In cases of a land-use change from *tree-covered areas in settlements* to *Cropland,* the carbon stock of the litter is lost in the year of land-use change.

Soil

Soil carbon stock changes were calculated by applying the methods of Chapter 2.3.3.1 of the 2006 IPCC Guidelines.

The carbon stock of the category before land-use change (Table 150) was subtracted from the carbon stock of the new land-use category (Table 144), which was then divided by IPCC default time period for transition between the SOC stocks (20 years).

Land reclamation from sea to Cropland

The methods for this land reclamation from sea to *Cropland* are the same as detailed above for *Wetlands* converted to *Cropland.*

Direct N_2O emissions from LUC/conversions to/within Cropland subcategories

In accordance with the 2006 IPCC Guidelines, N_2O emissions from mineral soils in land-use change/ conversion to *Cropland* have to be reported in cases of a net carbon loss in the mineral soil. For Singapore, these emissions occur in the following categories:

- Conversions within the *Cropland* subcategories with soil carbon
- Stock losses
- Land-use changes from some *Forest Land* subcategories to some *Cropland* subcategories
- Land-use changes from some *Settlements* subcategories to some *Cropland* subcategories

The N_2O emissions were estimated based on a Tier 1 method (Eq 11.8 Ch.11 of the 2006 IPCC Guidelines). A default emission factor of 0.01 kg N_2O-N/kg N was used (2006 IPCC Guidelines, Chapter 11, Table 11.1).

The C/N ratios are provided in the following table:

Table 146: C/N ratio of soil organic matter

Category	C/N ratio	Source:
Stocked forest areas	17.88	Field measurements
Treeless areas within forest land	16.49	Field measurements
Other vegetated areas in settlements	16.49	Field measurements
Tree-covered areas in settlements	16.49	Field measurements
Sealed/unvegetated areas in settlements	16.49	Field measurements
Perennial cropland	15	Default C/N ratio (2006 IPCC Guidelines, eq. 11.8)
Annual cropland	10	Default C/N ratio (2006 IPCC Guidelines, eq. 11.8)

Indirect N_2O emissions from LUC/conversions to/ within Cropland subcategories

In addition to the direct N_2O emissions from mineralised soil nitrogen, indirect N_2O emissions occur due to the mineralised N which is leached from the soil. The 2006 IPCC Guidelines provide the following tier 1 methodology in Chapter 11:

$$N_2O - N = F_{SOM} \times Frac_{LEACH} \times EF_5 \text{ (eq.11.10)}$$

Where

- N_2O-N = annual amount of N_2O-N produced from leaching and runoff of N additions to managed soils, kg yr^{-1}
- F_{SOM} = the net annual amount of N mineralised in mineral soil associated with loss of soil C from soil organic matter as a result of changes in land use or management kg N yr^{-1}
- $Frac_{LEACH}$ = 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 per kg of N additions

$Frac_{LEACH}$ is a default factor (0.3) of Table 11.3 of the 2006 IPCC Guidelines. EF_5 (0.0075) is provided in Table 11.3 as well.

6.5.3. Uncertainty assessment and time series consistency

See Annex II.

6.5.4. Description of any flexibility applied

Flexibility for time series which starts from year 2000 to 2022 as described in Section 1.9. Summary of any flexibility applied had been applied throughout the report.

6.5.5. Category-specific QA/QC and verification

The implemented steps of QA/QC were compiled in Chapter 6, Section 6.1.3.

6.5.6. Category-specific recalculations

There are no category-specific recalculations for *Cropland*.

6.5.7. Category-specific planned improvements

See Chapter 6, Section 6.1.6.

6.6. Grassland (CRT Category 4.C.)

6.6.1. Description

As per the definition of *Grassland* in the 2006 IPCC Guidelines, *Grassland* does not exist in Singapore. There are no agricultural grasslands in Singapore. Lawns and grassland patches are located in between infrastructure and within stocked forests and in city parks. Such areas are accounted under the *Forest Land* category and under the *Settlement* category, depending on the location of these areas.

6.7. Wetlands (CRT Category 4.D.)

6.7.1. Description

The *Wetlands* category includes emission estimations for land-use changes to *Wetlands*, because it is assumed that no carbon stocks are occurring in this category. The calculations cover the time series from 2000 to 2022 for all land-use change subcategories and carbon pools which occur.

In 2022, the total *Wetlands* category amounted to emissions of 1.80 kt CO_2 eq. These emissions are reported under land converted to *Wetlands* because, in the category *Wetlands remaining Wetlands*, no net emissions/removals occur. The major land-use change in *Wetlands* in 2022 is from *Forest Land* to *Wetlands*.

Figure 39: Total GHG emissions from Wetlands (2000 to 2022)

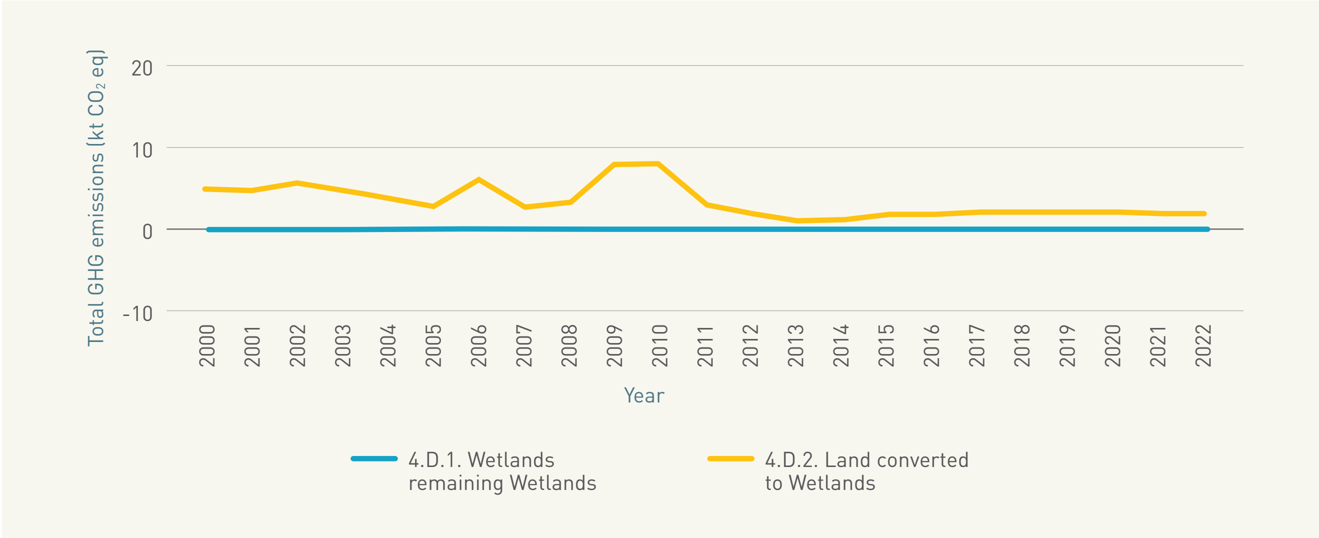


Table 147: Total GHG emissions from Wetlands (2000 to 2022)

Greenhouse Gas Category	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
	GHG Emissions (kt CO_2 eq)											
4.D. Wetlands	4.71	4.57	5.53	4.58	3.68	2.71	5.94	2.56	3.05	7.59	8.04	3.17
4.D.1. Wetlands remaining Wetlands	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.D.2. Land converted to Wetlands	4.71	4.57	5.53	4.58	3.68	2.71	5.94	2.56	3.05	7.59	8.04	3.17

Greenhouse Gas Category	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
	GHG Emissions (kt CO_2 eq)										
4.D. Wetlands	1.80	0.87	0.98	1.66	1.67	1.95	1.96	1.88	1.87	1.84	1.81
4.D.1. Wetlands remaining Wetlands	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.D.2. Land converted to Wetlands	1.80	0.87	0.98	1.66	1.67	1.95	1.96	1.88	1.87	1.84	1.81

6.7.2. Methodological issues

6.7.2.1. AGB, dead wood, litter and soil

Biomass

In *Wetlands*, no biomass carbon stocks are present and therefore no carbon gains/losses are reported in the remaining category. For land-use changes to *Wetlands*, the carbon stock present in the category before the conversion to *Wetlands* is reported as a net carbon loss in the year of land-use change.

Dead wood

In *Wetlands*, no dead wood carbon stocks are present and therefore no carbon gains/losses are reported in the remaining category. For land-use changes to *Wetlands*, the carbon stock present in the category before the conversion to *Wetlands* is reported as a net carbon loss in the year of land-use change.

Litter

In *Wetlands*, no litter carbon stocks are present and therefore no carbon gains/losses are reported in the remaining category. For land-use changes to *Wetlands*, the carbon stock present in the category before the conversion to *Wetlands* is reported as a net carbon loss in the year of land-use change.

Soil

In *Wetlands*, no soil carbon stocks are present and therefore no carbon gains/losses are reported in the remaining category. For land-use changes to *Wetlands*, the soil carbon stock present in the category before the conversion to *Wetlands* is reported as a net carbon loss over the default transition period of 20 years.

6.7.2.2. Wetlands remaining Wetlands

Net carbon stock changes are NO in all pools.

6.7.2.3. Land converted to Wetlands

Forest Land converted to Wetlands

Biomass, dead wood, litter

The carbon stocks in biomass, dead wood and litter of the previous land use are reported as an annual loss in the year of conversion. The annual area of *Forest Land* changed to *Wetlands* is multiplied by the country-specific carbon stocks which are lost (see Table 136 for biomass, Table 137 for dead wood, Table 139 for litter).

Soil

Soil carbon stock changes are calculated by applying the methods of Chapter 2.3.3.1 of the 2006 IPCC Guidelines. The soil carbon stock of the category before land-use change (country-specific stocks, see Table 139) was subtracted from the soil carbon stock of the new land-use category (0 t C/ha), which was then divided by IPCC default time period for transition between the SOC stocks (20 years). The exception are land-use changes from *mangrove forest* to *Wetlands*. In this case, the soil carbon stock is lost immediately in the year of the land-use change.

Cropland converted to Wetlands

Biomass

In the year of the land-use change the carbon stock of the total biomass in *Cropland* (default values, see Table 144) is reported as a net carbon loss.

Dead wood, litter

Dead wood and litter are NO in *Cropland*.

Soil

The soil carbon stock of the category before conversion (derived from default values, see Table 144) was subtracted from the soil carbon stock of the new land-use category (0 t C/ha), which was then divided by IPCC default time period for transition between the SOC stocks (20 years).

Settlements changed to Wetlands

No carbon stock changes are calculated for *Settlements* converted to *Wetlands* because definitional issues are assumed to be the main reason for the reclassification of such lands.

Sea converted to wetlands

Construction activities (e.g., building of dams) lead to a conversion of open sea to inland waters in Singapore. Since information on carbon stocks is not available for both categories, it is assumed that such changes do not lead to emissions or removals.

6.7.3. Uncertainty assessment and time series consistency

See Annex II.

6.7.4. Description of any flexibility applied

Flexibility for time series which starts from year 2000 to 2022 as described in Section 1.9. Summary of any flexibility applied had been applied throughout the report.

6.7.5. Category-specific QA/QC and verification

The implemented steps of QA/QC were compiled in Chapter 6, Section 6.1.3.

6.7.6. Category-specific recalculations

There are no category-specific recalculations for *Wetlands*.

6.7.7. Category-specific planned improvements, if applicable

See Chapter 6, Section 6.1.6.

6.8. Settlements (CRT Category 4.E.)

6.8.1. Description

The *Settlement* category includes emissions and removals for the subcategories *Settlements remaining Settlements* and land-use changes to *Settlements*. The *Settlement* category consists of the subcategories *tree-covered areas within settlements*, *other vegetated areas in settlements*, and *sealed/unvegetated areas in settlements*. Any conversions/land-use changes between and to these subcategories were estimated under the *Settlement* category. The calculations cover the time series from 2000 to 2022 for all conversion/land-use change subcategories and carbon pools which occur.

In 2022, the total net emissions of *Settlements* amounted to 112.59 kt CO_2 eq, which is the largest category in the LULUCF sector in Singapore. An emission share of 3.46 kt CO_2 eq was caused by direct and indirect N_2O emission due to land-use changes to *Settlement*. Land-use changes to *Settlement* represent an emission source throughout the time series. The most significant emission source in 2022 and throughout the time series was the land-use change from *Forest Land* to *Settlements*. The "remaining" *Settlements* subcategories represent in total a net sink for almost all years of the time series, reflecting greening measures in *Settlements*. However, the trend of this net sink was decreasing through the time series and turned into a net source in the last years due to losses of tree cover in the remaining *Settlements* category.

Figure 40: Total GHG emissions from Settlements (2000 to 2022)

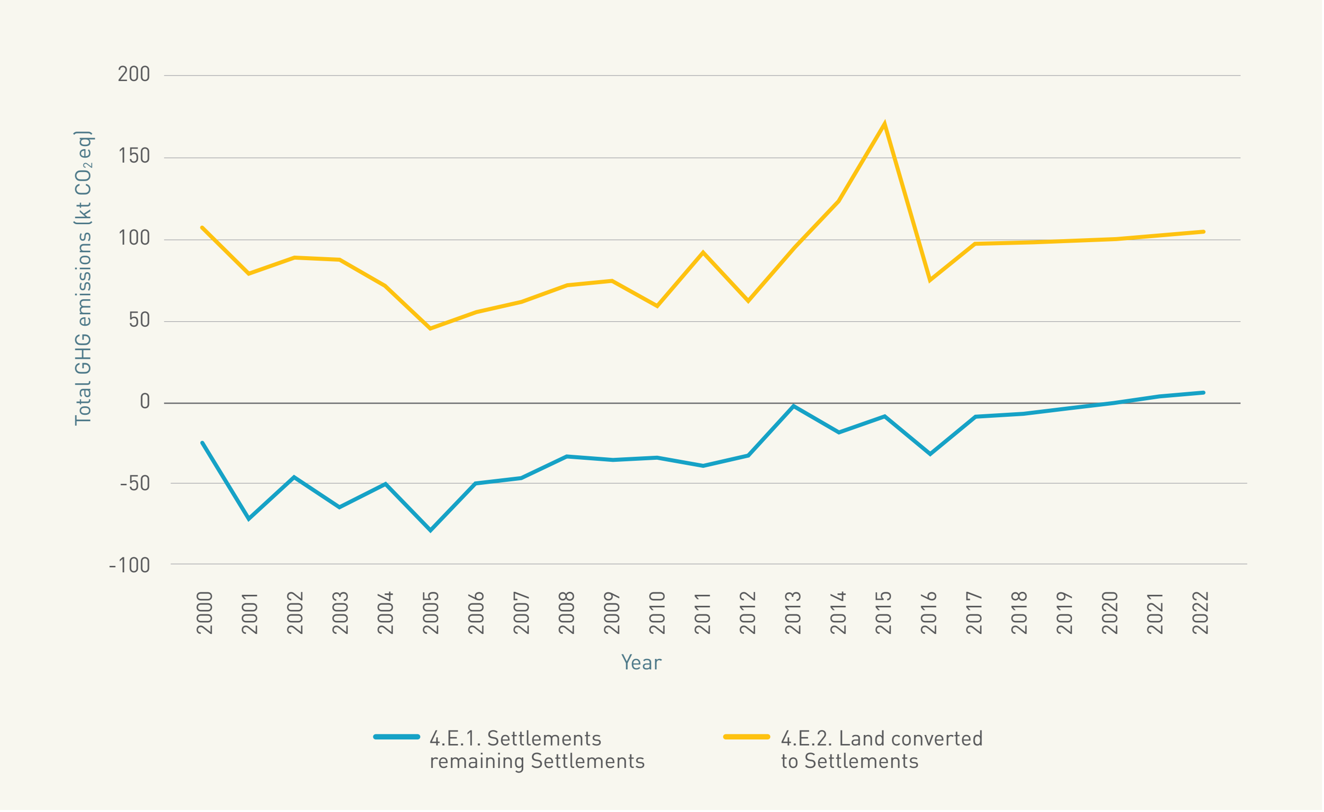


Table 148: Total GHG emissions from Settlements (2000 to 2022)

Greenhouse Gas Category	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
	GHG Emissions (kt CO_2 eq)											
4.E. Settlements	81.98	8.47	43.83	23.71	21.56	-31.50	6.67	15.50	38.51	39.46	24.89	53.12
4.E.1. Settlements remaining Settlements	-25.93	-71.37	-46.01	-64.44	-49.93	-78.91	-50.09	-46.93	-33.69	-35.62	-34.44	-39.01
4.E.2. Land converted to Settlements	107.91	79.84	89.84	88.15	71.49	47.41	56.75	62.43	72.20	75.09	59.32	92.13

Greenhouse Gas Category	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
	GHG Emissions (kt CO_2 eq)										
4.E. Settlements	29.01	92.01	104.56	162.60	44.00	88.77	91.96	96.64	101.27	107.59	112.59
4.E.1. Settlements remaining Settlements	-33.45	-2.86	-19.05	-8.75	-31.97	-9.21	-6.77	-3.12	0.13	4.48	7.18
4.E.2. Land converted to Settlements	62.45	94.87	123.61	171.35	75.97	97.97	98.73	99.76	101.14	103.11	105.41

6.8.2. Methodological issues

6.8.2.1. Field inventory for AGB, dead wood, litter and soil

In order to derive country-specific emission factors for the carbon stocks of the subcategories *stocked forest areas* and *tree-covered areas in settlements*, a field inventory was established for Singapore in 2015. Details of this inventory are described in Chapter 6, Section 6.4.2.1. The same root/shoot ratios and carbon contents, as described in Chapter 6, Section 6.4.2.1., were applied.

In 2018, new research results from streetscape trees became available (Ngo and Lum 2018). On the basis of these results, the biomass stocks of *tree-covered areas in settlements* were revised (Chapter 6, Section 6.4.2.1.), which has a related impact on the biomass stocks estimated for the other *Settlements* subcategories (see Section 6.8.2.6. below). The measured, revised total biomass carbon stocks of *tree-covered areas in settlements* are presented in Table 151.

This field inventory also includes the monitoring of carbon stocks in litter and soils of the subcategories *stocked forest areas* and *tree-covered areas in settlements*.

6.8.2.2. Growth models for estimating changes of AGB in land-use change areas to tree-covered areas in settlements

The biomass stock changes in the 20-year transition period for areas converted to *tree-covered areas in settlements* was estimated using the average number of trees per hectare and the tree species distribution from the field inventory data, an initial DBH of 12.5 cm for all trees (i.e., average DBH of planted trees at the time of planting) and local growth rates. For the second BUR, these growth rates were derived from measurement of roadside trees in Singapore. In 2017, there were additional repeated tree measurements within the sample plots. With this new information, these growth rates had to be significantly reduced by about 75% compared to those used for the second BUR. This had a significant and the highest impact on the estimated LULUCF emissions/removals of all improvements implemented for the third BUR because it has also a related impact on the growth rates in the other *Settlements* subcategories (see Section 6.8.2.2. below). Applying the growth models as described in Section 6.4.2.1.1. with these input data, a root-to-shoot ratio (0.201) and default carbon contents (0.47 t C/t biomass) as described in Section 6.4.2.1., an average annual AGB and BGB growth of LUC areas to *tree-covered areas in settlements* as presented in Table 150 was calculated.

6.8.2.3. Soil and litter carbon stocks and simulation of carbon stock changes

In *tree-covered areas in settlements*, carbon stocks were assessed for litter and mineral soil at depths up to 30 and 50 cm. The data of the field inventory in 2015 were complemented for the third BUR estimates with new results from further plots and streetscape data from NParks. The updated litter and soil carbon stocks for *tree-covered areas in settlements* are compiled in Table 152.

To simulate the carbon stock changes in soil and litter in the subcategory *tree-covered areas in settlements*, the YASSO20 (Liski et al., 2009) model was applied. Methodological details are provided in Section 6.4.2.2. However, it should be noted that there are some differences between *tree-covered areas in settlements* and *stocked forest areas*, specifically in the carbon pools of dead wood and litter, which affect the estimations of carbon in these subcategories.

Unlike in *Forest Land*, litter is raked and removed before its decay in the subcategory *tree-covered areas in settlements*, dead trees are also removed and may be replaced. Therefore, the input of organic matter to the soil is theoretically reduced to the below-ground carbon input from the decay of fine and coarse roots. Within the unsealed portions of these *Settlements* plots, the litter layer encountered was estimated to be an average of 5.1 t C/ha, which was lower than the average for *stocked forest areas* land plots of 6.8 t C/ha, due to the occasional litter raking and removal of fallen leaves. Still, about 70% of the leaves reach the ground and contribute to the soil carbon pool. In order to represent litter raking and removal, the flux of branches to the soil is taken to be zero. This attempts to represent tree pruning, with the assumption that no fallen branches are left on the ground until decayed fully. To represent the practice of removing dead trees in *tree-covered areas in settlements*, the carbon flux from dead stem wood was set to zero. The modelled litter and soil carbon stock changes for tree-covered settlement areas are presented in Table 153.

6.8.2.4. Carbon stocks and stock changes in Settlements

In this section, the carbon stocks and carbon stock changes, as used for the emissions/removals estimations of *Settlements* subcategories, are presented by pool.

Biomass

Table 150 shows the carbon stock gains of the categories *Settlements remaining Settlements* and land-use changes to *Settlements* for above and below-ground biomass. The average biomass carbon stock in the *Settlements* subcategories is higher than the total biomass growth rate in the transition period of 20 years at lands undergoing LUC to the *Settlements* subcategories (Table 150, Table 151). Consequently, it is assumed that the biomass stocks at the *Settlements* subcategories further increase after the transition period of 20 years. The difference between the annual biomass growth rate in the transition period time of 20 years and the average biomass stock in the *Settlements* subcategories equals to a further growth of the biomass stock for nine years, using the growth rates of the transition period. So, it is assumed and estimated that the remaining *Settlements* subcategories have a further biomass growth of nine years with the same annual growth rate as for the transition period, when they change from the land-use change subcategory to the remaining *Settlements* subcategory (Table 150). After these nine years the average biomass carbon stock is achieved and no further biomass stock increase is assumed. Further increase or decrease in biomass in *Settlements* is determined by conversions/ land-use changes between or to these *Settlements* subcategories.

To capture the carbon stocks associated with Singapore's intensive skyrise greening efforts, the biomass gains were estimated based on datasets of vertical greenery and rooftop greenery (extensive green roofs and intensive roof gardens) provided by NParks. The biomass gains from vertical greenery and extensive green roofs were estimated using estimates from lawns, while the estimates from intensive green roofs were based on perennial biomass of trees and palms commonly planted in such gardens. The tree density of rooftop gardens was provided by NParks, and it was assessed that the trees in these gardens are replaced after a 10-year rotation period. Based on the species in these gardens, and a growth model simulation detailed in Section 6.4.2.1., an average annual AGB growth rate of 3.92 kg per tree per year was estimated for rooftop greenery trees. Below-ground biomass growth and conversion to carbon was estimated with the expansion and conversion ratios described in Section 6.8.2.2. with a rotation period of 10 years and the related biomass losses, the perennial biomass stocks from these rooftop gardens are assumed to represent on average the perennial biomass stocks of a five-year old rooftop garden. The net carbon stock gains were estimated accordingly. In addition, the proportion of sealed to unsealed areas of these gardens were considered with an annual biomass increase for newly constructed gardens only in the year the trees were planted. Afterwards the carbon stock of the unsealed area is assumed to be in equilibrium. Vertical greenery is considered as low vegetation and only the annual biomass increase was estimated as they were determined to be similar to the biomass increase for lawns (Ng et al. 2015).

For land-use change and conversion categories to the *Settlements* subcategories the following values for biomass gains were used:

When land from other land-use categories is changed to *tree-covered areas in settlements*, the perennial AGB gains from the model simulations are applied. The perennial AGB carbon stocks increase by 2.23 t C/ha/yr over the transition period of 20 years (Table 150). The perennial below-ground biomass gains for land converted to *tree-covered areas in settlements* (0.45 t C/ha/yr; Table 150) was estimated with the AGB gains and the root-to-shoot ratio (0.201) on basis of Kenzo et al. (2009), under typical tropical conditions (see Section 6.2.2.4). In addition, biomass gains of low vegetation occur in the year of land-use change to *tree-covered areas in settlements*. These low vegetation biomass gains were derived from the grass biomass of lawns measured in a study by Ng et al. (2015) in Singapore. These measured grass biomass stocks were reduced according to the share of low vegetation in the surface, according to Table 149. These shares of vegetation cover in Table 149 are based on an estimate of the vegetation cover in the three *Settlements* subcategories with Very High Resolution satellite data. When land is converted to *tree-covered areas in settlements*, 0.14 t C/ha/yr in AGB and 0.06 t C/ha/yr in BGB are reported as annual carbon stock gains in low vegetation in the year of land-use change.

For land-use conversions to *other vegetated areas in settlement*, the perennial AGB and BGB gains were estimated on the basis of those for land-use change areas to *tree-covered areas in settlements* according to Table 150. These values for land-use change areas to *tree-covered areas in settlements* were reduced according to the different shares of the surface of tree-covered areas in both *Settlements* subcategories as listed in Table 149. The perennial AGB and BGB carbon stocks at land-use change areas to *other vegetated areas in settlement* increase by 0.30 t C/ha/yr and 0.06 t C/ha/yr, respectively, over the transition period of 20 years (see Table 150). The low vegetation biomass gains per ha for land-use conversions to *other vegetated areas in settlements* were derived in the same way as for land converted to *tree-covered areas in settlements* (see paragraph above) but with the appropriate area share of low vegetation cover for this category (see Table 149). When land is converted to *other vegetated areas in settlements*, 0.55 t C/ha/yr in AGB and 0.24 t C/ha/yr in BGB are reported as annual carbon stock gains in low vegetation in the year of land-use change.

For land-use conversions to *sealed/unvegetated areas in settlements*, the perennial AGB and BGB gains were estimated on the basis of those for land-use change areas to *tree-covered areas in settlements* according to Table 150. These values for land-use change areas to *tree-covered areas in settlements* were reduced according to the different shares of the surface of tree-covered areas in both *Settlements* categories as listed in Table 149. The perennial AGB and BGB carbon stocks at land-use change areas to *sealed/unvegetated areas in settlements* increase by 0.14 t C/ha/yr and 0.04 t C/ha/yr, respectively, over the transition period of 20 years (see Table 151). The low vegetation biomass gains per ha for land-use conversions to *sealed/unvegetated areas in settlements* were derived in the same way as for land converted to *tree-covered areas in settlements* (see above) but with the appropriate area share of low vegetation cover for this category (see Table 149). When land is converted to *sealed/unvegetated areas in settlements,* 0.08 t C/ha/yr in AGB and 0.03 t C/ha/yr in BGB are reported as annual carbon stock gains in low vegetation in the year of land-use change.

The biomass gains due to conversions from one *Settlements* subcategory to another *Settlements* subcategory were estimated in a different way. Such biomass gains occur only for conversions from a *Settlements* subcategory with a lower cover of perennial or low vegetation to a *Settlements* subcategory with a higher cover of perennial or low vegetation (e.g., conversions from *sealed/unvegetated areas in settlements* to *tree-covered areas in settlements*, see Table 149). In such cases, the difference in the annual biomass gains between both subcategories for perennial biomass and low vegetation according to Table 149 is applied for the transition period of 20 years or for the area in the year of conversion, respectively. This approach reflects the fact that the existing biomass in the previous *Settlements* subcategory is not removed and assumed to be in equilibrium (gains and losses are in balance). However, further greening measures were carried out in the previous *Settlements* subcategory which led to a change into the *Settlements* subcategory with higher vegetation cover. Consequently, only the new vegetation due to the further greening measures leads to biomass gains across the transition period. This approach represents a rather accurate assessment of the biomass carbon stock changes for the *Settlements* area in Singapore.

Table 149: Average percentage of land cover types (tree-covered, low vegetation, bare soil/sealed) in the Settlements subcategories as determined by remote sensing

Land use subcategory	Percentage of land cover
Tree-covered areas in settlements	
Tree-covered	72%
Low vegetation	20%
Bare soil/sealed	8%
Other vegetated areas in settlements	
Tree-covered	11%
Low vegetation	81%
Bare soil/sealed	8%
Sealed/unvegetated areas in settlements	
Tree-covered	6%
Low vegetation	12%
Bare soil/sealed	83%

Table 150: Settlements - net carbon stock changes from biomass

Remaining category	Carbon stock AGB (t C/ha/yr)	Carbon stock BGB (t C/ha/yr)	Total carbon stock living biomass (t C/ha/yr)	Source:
Tree-covered areas in settlements	1.97	0.40	2.37	Updated modelling based on field measurements 2020
Other vegetated areas in settlements	0.30	0.06	0.35	Updated modelling based on field measurements 2020, considering vegetation cover
Sealed/unvegetated areas in settlements	0.16	0.03	0.19	Updated modelling based on field measurements 2020, considering vegetation cover
Land-use change category (to Settlements)				
Tree-covered areas in settlements - perennials	1.97	0.40	2.37	Updated modelling based on field measurements 2020
Other vegetated areas in settlements - perennials	0.30	0.06	0.35	Updated modelling based on field measurements 2020, considering vegetation cover
Sealed/unvegetated areas in settlements - perennials	0.16	0.03	0.19	Updated modelling based on field measurements 2020,considering vegetation cover

For all land-use changes from *Settlements* subcategories to other land-use categories, the total biomass carbon stock in the individual *Settlements* subcategories is of interest as this is lost in the year of conversion (Table 151).

The AGB perennial stock for *tree-covered areas in settlements* (80.61 t C/ha) was derived from the AGB field inventory. The BGB stock for *tree-covered areas in settlements* (16.19 t C/ha) was estimated with a typical root-to-shoot ratio (0.201) for Singapore's conditions derived on basis of Kenzo et al. (2009). The low vegetation biomass stocks per ha (0.14 t C/ha AGB and 0.06 t C/ha) were derived from the grass biomass of lawns measured in a study by Ng et al. (2015) in Singapore. These measured grass biomass stocks per ha were reduced according to the share of low vegetation cover in the subcategory *tree-covered areas in settlements* in Table 149.

The AGB perennial stock for *other vegetated areas in settlements* (12.05 t C/ha) was derived from the values from the AGB field inventory for *tree-covered areas in settlements*[42]. These values for *tree-covered areas in settlements* were reduced according to the different shares of the surface of tree-covered areas in both *Settlements* subcategories as listed in Table 149. The below-ground biomass stock for trees in *other vegetated areas in settlements* (2.42 t C/ha) was estimated again with the root-to-shoot ratio on basis of Kenzo et al. (2009). The low vegetation biomass stocks per ha (0.55 t C/ha AGB and 0.24 t C/ha) were derived from the grass biomass of lawns measured in a study by Ng et al. (2015) in Singapore. These measured grass biomass stocks per ha were reduced according to the share of low vegetation cover in the subcategory *tree-covered areas in settlements* according in Table 149.

The AGB perennial stock for *sealed/unvegetated areas in settlements* (6.62 t C/ha) was derived from the values from the AGB field inventory for *tree-covered areas in settlements*. These values for *tree-covered areas in settlements* were reduced according to the different shares of the surface of tree-covered areas in both *Settlements* subcategories as listed in Table 149. The BGB stock for trees in *sealed/unvegetated areas in settlements* (1.33 t C/ha) was estimated again with the root-to-shoot ratio in Kenzo et al. (2009). The low vegetation biomass stocks per ha (0.08 t C/ha AGB and 0.03 t C/ha) were derived from the grass biomass of lawns measured in a study by Ng et al. (2015) in Singapore. These measured grass biomass stocks per ha were reduced according to the share of low vegetation cover in the subcategory *sealed/unvegetated areas in settlements* as seen in Table 149.

The biomass losses due to conversions from one *Settlements* subcategory to another *Settlements* subcategory were estimated in a different way. Such biomass losses occur only for conversions from a *Settlements* subcategory with a higher cover of perennial or low vegetation to a *Settlements* subcategory with a lower cover of perennial or low vegetation (e.g., conversion from *tree-covered areas in settlements* to *sealed/unvegetated areas in settlements*, see Table 149). In such cases, the difference in the biomass stocks between both subcategories for perennial biomass and low vegetation was estimated as being lost in the year of conversion, respectively (Table 151). This approach reflects the fact that only parts of the existing biomass was removed. This approach ensures a rather accurate assessment of the biomass carbon stock changes in the *Settlements* area in Singapore.

[42] It should be noted that the name *sealed/unvegetated areas in settlements* suggests that there was no biomass in this category. In fact, the *Settlements* subcategory has some unsealed soils and trees and low vegetation, but also contains patches that are smaller than the assessment limits. These vegetated parts of sealed/unvegetated settlement areas become particularly visible when using very high resolution images.

Table 151: Settlements - biomass carbon stocks

Category	Carbon stock AGB (t C/ha)	Carbon stock BGB (t C/ha)	Total carbon stock living biomass (t C/ha)	Source:
Tree-covered areas in settlements - perennials	80.61	16.19	96.79	Updated based on field measurements 2020
Tree-covered areas in settlements - low vegatation	0.14	0.06	0.19	Ng et al. (2015)
Other vegetated areas in settlements - perennials	12.05	2.42	14.46	Calculated based on field measurements 2020 and vegetation cover
Other vegetated areas in settlements - low vegetation	0.55	0.24	0.79	Calculated, based on Ng et al. (2015)
Sealed/unvegetated areas in settlements - perennials	6.62	1.33	7.95	Calculated based on field measurements 2020 and vegetation cover
Sealed/unvegetated areas in settlements - low vegetation	0.08	0.03	0.11	Calculated based on Ng et al. (2015)

Dead wood

Dead wood does not occur in *Settlements* subcategories.

Litter and soil

The mineral soil and litter carbon stocks of *tree-covered areas in settlements* were measured in the field inventory and revised for the third BUR based on data from additional plots and data from streetscape soil surveys by NParks (litter: 3.05 t C/ha, 0-50 cm mineral soil: 26.98 t C/ha, adjusted for the share of sealed area in this subcategory). The mineral soil carbon stocks of the other two *Settlements* subcategories were estimated with soil carbon stocks for *tree-covered areas in settlements* but adjusted for the different shares of sealed vs. unsealed parts of these *Settlements* subcategories according to Table 149. It was assumed that the *Settlements* subcategories *other vegetated areas in settlements* and *sealed/unvegetated areas in settlements* have no litter layer, because they have an open tree cover where wind and precipitation, in addition to raking and removal of litter, leads to erosion of the litter.

These litter and soil carbon stocks (Table 152) were used to calculate the annual stock change rate in litter and mineral soil for the 20-year transition period, in the cases of land-use change/conversion between, from and to these *Settlements* subcategories (together with the stocks of the previous or following land-use categories).

Table 152: Settlements - litter and soil carbon stocks

Category	Mean soil carbon stock (0-50 cm) (t C/ha)	Mean soil carbon stock (0-30 cm) (t C/ha)	Mean litter carbon stock (t C/ha)	Source:
Tree-covered areas in settlements	26.98	19.75	3.05	Calculated based on field measurements
Other vegetated areas in settlements	39.27	28.74	0.00	Calculated based on field measurements and the areas detailed in Table 149
Sealed/unvegetated areas in settlements	6.78	4.96	0.00	Calculated based on field measurements and the areas detailed in Table 149

Table 153 provides the annual soil carbon stock changes for *tree-covered areas in settlements remaining tree-covered areas in settlements* (0.09 t C/ha/yr) including litter which has been simulated with the YASSO07 model. For the other remaining *Settlements* subcategories it is assumed that the soil C stocks do not change.

Table 153: Settlements -net carbon stock changes from litter and soil

Remaining category	Mean soil carbon stock change (t C/ha/yr)	Mean litter carbon stock change (t C/ha/yr)	Source:
Tree-covered areas in settlements	0.09	0	Updated with new YASSO20 and new AGB field data from 2020
Other vegetated areas in settlements	0	0	
Sealed/unvegetated areas in settlements	0	0	

6.8.2.5. Settlements remaining Settlements

This category comprises the estimation of net emissions/removals for *tree-covered areas within settlements remaining tree-covered areas within settlements*, *other vegetated areas in settlements remaining other vegetated areas in settlements*, *sealed/unvegetated areas in settlements remaining sealed/unvegetated areas in settlements* and the conversions between these *Settlements* subcategories. The calculations use country-specific emission factors and are in line with the Tier 3 methodology according to the 2006 IPCC Guidelines.

Biomass

The biomass changes for these *Settlements* subcategories are estimated according to the approaches described in the Biomass part of Section 6.8.2.2.

Dead wood

Dead wood does not occur in *Settlements* subcategories.

Litter and soil

For *tree-covered areas in settlements remaining tree-covered areas in settlements*, the litter and soil carbon stock changes were simulated in a model and the annual net change amount to 0.09 t C/ha/yr (litter plus mineral soil) as presented in Table 153. This change is calculated with the area of this subcategory.

Soil carbon stock changes for land conversions among the *Settlements* subcategories were calculated by applying the methods of Chapter 2.3.3.1 of the 2006 IPCC Guidelines. The soil carbon stock (Table 151) of the *Settlements* subcategory before conversion was subtracted from the carbon stock of the new *Settlements* subcategory, which was then divided by the IPCC default time period for transition between the SOC stocks (20 years). Litter carbon stock changes at conversions with litter gains (conversions to *tree-covered area in settlements*) were estimated in the same way as for mineral soil. Litter carbon stock losses (conversion from *tree-covered areas in settlements*) are assumed to occur in the year of conversion in line with the 2006 IPCC Guidelines.

In cases of changes between *tree-covered areas in settlements* and *other vegetated areas in settlements*, no mineral soil carbon stock changes are estimated. The soil carbon stocks of *other vegetated areas in settlements* is higher because of the smaller share of sealed areas in this subcategory. On the other hand, *tree-covered areas in settlements* has a higher tree biomass.

6.8.2.6. Land converted to Settlements

Forest Land converted to Settlements

Land-use changes from *Forest Land* to *Settlements* are reported for all subcategories.

Biomass

Stocked forest areas to tree-covered areas in settlements:

Tree-covered areas in settlements have slightly higher mean biomass carbon stocks than *stocked forest areas* (compare Table 136 and Table 151). However, it is extremely unlikely that a land-use change of stocked forest areas to tree-covered areas in settlements leads to biomass losses. So, biomass changes in this land-use change subcategory were considered unlikely and not estimated.

Other *Forest Land* subcategories converted to *Settlements* subcategories:

The annual carbon stock losses in biomass were calculated by multiplying the annual area of *Forest Land* cleared for the *Settlements* subcategory by the related carbon stock in *Forest Land* biomass (Table 136) before land-use change. The biomass carbon stock increase in the land-use change area to the *Settlements* subcategory after land-use change was calculated by multiplying the annual area of land-use change to the *Settlements* subcategory with the biomass carbon gains from low vegetation and by multiplying the 20 years transition area of land-use change to the Settlement subcategory by the biomass carbon gains from perennial biomass (see Table 150).

Dead wood

Dead wood is not present in any *Settlements* subcategory, but in *stocked forest areas*. In case of a land-use change from *stocked forest areas* to *Settlements,* the carbon stock of dead wood (Table 138) is lost in the year of conversion.

Litter

Litter is reported in the *Settlements* subcategory *tree-covered areas in settlements* only. In the case of a land-use change from *stocked forest areas* to *tree-covered area in settlements*, the carbon stock difference between both subcategories, according to Table 139 and Table 152, is lost in the year of land-use change. All other *Forest Land* subcategories do not have a litter layer. Consequently, for any land-use change from such categories to *tree-covered area in settlements*, a net carbon stock increase in litter was reported over the transition period of 20 years (0.15 t C/ha, Table 153).

Soil

The carbon stock of the *Forest Land* subcategory before land-use change (see Table 139) was subtracted from the carbon stock of the new *Settlements* land-use category (Table 152), which was then divided by the IPCC default time period for transition between the SOC stocks (20 years). However, for all land-use changes from *mangrove forest* to *Settlements* subcategories, the soil carbon stock of *mangrove forest* (see Table 139) was lost immediately in the year of the land-use change and the soil carbon stock of the *Settlements* subcategory (Table 152) was built up in the 20-year transition period after land-use change.

Cropland converted to Settlements

This category includes land-use changes from *Cropland* subcategories to *Settlements* subcategories.

Biomass

The biomass of the *Cropland* subcategory (Table 144) was lost in the year of land-use change. The annual carbon stock losses in biomass were calculated by multiplying the annual area of *Cropland* that was changed to the *Settlements* subcategory by the related carbon stock in *Cropland* biomass (see Table 144) before land-use change. The biomass carbon stock increase in the land-use change area to the *Settlements* subcategory was calculated by multiplying the annual land-use change area to the *Settlements* subcategory with the biomass carbon gains from low vegetation and by multiplying the 20-year transition area of land-use change to the *Settlements* subcategory by the biomass carbon gains from perennial biomass (see Table 150).

Dead wood

This pool does not exist in any *Cropland* and *Settlements* subcategory. Consequently, no carbon stock changes occur for such land-use changes.

Litter

Litter is only reported in *Cropland* converted to *tree-covered areas in settlements*. The annual increase of litter amounts to 0.15 t C/ha/yr over the 20-year transition period (Table 153).

Soil

Soil carbon stock changes were calculated by applying the methods of Chapter 2.3.3.1 of the 2006 IPCC Guidelines. The carbon stock of the *Cropland* subcategory before land-use change (Table 145) was subtracted from the carbon stock of the new *Settlements* land-use category (Table 152), which was then divided by IPCC default time period for transition between the SOC stocks (20 years).

Wetlands converted to Settlements

In all the reported land-use change categories, no carbon stock losses occur as no carbon stocks are assumed to be present in *Wetlands* due to lack of information in the literature and IPCC guidelines.

Biomass

For *Wetlands* changed to *Settlements* subcategories, the carbon stock gains in biomass was calculated by multiplying the annual land-use change area to the *Settlements* subcategory with the biomass C gains from low vegetation and by multiplying the 20 years transition area of land-use change to the *Settlements* subcategory by the biomass carbon gains from perennial biomass (Table 150).

Dead wood

This pool does not exist in any *Settlements* subcategory. Consequently, no carbon stock changes occur for such land-use changes.

Litter

Litter is only reported in *Wetlands* changed to *tree-covered areas in settlements*. The annual increase of litter amounts to 0.15 t C/ha over the 20-year transition period (Table 152).

Soil

The carbon stock of the category before land-use change (0 t C/ha) was subtracted from the carbon stock of the new land-use category (see Table 152), which was then divided by IPCC default time period for transition between the SOC stocks (20 years).

Land reclamation from sea to Settlements

The methods are the same as the subcategory *Wetlands* changed to *Settlements* (see above).

Direct N_2O emissions from land-use change/conversion to/within Settlements subcategories

In accordance with the 2006 IPCC Guidelines, N_2O emissions from mineral soils at land-use change and conversion areas to *Settlements* have to be reported in cases of a net carbon loss in the mineral soil. For Singapore, these emissions occur in the following subcategories:

Conversions within *Settlements* subcategories with soil carbon stock losses

Land-use changes from some *Cropland* and *Forest Land* subcategories to some *Settlements* subcategories

The direct N_2O emissions were estimated based on a Tier 1 method (Eq 11.8 Ch.11 of the 2006 IPCC Guidelines). A default emission factor of 0.01 kg N_2O-N/kg N was used (2006 IPC Guidelines, Chapter 11, Table 11.1).

The C/N ratios are provided in Table 141.

Indirect N_2O emissions from land-use change/conversion to/within Settlements subcategories

In addition to the direct N_2O emissions from mineralised soil nitrogen, indirect N_2O emissions occur due to the mineralised N which is leached from the soil. The 2006 IPCC Guidelines provide the following Tier 1 methodology in Chapter 11:

$$N_2O\text{-}N = F_{SOM} * Frac_{LEACH} * EF_5 \text{ (eq.11.10)}$$

Where

- N_2O-N = annual amount of N_2O-N produced from leaching and runoff of N additions to managed soils, kg yr^{-1}
- F_{SOM} = the net annual amount of N mineralised in mineral soil associated with loss of soil carbon from soil organic matter as a result of changes in land use or management, kg N yr^{-1}
- $Frac_{LEACH}$ = 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 per kg of N additions

$Frac_{LEACH}$ is a default factor (0.3) of Table 11.3 of the 2006 IPCC Guidelines. EF_5 (0.0075) is provided in this Table 11.3 as well.

6.8.3. Uncertainty assessment and time series consistency

See Annex II.

6.8.4. Description of any flexibility applied

Flexibility for time series which starts from year 2000 to 2022 as described in Section 1.9. Summary of any flexibility applied had been applied throughout the report.

6.8.5. Category-specific QA/QC and verification

The implemented steps of QA/QC were compiled in Chapter 6, Section 6.1.3.

6.8.6. Category-specific recalculations

See Chapter 8, Section 8.3.

6.8.7. Category-specific planned improvements

See Chapter 6, Section 6.1.6.

6.9. Other Land (CRT Category 4.F.)

This category includes bare soil, rock and all land areas that do not fall into any of the other categories. Currently, this category does not occur in Singapore. Differences between the mapped area and the official area of Singapore are added to the *Settlements* subcategory *sealed/unvegetated areas in settlements remaining sealed/ unvegetated areas in settlements*.

6.10. Harvested Wood Products (CRT Category 4.G.)

There is no commercial timber harvest in Singapore.

6.11. Other (Sea) (CRT Category 4.H.)

6.11.1. Description

Land-use changes to sea were detected in the subcategories *Forest Land to Other (Sea)* and *Settlements to Other (Sea)*. For the latter, an analysis of the satellite images suggests that such areas are the result of tide and annual changes of flooded parts during the process of land reclamation. Consequently, emissions were only estimated for *Forest Land to Others (Sea)*. In 2022, the net emissions are minor (0.004 kt CO_2 eq).

6.11.2. Methodological issues

6.11.2.1. AGB, dead wood, litter and soil

Biomass

The carbon stock that is present in the category before the land-use change to *Other (Sea)* was reported as a net carbon loss in the year of land-use change.

Dead wood

The carbon stock that is present in the category before the land-use change to *Other (Sea)* was reported as a net carbon loss in the year of land-use change.

Litter

The carbon stock that is present in the category before the land-use change to *Other (Sea)* was reported as a net carbon loss in the year of land-use change.

Soil

The soil carbon stock that is present in the category before the land-use change to *Other (Sea)* was reported as a net carbon loss in the year of land-use change.

6.11.2.2. Land converted to Other (Sea)

Forest Land changed to Other (Sea)

When Forest Land is converted to sea, the total biomass, dead wood, litter and soil stock is lost in the year of conversion. The annual area of *Forest Land* that is changed to *Other (Sea)* was multiplied by the carbon stocks which were lost (country-specific values, see Table 136 for biomass, Table 138 for dead wood, Table 139 for litter and soil).

Settlements converted to sea

An analysis of the satellite images suggests that such areas are the result of tide and annual changes of flooded parts during the process of land reclamation without any significant vegetation. Therefore, no carbon stock changes were calculated.

6.11.3. Uncertainty assessment and time series consistency

See Annex II.

6.11.4. Description of any flexibility applied

Flexibility for time series which starts from year 2000 to 2022 as described in Section 1.9. Summary of any flexibility applied had been applied throughout the report.

6.11.5. Category-specific QA/QC and verification

The implemented steps of QA/QC were compiled in Chapter 6, Section 6.1.3.

6.11.6. Category-specific recalculations

See Chapter 8, Section 8.3.

6.11.7. Category-specific planned improvements

See Chapter 6, Section 6.1.6.

Chapter 7

WASTE (CRT SECTOR 5)

7.1.

Overview of the sector

In general, the waste sector comprises the following categories:

- Solid Waste Disposal,
- Biological treatment of solid waste,
- Incineration and open burning of waste, and
- Wastewater treatment and discharge.

The waste sector in Singapore includes emissions mainly from waste incineration and wastewater treatment and discharge where CO_2 emissions make up the largest source of GHG emissions in the waste sector amongst other CH_4 and N_2O emissions. Most of the GHG emissions from incineration are reported under the Energy Sector where the waste material is used directly as fuel or converted into a fuel in the WtE incineration plants in Singapore.

Figure 41: Total GHG emissions (kt CO_2 eq) from Waste sector

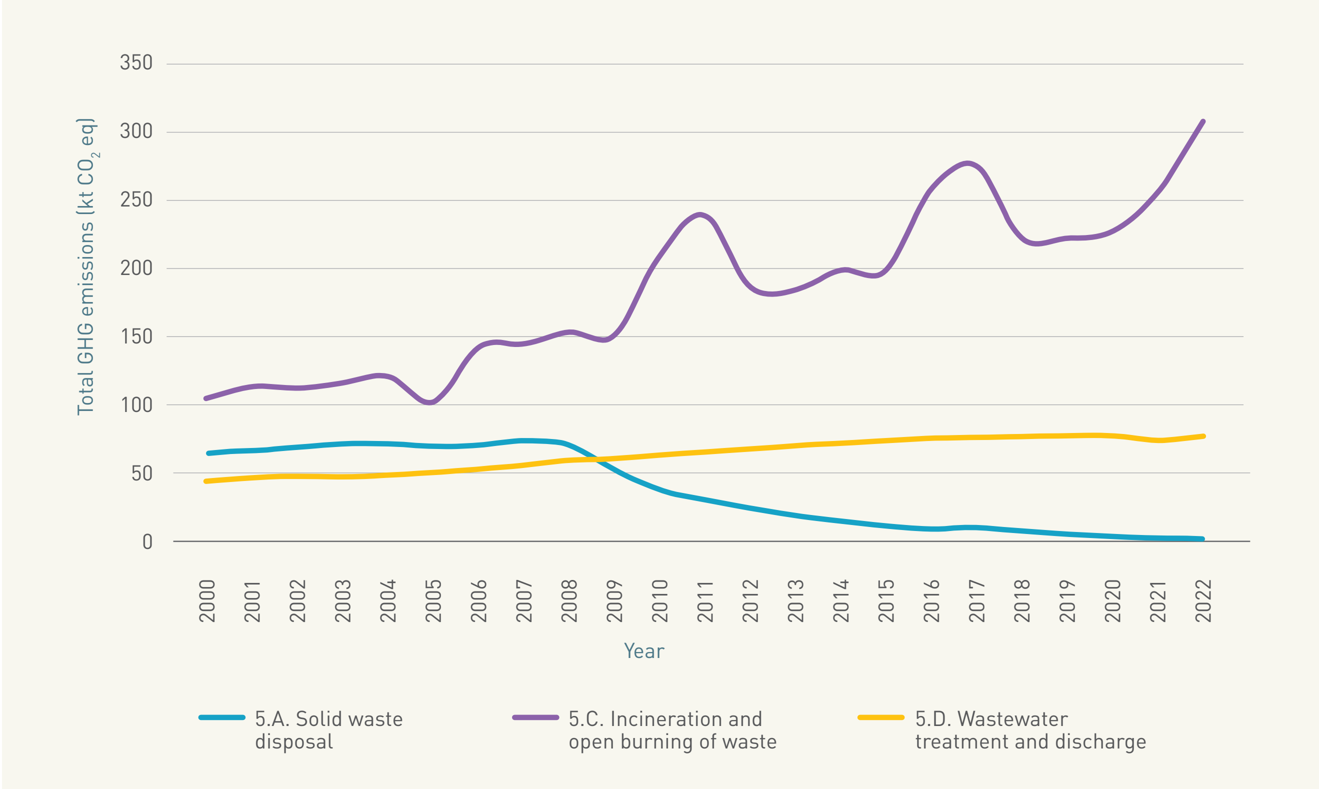


Table 154: Total GHG emissions (kt CO_2 eq) from Waste sector

Greenhouse Gas Category	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
	GHG Emissions (kt CO_2 eq)											
Total waste emissions	213.78	225.08	227.74	234.28	240.08	221.50	264.69	272.57	282.19	262.92	308.92	334.34
5.A. Solid waste disposal	64.87	65.98	68.57	71.42	71.48	69.68	70.32	73.32	70.50	52.40	37.98	30.71
5.B. Biological Treatment of Solid Waste	IE, NE	IE, NE	IE, NE	IE, NE	IE, NE	IE, NE	IE, NE	IE, NE	IE, NE	IE, NE	IE, NE	IE, NE
5.C. Incineration and open burning of waste	104.69	112.86	111.84	115.60	120.19	101.55	141.78	143.92	152.68	150.45	208.50	238.80
5.D. Wastewater treatment and discharge	44.23	46.24	47.33	47.27	48.41	50.28	52.60	55.33	59.01	60.07	62.44	64.83

Greenhouse Gas Category	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
	GHG Emissions (kt CO_2 eq)										
Total waste emissions	277.64	271.99	284.08	282.36	340.54	360.25	305.60	303.59	306.37	330.19	384.19
5.A. Solid waste disposal	24.29	19.12	14.87	11.50	9.12	9.99	7.74	5.29	3.55	2.38	1.80
5.B. Biological Treatment of Solid Waste	IE, NE	IE, NE	IE, NE	IE, NE	IE, NE	IE, NE	IE, NE	IE, NE	IE, NE	IE, NE	IE, NE
5.C. Incineration and open burning of waste	186.26	183.59	198.13	197.97	257.04	275.25	222.08	221.66	226.41	254.52	306.64
5.D. Wastewater treatment and discharge	67.10	69.29	71.07	72.89	74.38	75.01	75.78	76.65	76.41	73.29	75.75

Notation key:
IE - Included elsewhere, NE - Not estimated

Figure 42: Total GHG emissions (kt CO_2 eq) from Waste sector by GHG type

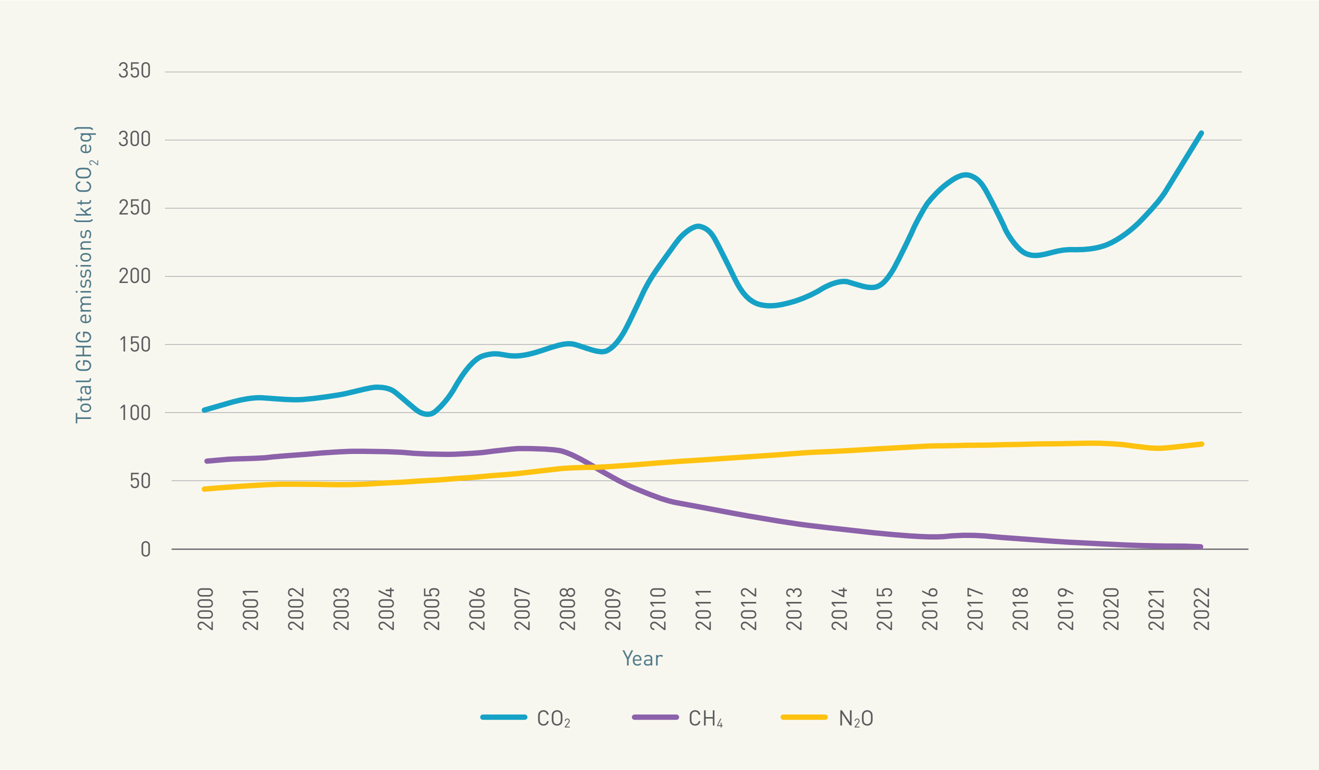


Table 155: Total GHG emissions (kt CO_2 eq) from Waste sector by GHG type

Greenhouse Gas Category	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
	GHG Emissions (kt CO_2 eq)											
Total waste emissions	213.78	225.08	227.74	234.28	240.08	221.50	264.69	272.57	282.19	262.92	308.92	334.34
CO_2	103.85	111.96	110.94	114.67	119.22	100.72	140.63	142.76	151.45	149.23	206.82	236.87
CH_4	64.87	65.98	68.58	71.42	71.48	69.68	70.32	73.32	70.50	52.40	37.98	30.71
N_2O	45.07	47.14	48.23	48.20	49.37	51.11	53.74	56.49	60.24	61.29	64.12	66.76

Greenhouse Gas Category	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
	GHG Emissions (kt CO_2 eq)										
Total waste emissions	277.64	271.99	284.08	282.36	340.54	360.25	305.60	303.59	306.37	330.19	384.19
CO_2	184.75	182.10	196.53	196.36	254.95	273.01	220.27	219.86	224.55	252.43	304.14
CH_4	24.29	19.12	14.87	11.50	9.12	9.99	7.74	5.29	3.55	2.38	1.80
N_2O	68.60	70.77	72.68	74.50	76.47	77.25	77.59	78.45	78.26	75.38	78.26

7.2.

Solid Waste Disposal (CRT category 5.A.)

7.2.1. Category description

Figure 43: Total GHG emissions from solid waste disposal (2000 to 2022)

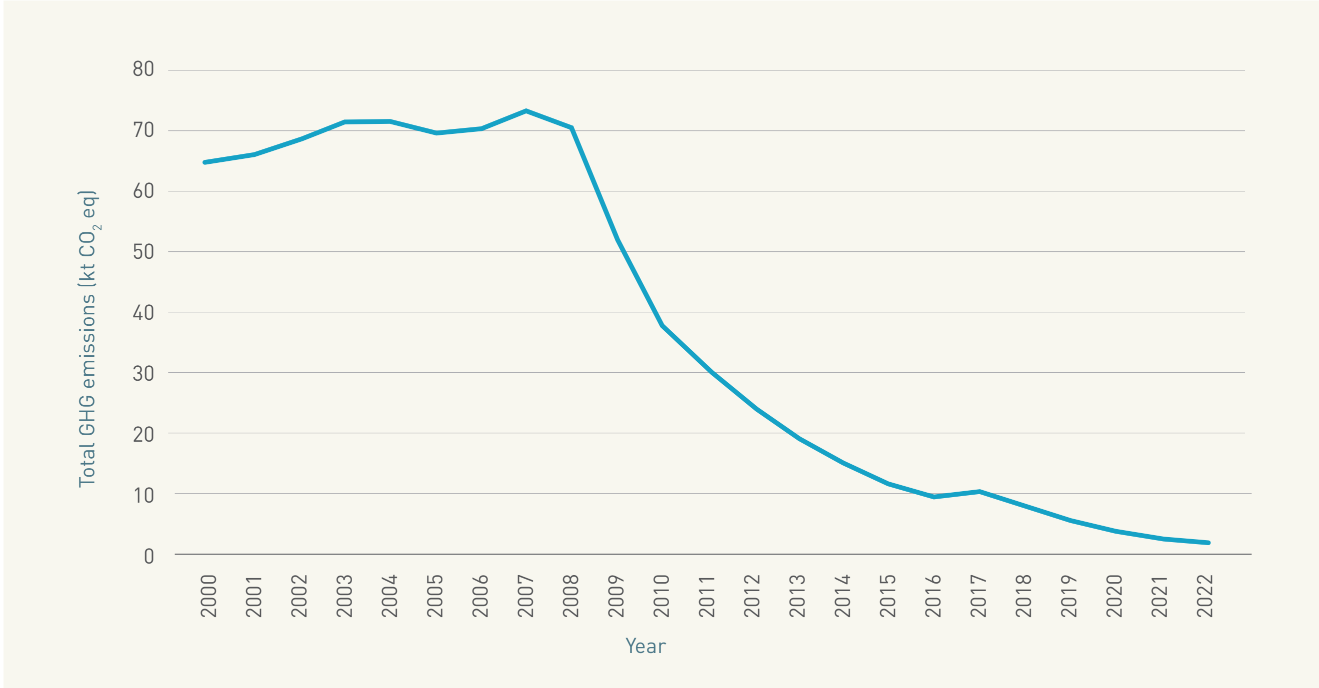


Table 156: Total GHG emissions from solid waste disposal (2000 to 2022)

Greenhouse Gas Category	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
	GHG Emissions (kt CO_2 eq)											
Solid waste disposal	64.87	65.98	68.57	71.42	71.48	69.68	70.32	73.32	70.50	52.40	37.98	30.71
5.A.1. Managed waste disposal sites	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
5.A.2. Unmanaged waste disposal sites	64.87	65.98	68.57	71.42	71.48	69.68	70.32	73.32	70.50	52.40	37.98	30.71
5.A.3. Uncategorised waste disposal sites	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

Greenhouse Gas Category	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
	GHG Emissions (kt CO_2 eq)										
Solid waste disposal	24.29	19.12	14.87	11.50	9.12	9.99	7.74	5.29	3.55	2.38	1.80
5.A.1. Managed waste disposal sites	NE	NE	NE	NE	NE	NE	NO	NO	NO	NO	NO
5.A.2. Unmanaged waste disposal sites	24.29	19.12	14.87	11.50	9.12	9.99	7.74	5.29	3.55	2.38	1.80
5.A.3. Uncategorised waste disposal sites	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

Notation keys:
NO - Not occurring, NE - Not estimated

Managed waste disposal sites

Singapore has adopted WtE incineration technology to reduce the volume of waste disposed of at landfill since the 1970s. As heat from the incineration of waste is recovered to produce electricity, according to the 2006 IPCC Guidelines, CO_2, CH_4 and N_2O emissions from waste incineration are reported in the energy sector. Biogenic CO_2 emissions from the incineration of non-fossil-based waste are excluded from the national total emissions estimates and are included as an information item in the energy sector.

Today, all incinerable wastes that are not recycled are disposed of at the WtE plants. Only non-incinerable waste and ashes from the incineration process are disposed of at the offshore Semakau Landfill, which is the only active sanitary landfill in Singapore. The Lorong Halus Landfill, which was closed in 1999, has a gas management system and a leachate collection system. A bentonite wall and a leachate collection system were also installed adjacent to the landfill site along the riverbank to transform the river into a reservoir. These help to mitigate the risk of leachate from the landfill polluting water, as well as managing CH_4 emissions to the atmosphere. The CH_4 concentration in Lorong Halus Landfill has since reached a low concentration level and the extraction of gases was discontinued in 2017. There are also no CH_4 emissions from Semakau Landfill, as it receives only incineration ash and non-incinerable waste where excavators, bulldozers and compactors will spread, level and compact the incineration ash and non-incinerable waste after the waste has been unloaded into the landfill cells. Each cell is then covered with a layer of earth or ash once it has been filled to ground level. Subsequently, grass and trees take root to form a green landscape.

Unmanaged waste disposal sites

Since 2009, direct methane emissions from sewage sludge from wastewater treatment plants have been significantly reduced through sludge incineration. The amount of sewage sludge emissions from unmanaged waste disposal sites have decreased from 64.87 kt CO_2 eq in 2000 to 1.8 kt CO_2 eq in 2022. (Figure 43).

Uncategorised waste disposal sites

There are no uncategorised waste disposal sites in Singapore. Singapore's solid (or general) and hazardous waste management systems include licensing and regulatory functions to ensure that waste is properly collected, treated and disposed of. The management of solid and hazardous wastes is governed by the Environmental Public Health Act (EPHA), Environmental Public Health (General Waste Collection) Regulations, Environmental Public Health (General Waste Disposal Facilities) Regulations and Environmental Public Health (Toxic Industrial Waste) Regulations.

7.2.2. Methodological issues

Table 157: Method and emission factor used for emission estimate of solid waste disposal

Greenhouse Gas Source and Sink Categories	CO_2		CH_4		N_2O	
	Method Applied	Emission Factor	Method Applied	Emission Factor	Method Applied	Emission Factor
5.A.2. Unmanaged waste disposal sites	NA	NA	T2	D	NA	NA

Notation keys:
T2 - Tier 2, D - Default IPCC, NA - Not applicable

Managed waste disposal sites

There are no emissions from Semakau Landfill since it only receives incineration ash and non-incinerable waste and no data are available to estimate the emissions from Lorong Halus Landfill. Nonetheless, the emissions from Lorong Halus Landfill would be insignificant as the landfill has been closed since 1999.

Unmanaged waste disposal sites

The method used to estimate CH_4 emissions from dewatered and dried sludge from wastewater treatment plants has been adopted from CDM methodology[43]. The formula can be found below.

$$BE_{CH_4,SWDS,Y} = \phi \times (1-f) \times GWP_{CH_4} \times (1-OX) \times \frac{16}{12} \times F \times DOC_f \times MCF \times \sum_{x=1}^{y} W_x \times DOC \times e^{-k(y-x)} \times (1-e^{-k})$$

Where
ϕ uncertainty factor
f Fraction of methane captured at the Solid Waste Disposal Site (SWDS) and flared, combusted or used in another manner
OX oxidation factor
F Fraction of methane in the SWDS gas (volume fraction)
DOC_f Fraction of degradable organic carbon (DOC) that can decompose
MCF Methane Correction Factor
Wx Total amount of organic waste prevented from disposal in year x (tons)
DOC Degradable Organic Carbon (by weight) %
k Decay constant

7.2.3. Description of any flexibility applied

Flexibility for time series which starts from year 2000 to 2022 as described in Section 1.9. Summary of any flexibility applied had been applied throughout the report.

7.2.4. Uncertainty assessment and time series consistency

There are two main aspects that contribute to the uncertainty in the calculation of CH_4 emissions from SWDS: (i) the uncertainty from the collection of activity data; and the (ii) uncertainty associated with the parameters involved in the calculation of CH_4 emissions.

The uncertainty associated with the mass of disposed dewatered and dried sludge from wastewater treatment processes is assumed to be ±50% due to the high inherent uncertainty from the drying and dewatering.

The uncertainty factors for the parameters used for the calculation of CH_4 emissions are as referenced from 2006 IPCC Guidelines.

Table 158: Uncertainty factors for solid waste disposal

Parameters	Uncertainty factors
Waste composition	±50%
Degradable Organic Carbon (DOC)	±20%
Methane Correction Factor (MCF)	±30%
Fraction of Degradable Organic Carbon Decomposed (DOC_f)	±20%
Fraction of methane in the SWDS gas F	±5%
Decay constant k	±75%

7.2.5. Category-specific QA/QC and verification

The QA/QC process for the sludge weight (for landfill and incineration) is as follows:

- The unladen sludge truck is weighed at the weighbridge at water reclamation plants. The truck is subsequently loaded with sludge and weighed again at the weighbridge. The net weight of the collected sludge is the difference between the laden and unladen weights of the truck.
- Weight tickets are automatically generated based on the net weight of collected sludge. Monthly reports are also submitted by the sludge disposal contractor which includes aggregated sludge weights across the month.
- Weighbridges are calibrated by an Accredited Verifier in accordance to requirements by the Weights and Measure Office, Enterprise Singapore, or calibrated in accordance to Operations and Maintenance manuals to ensure accurate weight measurements.

7.2.6. Category-specific recalculations

With the recategorisation of the CH_4 emissions from managed waste disposal to unmanaged waste disposal, the MCF has been updated from 1.0 to 0.4 as per 2006 IPCC Guidelines, Volume 5, Chapter 3, Table 3.1. With the change in MCF, the CH_4 emissions have decreased from 19.36 kt CO_2 eq to 7.74 kt CO_2 eq in 2018.

7.2.7. Category-specific planned improvements

There is no planned improvement for this category.

[43] Adopted from "Tool to determine methane emissions avoided from disposal of waste at a solid waste disposal site" (Version 04)

7.3.

Biological Treatment of Solid Waste (CRT category 5.B.)

7.3.1. Category description

Table 159: Total GHG emissions from Biological Treatment of Solid Waste (2000 to 2022)

Greenhouse Gas Category	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
	GHG Emissions (kt CO_2 eq)											
5.B.1. Composting	IE, NE	IE, NE	IE, NE	IE, NE	IE, NE	IE, NE	IE, NE	IE, NE	IE, NE	IE, NE	IE, NE	IE, NE
5.B.2. Anaerobic digestion at biogas facilities	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE

Greenhouse Gas Category	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
	GHG Emissions (kt CO_2 eq)										
5.B.1. Composting	IE, NE	IE, NE	IE, NE	IE, NE	IE, NE	IE, NE	IE, NE	IE, NE	IE, NE	IE, NE	IE, NE
5.B.2. Anaerobic digestion at biogas facilities	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE

Notation key:
IE - Included elsewhere, NE - Not estimated

Composting

Composting, an aerobic process, occurs in the landscape of Singapore, mostly from animal manure of livestock farms and has been reported in Manure Management in Section 5.3 of the report. For community composting, since emissions may be occurring and data for this activity is not collected, "NE" is applied from 2000 to 2022. CH_4 is mainly formed in the anaerobic part of the compost while N_2O is also produced from composting.

Anaerobic digestion at biogas facilities

Apart from anaerobic digestion at sludge digestors in the water reclamation plants, which is reported in Section 7.5 Wastewater treatment and discharge, methane recovery from anaerobic digestion is also used by farms to convert the biogas into electricity. For the non-energy recovery of the biogas from the anaerobic digestion facilities, the emissions would be reported in Section 5.3., 3.B. Manure management instead of this section to avoid double counting.

7.3.2. Methodological issues

For CH_4 and N_2O emissions from composting, refer to Section 5.3., 3.B. Manure management in the report. For CH_4 emissions from anaerobic digestion at sludge digesters in both water reclamation plants and farms, as the biogas has been used to produce electricity and heat, there is no CH_4 emitted. Notwithstanding, the biogenic CO_2 emissions has been reported under Section 3.2.4., 1.A.1 Energy Industries.

7.3.3. Description of any flexibility applied

Flexibility for time series which starts from year 2000 to 2022 as described in Section 1.9. Summary of any flexibility applied had been applied throughout the report.

7.3.4. Uncertainty assessment and time series consistency

Uncertainty assessment is not performed for this subcategory as the GHG emissions are included and reported under other subcategories.

7.3.5. Category-specific QA/QC and verification

As the activities in this category are reported elsewhere, please refer to the relevant sections on QA/QC and verification.

7.3.6. Category-specific recalculations

There is no recalculation for this category.

7.3.7. Category-specific planned improvements

There is no planned improvement for this category.

7.4.

Incineration and open burning of waste (CRT category 5.C.)

7.4.1. Category description

Figure 44: Total GHG emissions from TIW incineration (2000 to 2022)

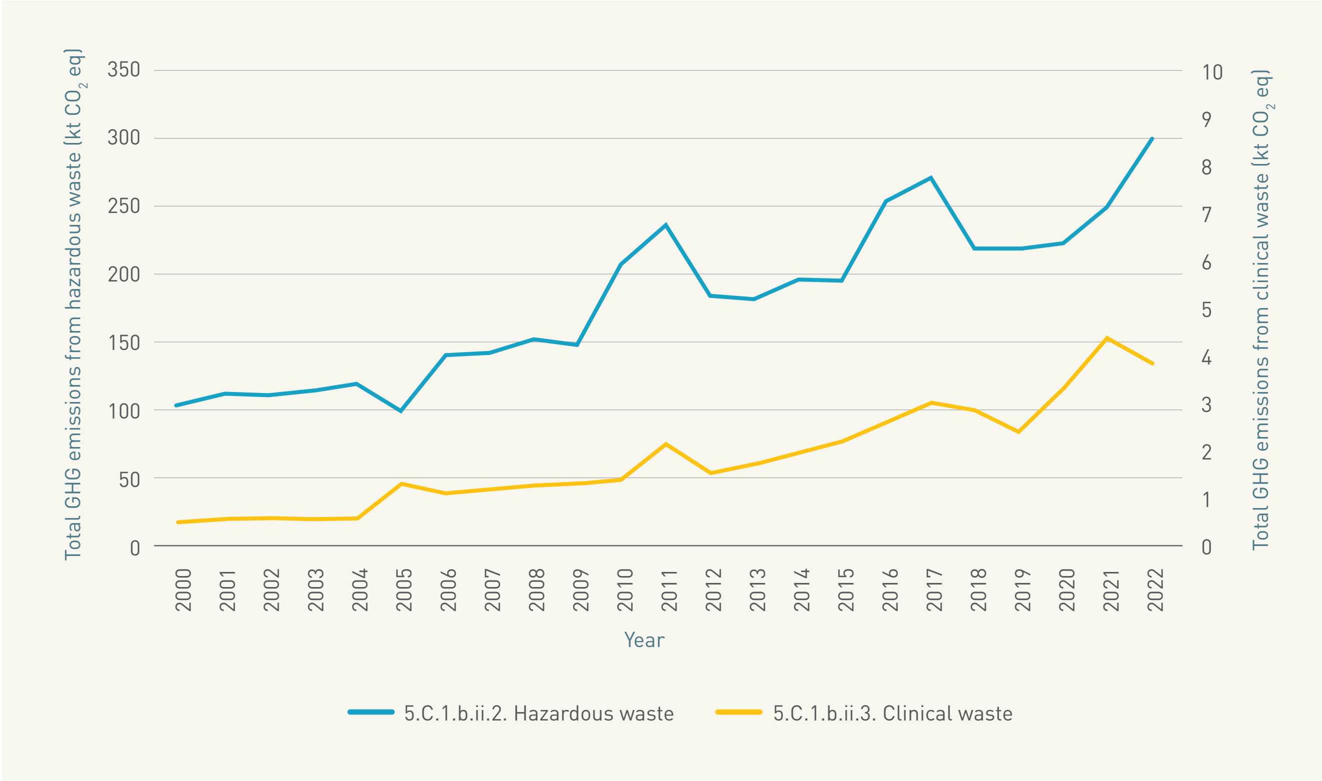


Table 160: Total GHG emissions from TIW incineration (2000 to 2022)

Greenhouse Gas Category	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
	GHG Emissions (kt CO_2 eq)											
Waste Incineration	104.69	112.86	111.84	115.6	120.19	101.55	141.78	143.92	152.68	150.45	208.50	238.80
5.C.1.a.i. Municipal solid waste	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5.C.1.b.ii.1. Industrial solid wastes	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5.C.1.b.ii.2. Hazardous waste	104.19	112.30	111.26	115.05	119.62	100.27	140.67	142.73	151.42	149.11	207.11	236.67
5.C.1.b.ii.3. Clinical waste	0.50	0.56	0.58	0.55	0.57	1.28	1.10	1.19	1.27	1.33	1.39	2.13
5.C.1.b.ii.4. Sewage sludge	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5.C.1.b.ii.5. Fossil liquid waste	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
Open burning of waste	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

Greenhouse Gas Category	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
	GHG Emissions (kt CO_2 eq)										
Waste Incineration	186.26	183.59	198.13	197.97	257.04	275.25	222.08	221.66	226.41	254.52	306.64
5.C.1.a.i. Municipal solid waste	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5.C.1.b.ii.1. Industrial solid wastes	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5.C.1.b.ii.2. Hazardous waste	184.74	181.88	196.18	195.79	254.44	272.23	219.22	219.26	223.10	250.12	302.70
5.C.1.b.ii.3. Clinical waste	1.52	1.71	1.95	2.19	2.59	3.02	2.86	2.40	3.31	4.40	3.93
5.C.1.b.ii.4. Sewage sludge	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5.C.1.b.ii.5. Fossil liquid waste	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
Open burning of waste	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

Notation keys:
NO - Not occurring, IE - Included elsewhere

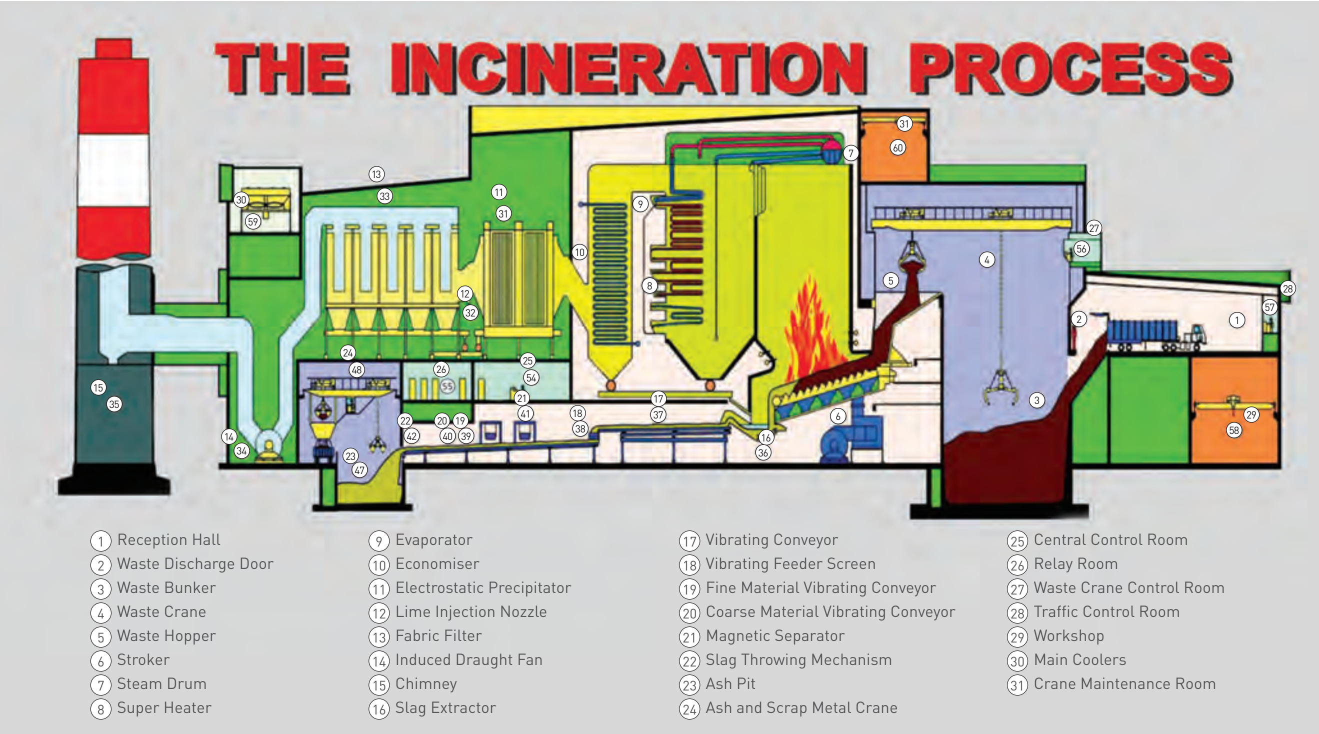
Incineration of Municipal Solid Waste (MSW)

In the 1960s and 1970s, waste was disposed of in landfills. However, in the late 1970s, NEA implemented WtE incineration as a method to reduce waste volume by 90% and minimise the required landfill space. The first WtE plant became operational in 1979. Presently, there are four WtE plants situated at Tuas and Senoko, along with an offshore landfill called Semakau Landfill, which receives non-incinerable waste and incineration ash through the Tuas Marine Transfer Station. Waste collectors are required to possess a waybill indicating the type and source of waste when delivering waste to the four WtE plants and Tuas Marine Transfer Station.

Presently, Singapore's solid waste disposal infrastructure comprises four WtE plants, namely: TuasOne Waste-To-Energy Plant (TWTE), Keppel Seghers Tuas Waste-To-Energy Plant (KSTP), Tuas South Incineration Plant (TSIP), and Senoko Waste-To-Energy Plant (SWTE).

KSTP was constructed under a Design, Build, Own and Operate (DBOO) model and was put into operation in 2009 to replace Singapore's initial WtE plant at Ulu Pandan, which ceased operations in August 2009 after 30 years. The Senoko Incineration Plant was also privatised in September 2009 and has since been renamed Senoko Waste-to-Energy Plant (SWTE). TWTE was similarly developed under a DBOO model and commenced operations in 2021 to replace Singapore's second WtE plant (Tuas Incineration Plant), which was shut down in February 2022 after 36 years of operation.

Figure 45: An illustration of the incineration process of a WtE plant



In a WtE plant, the heat from the combustion generates superheated steam in boilers, and the steam drives turbogenerators to produce electricity. A comprehensive description of the incineration process is described below.

- Waste collection vehicles transport incinerable waste to the WtE plants. The vehicles are weighed on a weighbridge before and after they discharge their loads into large refuse bunkers. This weighing process enables the WtE to keep track of the amount of waste disposed of by each vehicle.
- To prevent odours from escaping into the environment, the air in the refuse bunker is kept below atmospheric pressure.
- The waste from the bunker is fed into the incinerator by a grab crane. As the incinerator is operated at temperatures of between 850 and 1,000 degrees Celsius, a lining of refractory material protects the incinerator walls from the extreme heat and corrosion. After incineration, the waste is reduced to ash which is about 10 per cent of its original volume.
- An efficient flue gas cleaning system comprising electrostatic precipitators, lime powder dosing equipment and catalytic bag filters remove dust and pollutants from the flue gas before it is released into the atmosphere via 100-150m tall chimneys.
- Ferrous scrap metal contained in the ash is recovered and recycled. The ash is sent to the Tuas Marine Transfer Station for disposal at the offshore Semakau Landfill.

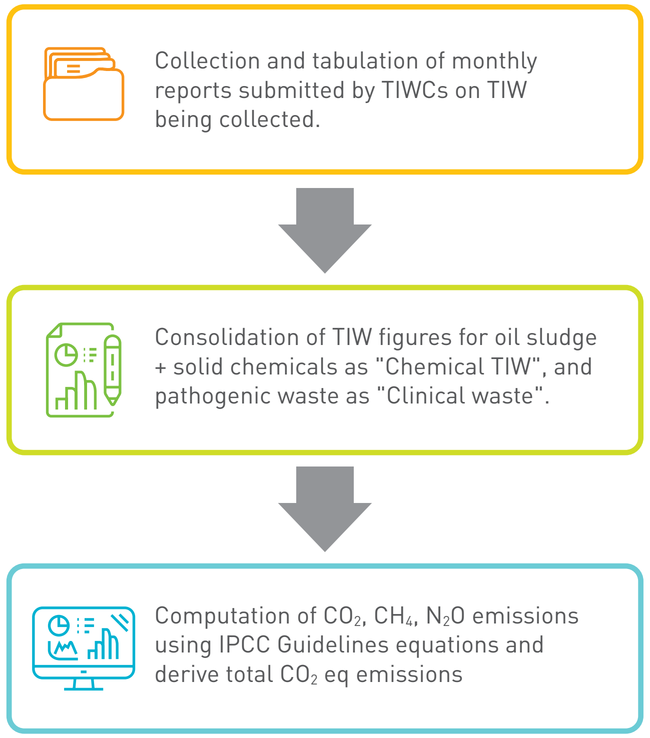
Emissions from MSW incineration have been reported in Chapter 3 Energy sector instead of Chapter 7 Waste sector due to energy recovered from waste incineration.

Incineration of Toxic Industrial Waste (TIW)

The data for the quantities of TIW incinerated are derived from monthly reports of the TIW waste types and quantities submitted by the TIWCs. The submission of TIW monthly reports is a condition stipulated in the Toxic Industrial Waste Collector (TIWC) licence, and is enforceable under the Environmental Public Health Act.

As the reportable figures are broken down by TIW types and not all TIW are treated via incineration, the TIW waste types that are used as the basis for the calculation of GHG from the TIWC sector are (i) oil sludge, (ii) solid chemicals, and (iii) pathogenic wastes. The quantities of items (i) and (ii) are grouped together as "Chemical TIW" and computed using the equation for hazardous waste, whereas item (iii) adopts the equation for "Clinical wastes" in the 2006 IPCC Guidelines. This process is summarised in Figure 46.

Figure 46: Data collection and emission computation of TIW



Incineration of waste such as municipal waste, or TIW or other industrial commercial waste produces emissions of CO_2, CH_4 and N_2O. In particular, some TIWCs incinerate certain TIW streams in Singapore. In this report, an assumption has been applied that only certain TIW streams are primarily treated via incineration, which forms the basis of the incineration quantity. The TIW categories identified, based on the typical waste streams incinerated by the TIWCs, are (i) oil sludge, (ii) solid chemicals, and (iii) pathogenic wastes (which include hazardous and clinical waste). There are currently about 13 TIWCs in Singapore that utilise the incineration process.

The WtE incineration plants and some of the TIW incineration plants in Singapore incinerate its waste to produce steam which drives the steam turbine to produce electricity for their own usage and for sale to the national grid. The GHG emissions from the incineration of waste with energy recovery are included under stationary combustion (refer to Section 3.2.4., 1.A.1. Energy Industries).

From 2000 to 2022 in Figure 44, the emissions from hazardous waste incineration increased from 104 kt CO_2 eq to 303 kt CO_2 eq as GDP increased and emissions from clinical waste incineration increased from 0.5 kt CO_2 eq to 3.93 kt CO_2 eq as population increased.

Opening burning of waste

Open burning of waste is not applicable in Singapore context as opening burning in general is prohibited under the Environmental Public Health (Public Cleansing) Regulation.

7.4.2. Methodological issues

Table 161: Method and emission factor used for emission estimation of waste incineration

Greenhouse Gas Source and Sink Categories	CO_2		CH_4		N_2O	
	Method Applied	Emission Factor	Method Applied	Emission Factor	Method Applied	Emission Factor
5.C.1. Waste incineration	T1, T2a, T3	D, PS	T1	D	T1, T3	D, PS

Notation keys:
T1 - Tier 1, T2a - Tier 2a, T3 - Tier 3, D - IPCC Default, PS - Plant-specific

Under the CPA, the GHG emissions quantification approach for waste incineration with energy recovery is aligned with 2006 IPCC Guidelines.

Incineration of MSW with energy recovery

The municipal waste contains both degradable organic carbon (biogenic) and fossil carbon (non-biogenic). Only CO_2 emissions resulting from incineration of carbon of fossil origin (e.g., plastics, certain textiles, rubber, liquid solvents and waste oil) should be counted towards CO_2 emissions. The CO_2 emissions from combustion of biomass materials (e.g., paper, food, and wood waste) contained in municipal waste are biogenic emissions and should be reported as memo item in the NID.

There is no default CO_2 emission factor as the CO_2 emission factor depends on the different waste components and its fossil carbon fraction. The WtE plants will perform waste sampling to determine the waste composition and the plastic moisture content. The WtE plants have the flexibility to use either 2006 IPCC default for the fossil carbon content and/or dry matter content or waste sampling to determine the dry matter content and fossil carbon content.

The default CH_4 and N_2O emission factors are referenced from the 2006 IPCC Guidelines, Volume 5, page 5.20 and 5.21, based on continuous incineration and stoker technology as it is adopted by the incineration plants in Singapore.

The GHG emissions quantification is based on the following equation derived from Equation 5.2 in 2006 IPCC Guidelines, Volume 5 Waste, Chapter 5 Incineration and Open Burning of Waste.

$$E_g = Q_f \times \sum (EF_{MSW,g} \times GWP_g)$$

Parameter	Parameter Description	Units
E_g	Emissions for GHG (g) i.e. CO_2, CH_4, and N_2O	tonne CO_2 eq
Q_f	Quantity of waste incinerated (on a wet weight basis)	tonne
$EF_{MSW,g}$	Emission factor for non-biogenic CO_2; CH_4 and N_2O	tonne GHG/tonne MSW
GWP_g	Global warming potential for GHG (g)	Nil

Incineration of industrial waste with energy recovery

Industrial waste generally does not contain degradable organic carbon. Hence, the CO_2, CH_4 and N_2O emissions should be counted towards CO_2 emissions.

The GHG emissions quantification is based on the following equation.

CO_2 emissions

$$V_{CO_2} = MV_{CO_2} \times VT$$

Where:

V_{CO_2} is the CO_2 emission flow rate from the incinerator in Nm^3/h

MV_{CO_2} is the measured CO_2 from the CEMS in %

VT is the total flue gas emissions measured at the stack in Nm^3/h

Non-CO_2 emissions

$$E_g = Q_t \times NCV_f \times \sum EF_{f,g} \times GWP_g$$

Where:

E_g is the emissions for GHG (g) for CH_4 and N_2O in tonne CO_2 eq

Q_f is the quantity of waste incinerated in tonne

NCV_f is the net calorific value

$\sum EF_{f,g}$ is the emission factor for CH_4 and N_2O

GWP_g is the global warming potential for GHG (g)

The CO_2 emissions is usually reported using direct measurement approach such as CEMS which measures the flue gas flow and the CO_2 concentration.

CH_4 and N_2O emissions are usually reported using calculation approach where default Tier 1 fuel combustion conversion factors (i.e., CH_4 and N_2O emission factor) for industrial waste are assumed. The Tier 1 default fuel combustion CH_4 and N_2O emission factor is based on Table 2.5 in Chapter 2: Stationary Combustion of 2006 IPCC Guidelines.

Currently, the WtE plants and toxic waste incineration plants in Singapore does not have carbon capture equipment to capture CO_2 at site.

Incineration of MSW

Accurate data on the material composition of waste were not available prior to 2001. Therefore, the data points for 2000 were estimated based on an extrapolation of waste composition data from 2001 onwards. The extrapolated percentages of each waste stream were multiplied by the total amount of waste incinerated in each corresponding year, to obtain the respective waste amounts. GHG emissions were then computed based on the 2006 IPCC Guidelines.

Table 162: CO_2, CH_4 and N_2O emissions from MSW incineration

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Waste Incinerated (kt)	2,440	2,551	2,421	2,311	2,263	2,279	2,329	2,379	2,450	2,480	2,585	2,656

Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Waste Incinerated (kt)	2,736	2,825	2,872	2,879	2,916	2,857	2,936	2,946	2,726	2,917	3,070

For the years 2001 to 2018, waste emission data were determined based on waste sampling conducted at a national level, across all operational incineration plants. From 2019 onwards, incineration plants reported waste emission data under CPA where facilities used plant-specific emission factors to estimate the CO_2 emissions, and IPCC default factors to estimate the CH_4 and N_2O emissions.

Incineration of TIW

GHG emissions from hazardous waste (i.e. oil sludge, solid chemicals and pathogenic waste) incineration are calculated from the total quantity of TIW being incinerated, in accordance with IPCC Good Practice Guidance using the default emission factors provided. The total TIW incinerated is compiled from the total amount of oil sludge, solid chemicals and pathogenic waste collected as these wastes are treated via incineration. Equations for the computation of CO_2, CH_4 and N_2O emissions were taken from the 2006 IPCC Guidelines Volume 5 Waste, Chapter 5 Incineration and Open Burning of Waste as shown below.

i) *Carbon Dioxide Emissions*

CO_2 Emissions based on the total amount of waste combusted

= Total amount of waste incinerated (wet weight) (SW_i) x Dry matter content in waste (wet weight) (dm_i) x Fraction of carbon in dry matter (CF_i) x Fraction of fossil carbon in total carbon (FCF_i) x oxidation factor(OF_i) x conversion factor

$$= \sum_i (SW_i \times dm_i \times CF_i \times FCF_i \times OF_i) \times \frac{44}{12}$$

ii) *Methane Emissions*

CH_4 Emissions estimate based on total amount of waste combusted

= Amount of solid waste incinerated(IW_i) x aggregate CH_4 emission factor (EF_i)

$$= \sum_i (IW_i \times EF_i) \times 10^{-6}$$

iii) *Nitrous Oxide Emission*

N_2O Emissions estimate based on total amount of waste input to the incinerators

= Amount of solid waste incinerated (IW_i) x N_2O emission factor (EF_i) × conversion factor (10^{-6})

$$= \sum_i (IW_i \times EF_i) \times 10^{-6}$$

Only TIW statistics starting from 2005 are available. Hence, to determine the amount of TIW generated from 2000 to 2004, backward projections are required.

GHG emissions are directly proportional to the amount of TIW incinerated based on the equations provided in the 2006 IPCC Guidelines. Hence, the projections can be done on the TIW incineration figures. In order to backward project the amount of TIW generated, NEA utilised Singapore's Total GDP and Total Population as surrogate parameters for both hazardous and clinical waste. Hazardous waste is generated as a result of economic activities, and GDP is an indicator of economic activities. Clinical waste is generated from public healthcare services and is generally related to the total population.

A linear model using Singapore's Total GDP and available hazardous waste data from 2008 to 2017 was used to project the quantity of hazardous waste collected from 2000 to 2004. As wastes from the treatment of infectious diseases have been defined as biohazardous, the quantity of clinical wastes produced will be closely related to the exponential trend in infectious diseases. Hence, an exponential model using Singapore's Total Population and available clinical waste from 2008 to 2017 was used to project the quantity of clinical waste collected from 2000 to 2004. Hazardous and clinical waste data from 2005 to 2007 were omitted in the projection models due to uncertainty in the accuracy of TIW collection data submitted by TIWCs.

GHG Emissions from Hazardous Waste

Table 163: CO_2, CH_4 and N_2O emissions from Hazardous Waste incineration

Year	Chemical TIW (Tonnage)	CO_2 emission (kt CO_2 eq)	CH_4 emission (kt CO_2 eq)	N_2O emission (kt CO_2 eq)	Total Total emissions (kt CO_2 eq)
2000	64,803	107	3.63E-04	0.86	108
2001	69,879	115	3.91E-04	0.93	116
2002	69,224	114	3.88E-04	0.92	115
2003	71,595	118	4.01E-04	0.95	119
2004	74,450	123	4.17E-04	0.99	124
2005	60,284	99	3.38E-04	0.8	100
2006	84,577	140	4.74E-04	1.12	141
2007	85,816	142	4.81E-04	1.14	143
2008	91,036	150	5.10E-04	1.21	151
2009	89,652	148	5.02E-04	1.19	149
2010	124,519	205	6.97E-04	1.65	207
2011	142,292	235	7.97E-04	1.89	237
2012	111,071	183	6.22E-04	1.47	185
2013	109,350	180	6.12E-04	1.45	182
2014	117,949	195	6.61E-04	1.56	196
2015	117,712	194	6.59E-04	1.56	196
2016	152,980	252	8.57E-04	2.03	254
2017	163,673	270	9.17E-04	2.17	272
2018	131,802	217	7.38E-04	1.75	219
2019	131,828	218	7.38E-04	1.75	219
2020	134,132	221	7.51E-04	1.78	223
2021	150,382	248	8.42E-04	1.99	250
2022	181,995	300	1.02E-03	2.41	303

GHG Emissions from Clinical Waste

Table 164: CO_2, CH_4 and N_2O emissions from Clinical Waste incineration

Year	Clinical TIW (Tonnage)	CO_2 emission (kt CO_2 eq)	CH_4 emission (kt CO_2 eq)	N_2O emission (kt CO_2 eq)	Total Total emissions (kt CO_2 eq)
2000	854	0.49	4.78E-06	1.13E-02	0.50
2001	953	0.55	5.34E-06	1.26E-02	0.56
2002	990	0.57	5.54E-06	1.31E-02	0.58
2003	931	0.53	5.22E-06	1.23E-02	0.55
2004	981	0.56	5.49E-06	1.30E-02	0.57
2005	2,183	1.25	1.22E-05	2.89E-02	1.28
2006	1,888	1.08	1.06E-05	2.50E-02	1.10
2007	2,027	1.16	1.14E-05	2.69E-02	1.19
2008	2,162	1.24	1.21E-05	2.86E-02	1.27
2009	2,278	1.30	1.28E-05	3.02E-02	1.33
2010	2,382	1.36	1.33E-05	3.16E-02	1.39
2011	3,642	2.08	2.04E-05	4.83E-02	2.13
2012	2,599	1.49	1.46E-05	3.44E-02	1.52
2013	2,920	1.67	1.64E-05	3.87E-02	1.71
2014	3,338	1.91	1.87E-05	4.42E-02	1.95
2015	3,734	2.14	2.09E-05	4.95E-02	2.19
2016	4,429	2.53	2.48E-05	5.87E-02	2.59
2017	5,159	2.95	2.89E-05	6.84E-02	3.02
2018	4,889	2.80	2.74E-05	6.48E-02	2.86
2019	4,093	2.34	2.29E-05	5.42E-02	2.40
2020	5,658	3.24	3.17E-05	7.50E-02	3.31
2021	7,519	4.30	4.21E-05	9.96E-02	4.40
2022	6,722	3.84	3.76E-05	8.91E-02	3.93

Incineration of used water sludge

From 1985 to 2008, treated wastewater sludge was applied on reclaimed land sites as a soil conditioner. Residual CH_4 emissions were due to anaerobic decay of the sludge organic content from these sites. Since 2009, direct emissions from sewage sludge have been reduced through sludge incineration. Emissions from sludge incineration include CO_2, CH_4 and N_2O and have remained consistent over time. In accordance with the 2006 IPCC Guidelines, CO_2 emissions from sludge incineration are classified as biogenic and not included in the national emissions inventory.

Emissions from sludge incineration are based on Clean Development Mechanism (CDM) methodologies. In 2010, a sludge incineration plant operated by ECO - Special Waste Management (SWM) was registered as a CDM project, and facility-specific emissions were measured as part of the CDM process. From 2012 onwards, the emissions from the incineration of sewage sludge were estimated based on a forward trend extrapolation of measured emissions data from 2010 to 2011.

7.4.3. Description of any flexibility applied

Flexibility for time series which starts from year 2000 to 2022 as described in Section 1.9. Summary of any flexibility applied had been applied throughout the report.

7.4.4. Uncertainty assessment and time series consistency

The level of uncertainty associated with CO_2, CH_4, and N_2O emissions from the incineration is estimated at ±32% based on the default uncertainty factors referenced from the 2006 IPCC Guidelines.

As Singapore's MSW are all incinerated at WtE incineration plants, its corresponding emissions are reported under 1.A.1. Energy Industries.

Only the uncertainty from incineration of TIW is estimated under 5.C.1. Waste Incineration.

Emission factor uncertainties

The emission factor uncertainty is largely related to the uncertainty in waste composition. The main cause of uncertainty with CO_2 emission factors for incineration of waste lies in the separation of biogenic and fossil carbon fractions in the waste and the uncertainty in waste composition. With frequent waste composition analysis conducted in Singapore's incineration facilities, the uncertainty due to this parameter is kept low.

N_2O and CH_4 emission figures are calculated using default IPCC emission factors and the mass of TIW incinerated.

Activity data uncertainties

The uncertainty from activity data depends on the frequency of measurement of the weight of waste to be incinerated. In Singapore's context, the uncertainty from this parameter is kept relatively low at ± 5%.

The conversion of waste amounts from wet weight to dry weight adds additional uncertainty. Depending on the frequency and the accuracy of the dry weight determination, this uncertainty varies substantially. Periodic laboratory tests are conducted to check on the accuracy of the dry weight determination, which keeps the uncertainty of dry matter content at ± 10% as referenced from the 2006 IPCC Guidelines.

The table below indicates the uncertainty factors used for uncertainty calculations for this category.

Table 165:Uncertainty factors used for TIW incineration uncertainty estimation for base year and reporting year

Uncertainty	Uncertainty Parameters		
Activity Data	Mass of waste	Dry matter content	
	±5%	±10%	
Emission factor	CO_2	CH_4	N_2O
	±5%	±100%	±100%

Time series consistency

As mentioned in Section 7.4.1, the data for the quantities of TIW incinerated are obtained from the monthly returns submitted by the TIWC as part of its TIWC licensing condition. Forward and/or backward projections were applied for periods where TIW data were not available (e.g. before 2005). The surrogate parameters used for hazardous and clinical wastes are Singapore's Total GDP and Total Population respectively.

7.4.5. Category-specific QA/QC and verification

NEA requires TIWCs to submit monthly reports of the hazardous waste types and quantities collected as one of the licensing conditions in the TIWC Licences issued by NEA. The quantities of incinerable hazardous waste collected and disposed of are used to compute the GHG produced from the incineration process using 2006 IPCC Guidelines. NEA carries out routine inspections on TIWC facilities for the management of TIW and pollution control, and also ensures proper record management by the TIWCs on the collection, treatment and disposal of the TIW.

7.4.6. Category-specific recalculations

No recalculations were applied for the calculation of GHG emissions from the TIWCs.

7.4.7. Category-specific planned improvements

A flow map describing the solid waste management system in Singapore could be developed to better illustrate the movement of the different types of waste in Singapore. To enhance data accuracy, a comprehensive analysis of the existing waste data is recommended which could help to facilitate separate reporting of GHG emissions from TIWC facilities with energy recovery in the future.

As energy consumption data from the incineration of used water sludge are not available for all years, we will study the possibility of quantifying the energy consumption data in future submissions.

7.5.

Wastewater treatment and discharge (CRT category 5.D.)

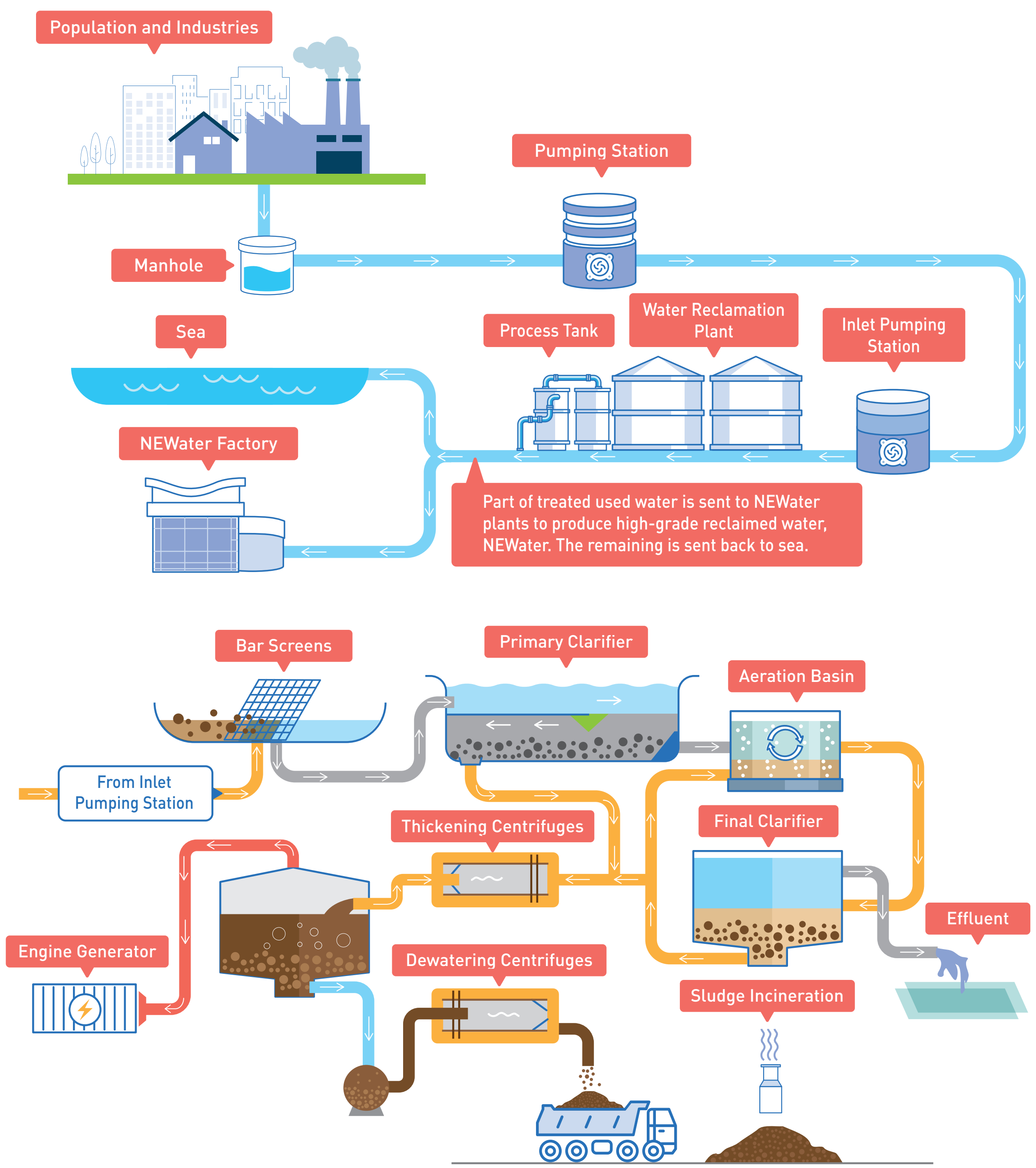
7.5.1. Category description

Singapore has achieved 100% access to modern sanitation. Used water from domestic and non-domestic sources are channelled through a combination of underground link sewers (by pumping) and Deep Tunnel Sewerage System (DTSS) (by gravity) for treatment at four water reclamation plants. Wastewater treatment involves the removal of organics, measured as biochemical oxygen demand or BOD_5 and nutrients.

Water reclamation encompasses several technologies, often classified by the degree of solids removal, reduction in organic matter content and nutrient removal. The treatment level can be classified as primary (e.g., solids removal via physical process), secondary (e.g., reduction in organic matter content and some nutrient removal via biological and physical processes) and tertiary (e.g., nutrient removal via chemical process). Water reclamation plants In Singapore primarily utilise primary and secondary treatment processes.

The solid by-product of used water treatment (i.e. used water sludge) undergoes anaerobic digestion at sludge digesters to produce biogas, which contains 60 - 70% methane. The biogas is sent to biogas engines and/or utilised in sludge dryers to produce electricity and heat respectively. Excess biogas, if any, is flared.

Figure 47: Singapore's water reclamation process



There is an increase in N_2O emissions from 44 kt CO_2 eq to 76 kt CO_2 eq from year 2000 to 2022. The increase in emissions over time is likely due to population growth and an increase in average per capita protein intake (based on UNFAO statistics).

Figure 48: Total GHG emissions from wastewater treatment and discharge (2000 to 2022)

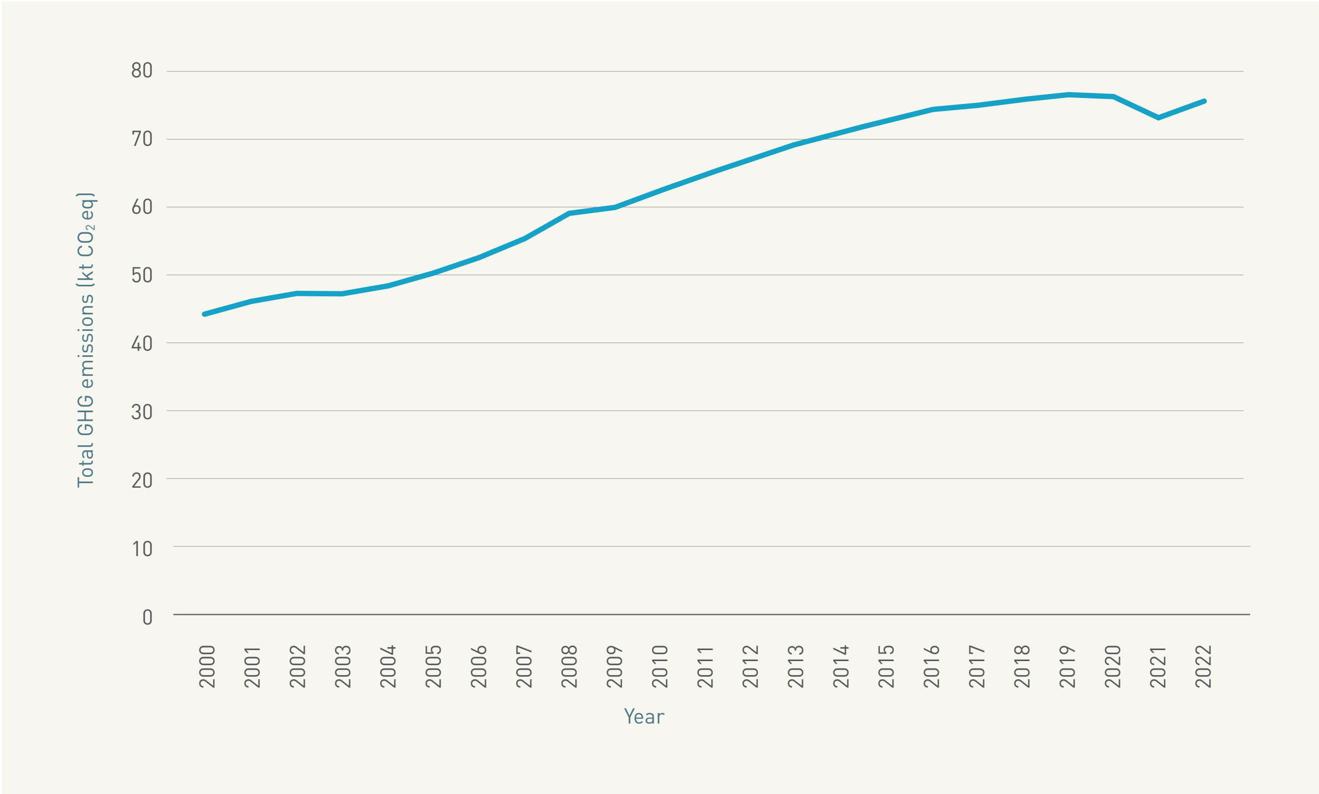


Table 166: Total GHG emissions from wastewater treatment and discharge (2000 to 2022)

Greenhouse Gas Category	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
	GHG Emissions (kt CO_2 eq)											
Domestic wastewater	44.23	46.24	47.33	47.27	48.41	50.28	52.60	55.33	59.01	60.07	62.44	64.83
Industrial wastewater	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE

Greenhouse Gas Category	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
	GHG Emissions (kt CO_2 eq)										
Domestic wastewater	67.10	69.29	71.07	72.89	74.38	75.01	75.78	76.65	76.41	73.29	75.75
Industrial wastewater	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE

Notation key:
IE - Included elsewhere

7.5.2. Methodological issues

Table 167: Method and emission factor used for emission estimation of wastewater treatment and discharge

Greenhouse Gas Source and Sink Categories	CO_2		CH_4		N_2O	
	Method Applied	Emission Factor	Method Applied	Emission Factor	Method Applied	Emission Factor
5.D. Wastewater treatment and discharge	NA	NA	NO	NO	T1	D

Notation keys:
T1 - Tier 1, D - IPCC Default, NO - Not occurring, NA - Not applicable

Wastewater treatment at Singapore's water reclamation plants through the nitrification and denitrification processes generates N_2O emissions. N_2O emissions are also produced from the discharge of treated effluent to the sea.

- The N_2O emissions generated from used water treatment are based on IPCC 2006 Guidelines - Equation 6.9 (Centralised wastewater treatment processes). The degree of utilisation of modern, water reclamation plants is 100%, and default IPCC 2006 values for fraction of Industrial and commercial co-discharged protein and emission factors for N_2O/person/year is assumed.
- The N_2O emissions generated from the discharge of treated used water effluent to sea are based on IPCC 2006 Guidelines - Equations 6.7 and 6.8 (N_2O emissions from wastewater effluent and total nitrogen in the effluent). UNFAO per-capita protein consumption statistics in South-East Asia are used to estimate Singapore's per-capita protein consumption. The values of other parameters are based on default IPCC 2006 values.

CH_4 emissions are not estimated. As Singapore's sewer network is closed and underground, it is not a source of CH_4 (or N_2O emissions) as per IPCC 2006 guidelines. Singapore's water reclamation plants primarily adopt a combination of aerobic and anoxic treatment systems, which produce limited to no CH_4 as per IPCC 2006 Guidelines. CH_4 produced from the anaerobic digestion of used water sludge is also recovered as electricity, heat or flared (see Section 7.3.2).

EQUATION 6.7
N_2O EMISSIONS FROM WASTEWATER EFFLUENT

$$N_2O\ Emissions = N_{EFFLUENT} \times EF_{EFFLUENT} \times 44/28$$

Where:

N_2O emissions = N_2O emissions in inventory year, kg N_2O/yr
$N_{EFFLUENT}$ = Nitrogen in the effluent discharged to aquatic environments, kg N/yr
$EF_{EFFLUENT}$ = Emission factor for N_2O emissions from discharged to wastewater, kg N_2O-N/kg N
The factor 44/28 is the conversion of kg N_2O-N into kg N_2O

EQUATION 6.8
TOTAL NITROGEN IN THE EFFLUENT

$$N_{EFFLUENT} = (P \times Protein \times F_{NPR} \times F_{NON\text{-}CON} \times F_{IND\text{-}COM}) - N_{SLUDGE}$$

Where:

$N_{EFFLUENT}$ = Total annual amount of nitrogen in the wastewater effluent, kg N/yr
P = Human population
Protein = Annual per capita protein consumption, kg/person/yr
F_{NPR} = Fraction of nitrogen in protein, default = 0.16, kg N/kg protein
$F_{NON\text{-}CON}$ = Factor for non-consumed protein added to the wastewater
$F_{IND\text{-}COM}$ = Factor for industrial and commercial co-discharged protein into the sewer system
N_{SLUDGE} = Nitrogen removed with sludge (default = zero), kg N/yr

EQUATION 6.9
N_2O EMISSIONS FROM
CENTRALISED WASTEWATER TREATMENT PROCESS

$$N_2O_{PLANTS} = P \times T_{PLANT} \times F_{IND\text{-}COM} \times EF_{PLANT}$$

Where:

N_2O_{PLANTS} = Total N_2O emissions from plants in inventory year, kg N_2O/yr
P = Human population
T_{PLANT} = Degree of utilisation of modern, centralised WWT plants, %
$F_{IND\text{-}COM}$ = Fraction of industrial and commercial co-discharged protein (default = 1.25, based on data in Metcalf & Eddy (2003) and expert judgement)
EF_{PLANT} = Emission factor, 3.2 g N_2O/person/year

Note: When a country chooses to include N_2O emissions from plants, the amount of nitrogen associated with these emissions (N_{WWT}) must be back calculated and subtracted from the $N_{EFFLUENT}$. The N_{WWT} can be calculated by multiplying N_2O_{PLANTS} by 28/44, using the molecular weights.

7.5.3. Description of any flexibility applied

Flexibility for time series which starts from year 2000 to 2022 as described in Section 1.9. Summary of any flexibility applied had been applied throughout the report.

7.5.4. Uncertainty assessment and time series consistency

The uncertainty for 5.D.1 Wastewater is estimated to be ±35% for N_2O.

The calculation of uncertainty associated with wastewater treatment is dependent on a few factors as can be seen from the formula above used to calculate N_2O emissions from wastewater effluent and centralised wastewater treatment process.

Table 168: Uncertainty parameters used for N_2O emissions from wastewater effluent

Emission factor Parameter	$Ef_{effluent}$				
Uncertainty values	±4900%				
Activity data uncertainty parameter	P	Protein	F_{NPR}	$F_{non\text{-}con}$	$F_{Ind\text{-}com}$
Uncertainty values	±10%	±10%	±7%	±36%	±20%
Combined AD uncertainty	±44%				

Table 169: Uncertainty parameters used for N_2O emissions from centralised wastewater treatment process

Emission factor Parameter	Ef_{plants}		
Uncertainty values	±150%		
Activity data uncertainty parameter	P	Tplant	FInd-com
Uncertainty values	±10%	±20%	±25%
Combined AD uncertainty	±30%		

The level of uncertainty with N_2O emissions from discharge of treated wastewater effluent is ±4,900%. The high degree of uncertainty associated with this emission stream is associated with the large range of N_2O emission factors as seen in the 2006 IPCC Guidelines (i.e. 0.00005 - 0.25 with default value of 0.005).

Although the uncertainty associated with N_2O emission factor is high, the magnitude of N_2O emissions from domestic wastewater treatment is relatively low. Therefore, the impact on the overall uncertainty of the national GHG inventory is minimal. Furthermore, the uncertainty factor is calculated from the 2006 IPCC Guidelines, so it is a conservative estimation of the uncertainty arising from the emission factor of N_2O from domestic wastewater treatment.

7.5.5. Category-specific QA/QC and verification

Compliant with QA/QC plan and implementation as outlined in Chapter 1, Section 1.5.

7.5.6. Category-specific recalculations

The reporting of N_2O emissions from plants had been incorporated into this NID. Hence, in 2018, the N_2O emissions had increased from 70.19 kt CO_2 eq as reported in the fifth BUR to 75.78 kt CO_2 eq for the same year.

7.5.7. Category-specific planned improvements

There is no planned improvement for this category.

Chapter 8

RECALCULATIONS AND IMPROVEMENTS

8.1.

Explanations and justifications for recalculations, including in response to the review process

Recalculations were conducted due to (i) methodological changes such as the development of new and different data sets and (ii) methodological refinement where the same tier was used to estimate emissions, but different level of aggregation was applied.

Both methodological changes and refinements arose mainly from different review processes such as from the international consultation and analysis (ICA) process when BURs were submitted previously, QA workshop conducted by UNFCCC Secretariat and the ongoing QA/QC process of the national GHG inventory. Some of the changes or refinements can be found below:

i. Data availability: With new regulations being progressively implemented, data will be available over time and hence the changes in available data may lead to changes or refinements in the method used.

ii. Key category: KCA enables a country to identify emission streams with higher emissions, hence country can prioritise efforts to improve overall estimates.

iii. Consistency with IPCC Guidelines: Continual efforts to align with IPCC Guidelines were made to ensure consistency with the IPCC Guidelines.

iv. QA/QC procedures: Error may be identified during the QA/QC process, thus for time series consistency, changes and refinement to the inventory may be required.

8.2.

Implications for emission and removal levels

The comparison between the current and previous inventory was made with reference to the 2018 inventory as it was the latest submission of Singapore's national GHG inventory under the fifth BUR. Comparing the 2018 total GHG emissions reported in the fifth BUR and first BTR, the total GHG emissions increased by 6.6%, that is 3,530 Gg CO_2 eq. The overall impact on the time series for total GHG emissions from 2000 to 2018 can be found in Table 170. The main reason that resulted in the 6.6% increase in the national totals was due to the improvement in the estimation methodologies and data availability in the IPPU sector, particularly the RAC sector which had been explained in Section 4.7, 2.F. Product uses as substitutes for ODS. The implication for emissions and removals by sector can also be found in the next section.

Figure 49: Summary of Recalculations in 2024

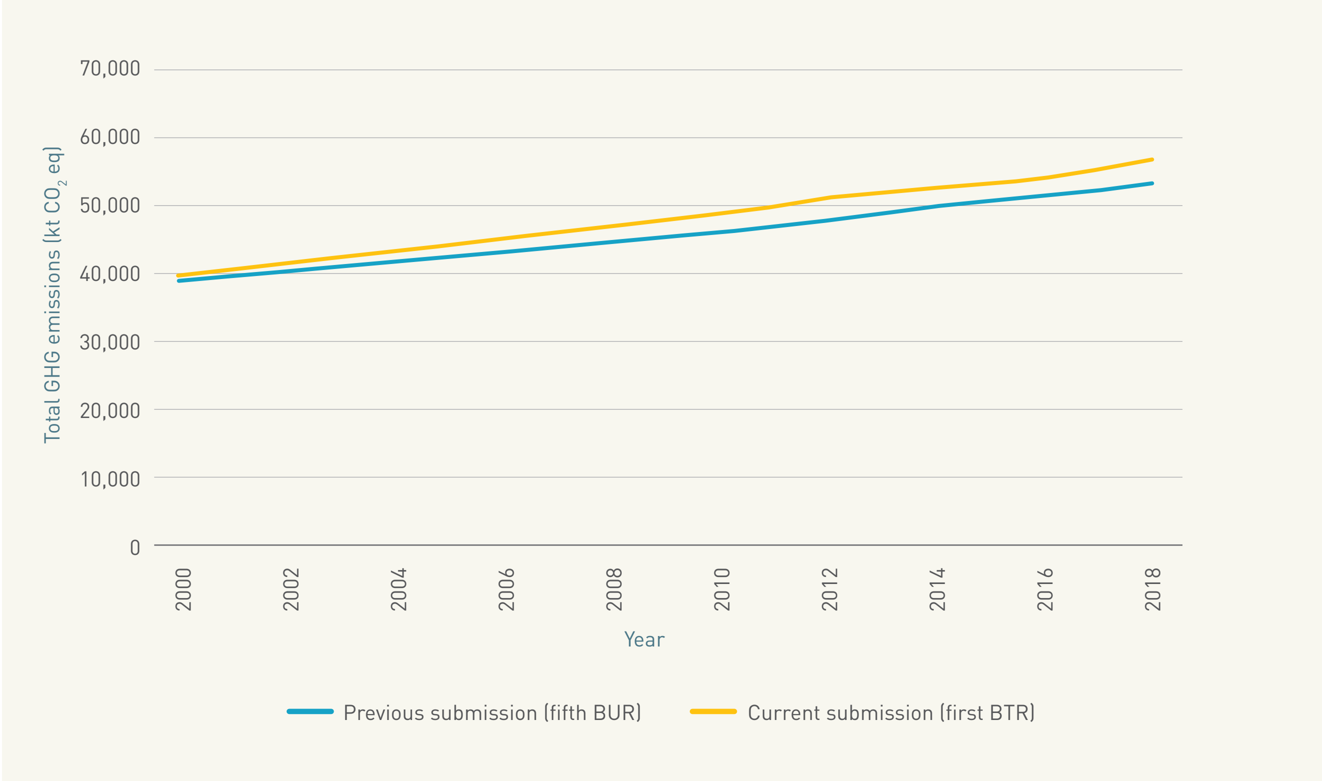


Table 170: Summary of Recalculations in 2024

National Total	Total emissions (Gg CO_2 eq)						Trend
	2000	2010	2012	2014	2016	2018	2000 - 2018
Previous submission (fifth BUR)	38,987	46,166	47,932	49,973	51,531	53,313	37%
Current submission (first BTR)	39,695	48,896	51,260	52,611	54,143	56,843	43%
Change in total emissions	708	2,730	3,328	2,638	2,612	3,530	
	2%	6%	7%	5%	5%	7%	

8.3.

Implications for emission and removal trends, including time series consistency

The table below reflects the changes made to the emission trends for each sector from 2000 to 2018 due to the improvements and recalculations as indicated in each section of the relevant chapters. The sector that reflects the highest absolute difference in 2018 was the IPPU sector with a difference of approximately 3 Mt CO_2 eq increase (99.6% increase) in total emissions, this is followed by the energy sector with an increase of 640 Gg CO_2 eq (1.28% increase), AFOLU sector with a decrease of 103 Gg CO_2 eq (85% decrease) and waste sector with a slight decrease of 6 Gg CO_2 eq (2% decrease).

Table 171: Summary of Recalculations in 2024

Energy	Total emissions (Gg CO_2 eq)						Trend
	2000	2010	2012	2014	2016	2018	2000 - 2018
Previous submission (fifth BUR)	37,934	44,425	46,089	47,280	48,849	49,868	31%
Current submission (first BTR)	38,273	45,640	47,514	48,154	49,435	50,507	32%
Change in total emissions	339	1,215	1,425	874	585	640	
	1%	3%	3%	2%	1%	1%	

IPPU	Total emissions (Gg CO_2 eq)						Trend
	2000	2010	2012	2014	2016	2018	2000 - 2018
Previous submission (fifth BUR)	687	1,375	1,522	2,298	2,292	3,013	339%
Current submission (first BTR)	1,199	3,004	3,524	4,149	4,394	6,013	401%
Change in total emissions	513	1,629	2,002	1,850	2,102	2,999	
	75%	119%	132%	81%	92%	100%	

AFOLU	Total emissions (Gg CO_2 eq)						Trend
	2000	2010	2012	2014	2016	2018	2000 - 2018
Previous submission (fifth BUR)	60	4	11	94	41	120	100%
Current submission (first BTR)	9	-57	-55	24	-27	18	97%
Change in total emissions	-51	-60	-66	-70	-67	-103	
	-85%	-1,655%	-600%	-74%	-165%	-85%	

Waste	Total emissions (Gg CO_2 eq)						Trend
	2000	2010	2012	2014	2016	2018	2000 - 2018
Previous submission (fifth BUR)	306	362	310	301	349	312	2%
Current submission (first BTR)	214	309	278	284	341	306	43%
Change in total emissions	-93	-53	-33	-17	-9	-6	
	-30%	-15%	-11%	-6%	-2%	-2%	

Energy sector

The increase in emissions in the time series was mainly due to the new dataset obtained from legislation from 2019 to 2022. With the new data available, backward projection was conducted to ensure time series consistency. Further details of recalculations in the Energy sector can be found in the following Section 3.2.5.6., 3.2.8.6. and 3.3.2.6.

IPPU sector

The significant increase in emissions from IPPU sector is mainly attributed to the inclusion of HFC emissions arising from the development of a Tier 2 emission estimate in Section 4.7, 2.F. Product uses as substitutes for ODS. The HFCs from 2.F. Product uses as substitutes for ODS increased from 376 Gg CO_2 eq to 2,705 Gg CO_2 eq in 2018. The development of the Tier 2 estimates for 2.F. Product uses as substitutes for ODS also includes methodology used for backward projection to ensure time series consistency. Apart from the inclusion of HFC emissions from 2.F. Product uses as substitutes for ODS in IPPU sector, the increase in emissions was also due to the recategorisation of reporting of emissions from flaring and venting for all industries under 1.B.2. Oil, Natural Gas and other emissions from energy production to its relevant category such as chemical industries in the IPPU sector. Further details of recalculations in the IPPU sector can be found in the following Section 4.3.6, 4.6.6, 4.7.6 and 4.9.6.

AFOLU sector

For the LULUCF sector, several recalculations were conducted which led to lower emissions/higher removals across the whole time series. The emission factors for carbon stock changes of biomass in *Forest Land* (4.A.) and *Settlements* (4.E.) were updated based on new field data. This led to higher net removals in the *Settlements* category as the period of carbon accumulation of newly established *Settlements* areas has increased according to the new results. For *Forest Land*, the emission factor for dead wood was updated based on the new field data. In addition, the modelling exercises, which provide the emission factor for mineral soils in remaining *Forest Land* and *Settlements*, have been updated: The new model version of YASSO (YASSO20) was introduced taking into account the updated biomass factors which serve as input to the model. The updated emission factors for the mineral soil pool in remaining *Forest Land* and *Settlements* are now a sink compared to the fifth BUR where they were reported as a source of emission. Regarding activity data, the land-use change areas reported for the year 2018 were updated with the land use change areas from 2017 (extrapolation), as a methodological inconsistency was detected in the 2018 data which needs to be further investigated and corrected. The same land use change data of 2017 were used to extrapolate the time series until 2022 when more recent data becomes available. The area of rooftop greenery in the *Settlements* category was updated based on new information available, which allowed for the distinguishing of extensive and intensive rooftop greenery. All updates and changes were applied to the whole time series 2000-2022.

Waste sector

The slight decrease in emissions from waste sector was primarily due to the correct categorisation of the solid waste disposal site from managed waste disposal to unmanaged waste disposal. As such, the MCF has also been updated from 1.0 to 0.4 as per 2006 IPCC Guidelines resulting in a drop in emissions from 19.36 Gg CO_2 eq to 7.74 Gg CO_2 eq in 2018. Further details of recalculations in the Waste sector can be found in Section 7.2.6. and 7.5.6.

8.4.

Areas of improvement and/or capacity-building in response to the review process

Singapore recognises the importance of a continuous improvement of its inventory over time, whether it is to identify or regularly update, and includes information on areas of improvement as part of its BTR. Improvements to the inventory generally resulted from recommendations from:

(i) team of technical experts (TTE) for the BURs and in future, the TER team of the BTRs;

(ii) Continuous improvements through activities such as consultative studies, QA workshop, peer reviews, QA/QC and verification activities (in accordance with the QA/QC Plan) etc.

Recommendations from TTE

Singapore has been actively participating in the ICA process from the first BUR to its fifth BUR which is conducted by a TTE in accordance with the modalities and procedures contained in the annex to decision 20/CP.19. Based on the TTE's recommendations laid out in the Technical Analysis Summary Report (TASR), the recommendations would be included in the NIIP where data owners will identify potential improvements for the current or subsequent BTRs. Detailed outcomes from the recommendations from TTE can be found in Table 172.

Continuous improvement

The 2006 IPCC Guidelines had been constantly referred to identify new emission streams and to improve the tier, particularly for emissions stream that has been identified as a key category.

As 2006 IPCC Guidelines had been agreed upon by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement (CMA) for inventory reporting, this inventory is heavily guided by the 2006 IPCC Guidelines for any improvement made until any subsequent version or refinement of the IPCC guidelines has been agreed upon.

To constantly improve the national inventory, Singapore also participated in training and capacity-building programs to identify areas of improvement. The GHG inventory team and the relevant government agencies that were involved in the inventory work in 2023 had engaged the UNFCCC Secretariat to conduct an in-country QA workshop to review the national GHG inventory. Detailed outcomes from the recommendations from the consultants engaged by the UNFCCC Secretariat can be found in Table 172.

Table 172: Improvements to Singapore's NID 2024

Sector	Category	Description	Improvement made	Relevant section in NID	Source of improvement
-	Institutional arrangement	Assess carefully all potential data and information providers that could have a role in the development of the GHGI and include all relevant government agencies in the inventory process cycle.	With changes to the data owners for the reporting of some emission streams, we have updated to include relevant government agencies in the inventory process.	Chapter 1, Section1.3.	QA workshop (2023)
-	Quality Assurance and Quality Control (QA/QC)	Report on the QA (certification process) realised by the verification/certification process of emissions and AD reported by facilities under CPA.	Included external verification company's QA process on CPA taxable facilities.	Chapter 1, Section 1.5.	QA workshop (2023)
-	Archiving System	Report on the archiving system adopted for the national GHG inventory in Singapore.	Updated to include email archival and how documents are timestamped.	Chapter 1, Section 1.2.3.	QA workshop (2023)
-	Transparency, Accuracy, Consistency, Completeness and Comparability (TACCC) Principles	Report in detail how gap-filling is done in accordance with the 2006 IPCC Guidelines (Volume 1, Chapter 2 and 5).	Gap-filling exercise, done through backward projection of data for some subcategories had been conducted and documented in the relevant sections of the NID.	Chapter 3 to 7	QA workshop (2023)
Energy	1.A.1. Energy Industries	Report in the NID on the sources of the EF used, either default from IPCC, API, or PS from facilities and on the methodology used to generate EF in cases where EF is provided by the facility.	Information on the sources of EF whether it is from IPCC, API or PS has been included in each relevant section of the NID.	Chapter 3	QA workshop (2023)
Energy	1.A.1. Energy Industries	Use notation key correctly to highlight the context of Singapore for each source.	Notation key for each category has been reviewed and updated.	Chapter 3	QA workshop (2023)
Energy	1.A.1. Energy Industries	Provide the description in the NID on the methodology used by the facilities to report on emission under the CPA in the EDMA system.	Description of the methodology used by facilities in the emissions stream under energy sector has been included in the NID.	Chapter 3	QA workshop (2023)
Energy	1.A.1. Energy Industries	Report on the methodology of estimating emission from waste fraction of fossil material used to generate energy.	Description of the methodology used to estimate emissions from waste fraction of fossil material for energy recovery has been included in the NID.	Chapter 7, Section 7.4.2.	QA workshop (2023)
Energy	1.A.2. Manufacturing Industries and Construction	Use notation key "IE" where appropriate for off-road vehicles aggregated with mobile vehicles.	Notation key "IE" has been included for off-road vehicles which was aggregated with other mobile vehicles.	Chapter 3, Section 3.2.6.1.	QA workshop (2023)
Energy	1.A.2. Manufacturing Industries and Construction	Report clearly on EFs used and document their corresponding sources.	The report of EF used in 1.A.2 Manufacturing Industries and Construction had been included in the NID.	Chapter 3, Section 3.2.7.2.	QA workshop (2023)
Energy	1.A.2. Manufacturing Industries and Construction	Report on how consistency is ensured through the certification report of emissions reported by facilities under the CPA by external auditors and accredited certifiers.	Consistency is ensured through the submission of an electronic ER, MP and through the provision of "Greenhouse Gas (GHG) Emissions Measurement and Reporting Guidelines" where the reporting requirements under the CPA can be followed across all facilities regulated under the Act.	Chapter 3, Section 3.2.5.1.	QA workshop (2023)
Energy	1.A.3. Transport	Report on the reasons why Tier 1 is used for key category sources.	The reason for the use of Tier 1 for key category was explained in the methodological issues section.	Chapter 3, Section 3.2.6.2.	QA workshop (2023)
Energy	1.A.3. Transport	Report if emission from military aviation is estimated or not and use notation key "C" if AD is confidential.	Emissions from military aviation were estimated from 2020 to 2022 but notation key "IE" had been used since data are aggregated with other emissions under the same category.	Chapter 3, Section 3.2.8.	QA workshop (2023)
Energy	1.A.3. Transport	Describe the natural gas pipeline transport operated in Singapore.	Emissions from military aviation were estimated from 2020 to 2022 but the notation key "IE" had been used since data are aggregated with other emissions under the same category.	Chapter 3, Section 3.2.8.	QA workshop (2023)
Energy	1.A.4. Other Sectors	Use notation key "IE" in 1.A.4.c. for transparency.	Notation key "IE" has been indicated in 1.A.4.c.	Chapter 3, Section 3.2.7.1.	QA workshop (2023)
Energy	1.B.2. Oil and Natural Gas	Assess and describe all potential fugitive sources occurring in Singapore.	The potential fugitive sources had been provided in the section with an overview of a process diagram.	Chapter 3, Section 3.3.2.	QA workshop (2023)
Energy	1.B.2. Oil and Natural Gas	Report on the range of EF values applied by the companies using default EF or PS EF.	An overview of EF applied had been summarised in the section.	Chapter 3, Section 3.3.2.2.	QA workshop (2023)
Energy	1.B.2. Oil and Natural Gas	Describe how the CPA requirements are impacting the GHG emission estimation and reporting in Singapore.	The impact of CPA requirements on emissions from 1.B.2. Oil and Natural Gas had been addressed.	Chapter 3, Section 3.3.2.1.	QA workshop (2023)
Energy	1.B.2. Oil and Natural Gas	Describe how fugitives emissions are compiled as the sum of emissions provided by companies under CPA.	A brief description of the computation of fugitive emissions submitted by companies under CPA was provided.	Chapter 3, Section 3.3.2.1.	QA workshop (2023
Energy	1.B.2. Oil and Natural Gas	Party indicated that it may explore ways to describe operator estimation methods by source category in future submissions.	Estimation methods were provided in the methodological issues section.	Chapter 3, Section 3.3.2.2.	QA workshop (2023
IPPU	General Issues: Completeness and Understanding of Emissions Occurring in the IPPU Sector	Describe all the industrial activities occurring in Singapore with their respective products.	All the industrial activities occurring in Singapore with their respective products had been reported in the respective sections.	Chapter 4	QA workshop (2023)
IPPU	General Issues: Completeness and Understanding of Emissions Occurring in the IPPU Sector	Describe how AD and emissions of all industrial plants under the CPA are reported in the EDMA system and report on the QA/QC procedures applied to the AD and emissions reported by the facilities.	A brief description of how AD and emissions of facilities under CPA and its QA/QC procedures had been included in the NID.	Chapter 4, Section 4.1. paragraph 4	QA workshop (2023)
IPPU	2.B. Chemical Industry	Report on the methodology of reporting under CPA where facilities are reporting separately GHG emissions from fuel combustion and those from industrial processes (non-combustion) in line with 2006 IPCC Guidelines.	A description of the methodology of reporting under CPA on the segregation of GHG emissions for fuel combustion and IPPU had been provided under methodological issues in the IPPU chapter.	Chapter 4	QA workshop (2023)

Sector	Category	Description	Improvement made	Relevant section in NID	Source of improvement
IPPU	2.B. Chemical Industry	Report in the NID on the source of AD and EF used by the facilities to estimate their emissions.	Further details on the source of AD and EF used by facilities to estimate their emissions were provided under methodological issues in the IPPU chapter.	Chapter 4	QA workshop (2023)
IPPU	2.B. Chemical Industry	Report the total emissions from ethylene and ethylene oxide production aggregated under 2.B.8.b. and use "IE" in subcategory 2.B.8.d. to keep confidentiality and enhance transparency.	Currently, both ethylene and ethylene oxide had been aggregated and reported under 2.B.8.g.ii. Other (Petrochemical).	Chapter 4, Section 4.3.	QA workshop (2023)
IPPU	2.E. Electronics Industry	Use the appropriate notation key for 2.E. Electronics industry.	It was noted that there was no methodology in 2006 IPCC Guidelines for the reporting of CO_2, CH_4 and N_2O for 2.E. Electronics industry. Hence, if the method used to estimate CO_2, CH_4 and N_2O emissions was PS, similar to EF where PS was also used, the method applied should be stated as PS instead of NA. Similarly, for PV, PS would also be used for the method applied and EF used for estimation of N_2O.	Chapter 4, Section 4.6.2.	QA workshop (2023)
IPPU	2.E. Electronics Industry	Singapore will consider how to improve the clarity of its reporting of the estimation methods used by operators in their annual reports to the NEA for future submissions.	Emission estimation methods were provided under methodological issues of each section in Chapter 4.	Chapter 4	TASR 2023 (fifth BUR)
IPPU	2.F. Product Uses as Substitutes for Ozone Depleting Substances	Singapore indicated that these new HFC emission estimates are likely to be ready for inclusion in the next submission	The new HFC emission estimates had been incorporated into the NID.	Chapter 4, Section 4.7.	TASR 2023 (fifth BUR)
IPPU	2.F. Product Uses as Substitutes for Ozone Depleting Substances	Generate uncertainty through data processing of the survey results and scale it up as well for the entire FC gas quantity sold yearly.	Implemented Approach 2 to derive the uncertainty of the different FC gases corresponding to the subapplication.	Chapter 4, Section 4.7.4.	QA workshop (2023)
IPPU	2.G. Other Product Manufacture and Use	Estimate the emissions for the entire time series for 2.G. Other product manufacture and use.	The entire time series from year 2000 to 2012 had been estimated using Manufacturing Output In Manufacturing By Industry (Electrical Equipment) obtained from DOS's Singstat Table Builder as the surrogate parameter.	Chapter 4, Section 4.8.2.	QA workshop (2023)
IPPU	2.H. Other 2.H.2. Food and beverages industry	Report on the method used as plant-specific instead of "NA".	As the method used was also PS similar to the PS emission factor, the method applied had been stated as PS instead of NA.	Chapter 4, Section 4.9.2.	QA workshop (2023)

Sector	Category	Description	Improvement made	Relevant section in NID	Source of improvement
Agriculture	Enteric Fermentation: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Assess the appropriateness of the 2006 IPCC default EFs, by comparing the underlying assumptions used for the development of the default IPCC EFs with the national circumstances, and provide relevant information in the NID. Take into account the information on the average milk production for dairy cows to assess the appropriateness of the EF. Revise the emission estimates when necessary.	Switched to the Eastern Europe EF for dairy cows. Adjusted default EF for CH_4 emissions from manure management for dairy cows and other cattle. More detailed explanation in the relevant NID sections.	Chapter 5, Section 5.2.2., 5.2.6. and 5.3.6.	QA workshop (2023)
LULUCF	General Issues: Stratification	Stratify the whole country territory at minimum according to climate, soil, ecological and management as required by the 2006 IPCC GLs before continuing with any further stratification and report detailed information in the NID on the stratification scheme applied.	See detailed description in NID.	Chapter 6, Section 6.1.2.	QA workshop (2023)
LULUCF	General Issues: Stratification	Provide detailed and transparent documentation on the stratification applied (e.g., source of information, appropriateness to national circumstances, background information), and whenever IPCC default EFs and parameters are used, report on the correspondence of the country-specific stratification with the IPCC stratification.	See detailed description in NID.	Chapter 6, Section 6.1.2., 6.3., 6.4.2., 6.5.2., 6.7.2., 6.8.2. and 6.10.2.	QA workshop (2023)
LULUCF	General Issues: Temperature regime	Provide detailed information in the NID on the temperature ranges used in estimating emissions/removals as well as clear references on the source of information for the average annual temperature for the country.	This issue is just relevant for soil modelling. All other LULUCF EF were not derived on basis of meteorological data. Explanation for the used temperature is provided in the NID.	Chapter 6, Section 6.4.2.1.4.	QA workshop (2023)
LULUCF	Land Representation: Completeness	Clarify in the NID that the entire national territory is covered by the inventory and report areas for all six main land-use categories in accordance with the 2006 IPCC guidelines ensuring the completeness (covering the whole national territory for the whole time series), consistency, and accuracy of the land representation.	See detailed description in NID.	Chapter 6, Section 6.1.2.	QA workshop (2023)
LULUCF	Land Representation: Completeness	Address the land reclamation through the use of other land or wetlands category using a specific subcategory (e.g. 'sea reclamation' under 'other wetlands').	Description provided in NID, why category "other" is used for emissions due to land losses to sea and why the final land use category of the land is used for land reclamation (and not the categories "other land" and "wetland").	Chapter 6, Section 6.1.2. and 6.3.1.	QA workshop (2023)
LULUCF	Land Representation: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Report in detail which approach for land representation is implemented following the 2006 IPCC guidelines.	See detailed description in NID.	Chapter 6, Section 6.1.2.	QA workshop (2023)
LULUCF	Land Representation: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Apply approach 3 for land representation following the guidance in the 2006 IPCC guidelines, since the activity data are collected in a way that allows its application.	See detailed description in NID.	Chapter 6, Section 6.1.2	QA workshop (2023)

Sector	Category	Description	Improvement made	Relevant section in NID	Source of improvement
LULUCF	Land Representation: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Report that a single approach is applied for the total country area.	See detailed description in NID.	Chapter 6, Section 6.1.2.	QA workshop (2023)
LULUCF	Land Representation: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Report detailed information on the land-use definitions applied in the inventory, together with their thresholds and how consistency across time series has been ensured.	See detailed description in NID.	Chapter 6, Section 6.2.	QA workshop (2023)
LULUCF	Land Representation: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Report in detail the information provided during the QA with regard to land-use definitions, land monitoring and their application by the data providers, etc.	See detailed description in NID.	Chapter 6, Section 6.2.	QA workshop (2023)
LULUCF	Land Representation: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Apply land-use definitions consistently across time and space.	See detailed description in NID.	Chapter 6, Section 6.2.	QA workshop (2023)
LULUCF	Land Representation: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Amend the land-use definitions as needed for addressing land reclamation (e.g. wetlands or other land, see ID#A.51).	See detailed description in NID.	Chapter 6, Section 6.1.2., 6.3.1.	QA workshop (2023)
LULUCF	Land Representation: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Report on the carbon pool definitions applied in the inventory.	See detailed description in NID.	Chapter 6, Section 6.1.2., 6.3., 6.4.2., 6.5.2., 6.7.2., 6.8.2., 6.10.2.	QA workshop (2023)
LULUCF	Land Representation: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Report detailed information on how consistency in the application of carbon pool definitions across time series has been ensured.	See detailed description in NID.	Chapter 6, Section 6.1.2., 6.3., 6.4.2., 6.5.2., 6.7.2., 6.8.2., 6.10.2.	QA workshop (2023)
LULUCF	Land Representation: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Provide clear information on how the classification system used for land area information corresponds to the IPCC LULUCF categories (i.e., mapping of national land-uses with IPCC land-use categories) and how the country harmonises the data obtained from different data sources, including detailed information on the stratification applied for each main land-use category.	See detailed description in NID.	Chapter 6, Section 6.1.2.	QA workshop (2023)
LULUCF	Land Representation: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Include in the NID explicit information that unmanaged land does not occur in the country and that all land in the country is considered managed land.	See detailed description in NID.	Chapter 6, Section 6.2.	QA workshop (2023)
LULUCF	Land Representation: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Stratify the whole country territory at minimum according to climate, soil, ecological and management as required by the 2006 IPCC GLs before continuing with any further stratification and report detailed information in the NID on the stratification scheme applied.	See detailed description in NID.	Chapter 6, Section 6.1.2.	QA workshop (2023)
LULUCF	Land Representation: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Report detailed information on the stratification used for the country.	See detailed description in NID.	Chapter 6, Section 6.1.2., 6.2.	QA workshop (2023)
LULUCF	Land Representation: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Provide detailed and transparent documentation on the stratification applied (e.g., source of information, appropriateness to national circumstances, background information), and whenever IPCC default EFs and parameters are used, report on the correspondence of the country-specific stratification with the IPCC stratification.	See detailed description in NID.	Chapter 6, Section 6.1.2., 6.2.	QA workshop (2023)
LULUCF	Land Representation: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Report in the NID the total country area and ensure that the total country area is consistent over time (i.e. constant) matching the total national territory. When reporting on how the land representation is developed, including the data sources/ providers and what kind of data each source provides for use for the land-use categories/ subcategories, include detailed information on the assumptions made for land representation, e.g. how land reclamation/submerging is addressed. Address the land reclamation through the use of other land or wetlands category using a specific subcategory (e.g. 'sea reclamation' under 'other wetlands').	Singapore carries out land reclamations. Therefore, the area and national territory of Singapore is not constant over time. This is reflected in the area statistics of the LULUCF inventory. Land reclamation mainly leads to areas of the categories settlement and forest land. The reclaimed land is reported in the final land use category (which is not wetland). All these details are reported in the NID.	Chapter 6, Section 6.1.2., 6.3.1.	QA workshop (2023)
LULUCF	Land Representation: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Report in the inventory the total country area and ensure that it is consistent over time (i.e. constant) matching the total national territory, and equal to the sum of the areas of all reported land-use categories.	See the comment above.	Chapter 6, Section 6.1.2., 6.3.1.	QA workshop (2023)
LULUCF	Land Representation: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Report information explaining any differences identified with other sources of information (e.g. area reported in FAO).	The official area of Singapore is reported in the GHG inventory. See detailed description in NID.	Chapter 6, Section 6.1.2.	QA workshop (2023)
LULUCF	Land Representation: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Make sure that the sum of land-use changes in land-use categories in year X equal to zero.	Singapore carries out land reclamations. Therefore, the area and national territory of Singapore is not constant over time.	Chapter 6, Section 6.1.2.	QA workshop (2023)
LULUCF	Land Representation: Method – Transparency/ documentation	Report in detail in the NID the land-use definitions applied in the inventory and how consistency in their application has been ensured across the time series. Report on the correspondence of national land-use definitions with the definitions provided by the 2006 IPCC Guidelines.	See detailed description in NID.	Chapter 6, Section 6.2.	QA workshop (2023)
LULUCF	Land Representation: Method – Transparency/ documentation	Report in detail the carbon pool definitions applied in the inventory (e.g., 2006 IPCC guidelines definitions) and how consistency in their application has been ensured across the time series.	See detailed description in NID.	Chapter 6, Section 6.1.2.2., 6.4.2., 6.5.2., 6.7.2., 6.8.2., 6.10.2.	QA workshop (2023)
LULUCF	Land Representation: Method – Transparency/ documentation	Provide an explanation If any differences exist between the national carbon pool definitions and the respective in the 2006 IPCC Guidelines.	See detailed description in NID.	Chapter 6, Section 6.1.2.2.	QA workshop (2023)

Sector	Category	Description	Improvement made	Relevant section in NID	Source of improvement
LULUCF	Land Representation: Method – Transparency/ documentation	Report that all land in the country is considered managed land.	See detailed description in NID.	Chapter 6, Section 6.2.	QA workshop (2023)
LULUCF	Land Representation: Method – Transparency/ documentation	Report detailed information on the stratification applied and how raw data, EFs, parameters have been used, especially the correspondence of the country-specific stratification with 2006 IPCC default parameters.	See detailed description in NID.	Chapter 6, Section 6.1.2., 6.3., 6.4.2., 6.5.2., 6.7.2., 6.8.2., 6.10.2.	QA workshop (2023)
LULUCF	Land Representation: Method – Transparency/ documentation	Report on the classification/ monitoring systems, including databases, remote-sensing sources used for land area information.	See detailed description in NID.	Chapter 6, Section 6.1.2.	QA workshop (2023)
LULUCF	Land Representation: Method – Transparency/ documentation	Report how consistency over time and space in land representation has been ensured.	See detailed description in NID.	Chapter 6, Section 6.1.2.	QA workshop (2023)
LULUCF	Land Representation: Method – Transparency/ documentation	Report which approach for land representation has been used in all land-use categories.	See detailed description in NID.	Chapter 6, Section 6.1.2.	QA workshop (2023)
LULUCF	Land Representation: Method – Transparency/ documentation	Report how data from different data sources have been combined for developing the land representation and how consistency, completeness, accuracy, comparability are ensured.	See detailed description in NID.	Chapter 6, Section 6.1.2.	QA workshop (2023)
LULUCF	Forest Land: Completeness	Report all emissions and removals occurring in the country.	See detailed description in NID.	Chapter 6, Section 6.4.1.	QA workshop (2023)
LULUCF	Forest Land: Completeness	Report that biomass burning (controlled or wildfires) does not occur in the country.	See detailed description in NID.	Chapter 6, Section 6.4.3.	QA workshop (2023)
LULUCF	Forest Land: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Report how the forest definition applied in the inventory compares with the forest definition for reporting to FAO, and provide relevant information and explanation on any differences between the two definitions.	See detailed description in NID.	Chapter 6, Section 6.2.1.	QA workshop (2023)
LULUCF	Forest Land: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Report that all land is considered managed land.	See detailed description in NID.	Chapter 6, Section 6.2.	QA workshop (2023)
LULUCF	Forest Land: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Report detailed information for the cases where sampling is used, including information on the sampling design, uncertainties estimation, sampling size and how representativeness is ensured, per land-use subcategory and carbon pool. Note that basic information should be included in the NID and additional information can be provided in a separate document, which can be referenced in the NID.	See detailed description in NID.	Chapter 6, Section 6.4.2.	QA workshop (2023)
LULUCF	Forest Land: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Report how consistency in the time series is ensured with regard to the consistent application of definitions and survey methods throughout time and space.	See detailed description in NID.	Chapter 6, Section 6.1.2., 6.4.2.	QA workshop (2023)
LULUCF	Forest Land: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Report the biomass increment values applied for every year of the time series as well as the methodology applied to estimate these increment rates.	See detailed description in NID.	Chapter 6, Section 6.4.2.	QA workshop (2023)

Sector	Category	Description	Improvement made	Relevant section in NID	Source of improvement
LULUCF	Forest Land: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Report detailed information on the stratification used in forest land (e.g. forest types) and on the reasons for applying such stratification.	See detailed description in NID.	Chapter 6, Section 6.2.	QA workshop (2023)
LULUCF	Forest Land: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Report for the complete time series the AD, EFs and parameters used, including their reference/sources in the NID at the most disaggregated level, i.e. the level at which the estimation of emissions has been done. You may consider using Annexes in the NID for this purpose.	See detailed description in NID.	Chapter 6, Section 6.4.2.	QA workshop (2023)
LULUCF	Forest Land: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Report detailed information on the process and frequency of AD collection, together with any challenges faced, changes in the process implemented and planned improvements.	See detailed description in NID.	Chapter 6, Section 6.1.2.	QA workshop (2023)
LULUCF	Forest Land: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Report detailed information on the methodologies applied such as equations, assumptions used. When IPCC default methods are applied you may cross-reference IPCC Guidelines (e.g., equation X, vol.Y, ch.Z, pg. D). Whenever methodologies applied deviate from the 2006 IPCC guidelines, relevant justification should be provided. Ensure that a third reader can replicate the final emissions/removals estimates from the information reported in the NID.	See detailed description in NID.	Chapter 6, Section 6.4.2.	QA workshop (2023)
LULUCF	Forest Land: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Report detailed information on the methodologies applied, including background information, such as equations (e.g. allometric equations), parameters, assumptions, models, verification activities, expert judgment, peer-review publications etc. used and the source of such information.	See detailed description in NID.	Chapter 6, Section 6.4.2.	QA workshop (2023)
LULUCF	Forest Land: Forest land remaining forest land	Ensure that net increment (i.e. mortality is taken into account) is applied in biomass and report that carbon losses from harvesting or disturbances do not occur.	See detailed description in NID.	Chapter 6, Section 6.4.2., 6.3.2., 6.3.3.	QA workshop (2023)
LULUCF	Forest Land: Forest land remaining forest land	Report on how CSCs are estimated for the different carbon pools and the transition period applied (e.g. 20-years in DOM in case of carbon accumulation and SOM mineral).	See detailed description in NID.	Chapter 6, Section 6.4.2.	QA workshop (2023)
LULUCF	Forest Land: Land converted to forest land	Report detailed information on how CSCs were estimated in land converted to forest land, separately for each subcategory of land converted to forest land and carbon pool, together with the parameters and stock-change factors used.	See detailed description in NID.	Chapter 6, Section 6.4.2.	QA workshop (2023)

Sector	Category	Description	Improvement made	Relevant section in NID	Source of improvement
LULUCF	Forest Land: Land converted to forest land	Report detailed information on the methodology applied for estimating CSCs in land converted to forest land, separately for each subcategory of land converted to forest land and carbon pool, together with the parameters and stock-change factors used. Note that whenever Tier 3 methods are applied transparent documentation of the validity and completeness of the data, assumptions, equations, models used, peer-review articles, references is therefore a critical issue.	See detailed description in NID.	Chapter 6, Section 6.4.2.	QA workshop (2023)
LULUCF	Cropland: Completeness	Report information on whether all cropland occurring in the country fall under either of the cropland subcategories used in the inventory.	See detailed description in NID.	Chapter 6, Section 6.3., 6.2.2.	QA workshop (2023)
LULUCF	Cropland: Completeness	Report separately CO_2 and non-CO_2 emissions. Report N_2O emissions due to mineralisation associated with carbon loss in mineral soils in the respective CRT 4(III) using the stratification applied in the inventory, taking into account footnote 2.	See detailed description in NID.	Chapter 6, Section 6.5.1.	QA workshop (2023)
LULUCF	Cropland: Completeness	Report CSCs in perennial cropland remaining perennial cropland and annual cropland remaining annual cropland or otherwise justify that CSCs are zero in these lands because management does not change throughout time.	See detailed description in NID.	Chapter 6, Section 6.5.2.	QA workshop (2023)
LULUCF	Cropland: Completeness	Report that biomass burning does not occur in the country (controlled burning or wildfires).	See detailed description in NID.	Chapter 6, Section 6.3.2.	QA workshop (2023)
LULUCF	Cropland: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Report in detail in the NID on the land-use definitions, on the classification system used, the correspondence of national definitions (strata) with IPCC land-use categories and how land that could be classified under more than one land-use category is treated in the inventory.	See detailed description in NID.	Chapter 6, Section 6.2.2.	QA workshop (2023)
LULUCF	Cropland: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Report detailed information in the NID on the parameters and methodologies used to report emissions/removals in soils per each subcategory.	See detailed description in NID.	Chapter 6, Section 6.5.2.	QA workshop (2023)
LULUCF	Cropland: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Report on the definitions used from the data sources and whether any definitional changes occur throughout time and how consistency has been ensured across the time series.	See detailed description in NID.	Chapter 6, Section 6.2.	QA workshop (2023)
LULUCF	Cropland: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Report the increment rate applied for all years of the time series.	See detailed description in NID.	Chapter 6, Section 6.5.2.	QA workshop (2023)
LULUCF	Cropland: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Report detailed information on the stratification used in cropland (e.g. crop types).	See detailed description in NID.	Chapter 6, Section 6.3.2., 6.5.2.	QA workshop (2023)

Sector	Category	Description	Improvement made	Relevant section in NID	Source of improvement
LULUCF	Cropland: Transparency/ documentation	Report the complete time series, the AD, EFs and parameters used, including their reference/ sources in the NID at the most disaggregated level, i.e. the level at which the estimation of emissions has been done. You may consider using Annexes in the NID for this purpose.	See detailed description in NID.	Chapter 6, Section 6.5.2.	QA workshop (2023)
LULUCF	Cropland: Transparency/ documentation	Report detailed information on the process and frequency of AD collection, together with any challenges faced, changes in the process implemented and planned improvements.	See detailed description in NID.	Chapter 6, Section 6.2.	QA workshop (2023)
LULUCF	Cropland: Transparency/ documentation	Report detailed information on the methodologies applied, such as equations, assumptions used. Ensure that a reader can replicate the final emissions/removals estimates from the information reported in the NID.	See detailed description in NID.	Chapter 6, Section 6.5.2.	QA workshop (2023)
LULUCF	Cropland: Cropland remaining cropland	Report which carbon gains and losses were covered by the inventory and how they have been estimated (e.g. the five years rotation period in perennial croplands).	See detailed description in NID.	Chapter 6, Section 6.5.2.	QA workshop (2023)
LULUCF	Cropland: Cropland remaining cropland	Report in detail the carbon pools covered by the inventory and the methodological choice.	See detailed description in NID.	Chapter 6, Section 6.5.2.	QA workshop (2023)
LULUCF	Cropland: Cropland remaining cropland	Report CSCs in perennial cropland remaining perennial cropland and annual cropland remaining annual cropland or otherwise justify that CSCs are zero in these lands because management does not change throughout time.	See detailed description in NID.	Chapter 6, Section 6.5.2.	QA workshop (2023)
LULUCF	Cropland: Cropland remaining cropland	Report the methodological choice and the reasons for using such methodology (e.g., Tier 1 for non-key categories).	See detailed description in NID.	Chapter 6, Section 6.2., 6.5.2.	QA workshop (2023)
LULUCF	Cropland: Cropland remaining cropland	Report all parameters used in the inventory and provide clear references.	See detailed description in NID.	Chapter 6, Section 6.5.2.	QA workshop (2023)
LULUCF	Cropland: Cropland remaining cropland	Report in detail all parameters used for Tier 1 and their source (e.g. reference to section, table in the 2006 IPCC guidelines).	See detailed description in NID.	Chapter 6, Section 6.5.2.	QA workshop (2023)
LULUCF	Cropland: Land converted to cropland	Report detailed information on the equations used and how they have been used even if Tier 1 is applied.	See detailed description in NID.	Chapter 6, Section 6.5.2.	QA workshop (2023)
LULUCF	Cropland: Land converted to cropland	Report in detail the carbon pools covered by the inventory and the methodological choice.	See detailed description in NID.	Chapter 6, Section 6.5.2.	QA workshop (2023)
LULUCF	Cropland: Land converted to cropland	Report the methodological choice and the reasons for using such methodology (e.g., Tier 1 for non-key categories).	See detailed description in NID.	Chapter 6, Section 6.2., 6.5.2.	QA workshop (2023)
LULUCF	Wetlands: Completeness	Report which gases have been covered by the inventory.	See detailed description in NID.	Chapter 6, Section 6.7.2.	QA workshop (2023)
LULUCF	Wetlands: Completeness	Report in detail for which carbon pools CSCs have been estimated.	See detailed description in NID.	Chapter 6, Section 6.7.2.	QA workshop (2023)
LULUCF	Wetlands: Completeness	Report that biomass burning (controlled or wildfires) does not occur in the country.	See detailed description in NID.	Chapter 6, Section 6.3.2.	QA workshop (2023)
LULUCF	Wetlands: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Report in detail the definition of flooded land used in the inventory.	See detailed description in NID.	Chapter 6, Section 6.2.3.	QA workshop (2023)

Sector	Category	Description	Improvement made	Relevant section in NID	Source of improvement
LULUCF	Wetlands: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Report which guidelines are used for estimating CSCs in wetlands.	See detailed description in NID.	Chapter 6, Section 6.7.2.	QA workshop (2023)
LULUCF	Wetlands: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Report that organic soils do not occur in Wetlands.	See detailed description in NID.	Chapter 6, Section 6.2.3.	QA workshop (2023)
LULUCF	Wetlands: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Report detailed information on the stratification used in wetlands.	See detailed description in NID.	Chapter 6, Section 6.2.3.	QA workshop (2023)
LULUCF	Wetlands: Transparency/ documentation	Report the complete time series, the AD, EFs and parameters used, including their reference/ sources in the NID at the most disaggregated level, i.e. the level at which the estimation of emissions has been done even when Tier 1 is used.	See detailed description in NID.	Chapter 6, Section 6.7.2.	QA workshop (2023)
LULUCF	Wetlands: Transparency/ documentation	Report detailed information on the methodologies applied such as equations, assumptions used. When IPCC default methods are applied you may cross-reference IPCC Guidelines.	See detailed description in NID.	Chapter 6, Section 6.7.2.	QA workshop (2023)
LULUCF	Wetlands: Transparency/ documentation	Report in detail all parameters used and the methods used to estimate carbon stock changes.	See detailed description in NID.	Chapter 6, Section 6.7.2.	QA workshop (2023)
LULUCF	Wetlands: Land converted to wetlands	Report which methods were used in the inventory and for which carbon pools CSCs were estimated.	See detailed description in NID.	Chapter 6, Section 6.7.2.	QA workshop (2023)
LULUCF	Wetlands: Land converted to wetlands	For DOM and SOM, justify the appropriateness of the methodologies applied.	See detailed description in NID.	Chapter 6, Section 6.7.2.	QA workshop (2023)
LULUCF	Wetlands: Land converted to wetlands	For DOM and SOM, justify the appropriateness of the methodologies applied.	See detailed description in NID.	Chapter 6, Section 6.7.2.	QA workshop (2023)
LULUCF	Wetlands: Land converted to wetlands	Report in detail all parameters used for Tier 1 and their source (e.g. reference to section, table in the 2006 IPCC guidelines).	See detailed description in NID.	Chapter 6, Section 6.7.2.	QA workshop (2023)
LULUCF	Wetlands: Land converted to wetlands	For DOM and SOM, justify the appropriateness of the methodologies applied.	See detailed description in NID.	Chapter 6, Section 6.7.2.	QA workshop (2023)
LULUCF	Settlements: Completeness	Report N_2O emissions due to mineralisation associated with carbon loss in mineral soils in the respective CRT 4(III) using the stratification applied in the inventory, taking into account footnote 2.	See detailed description in NID.	Chapter 6, Section 6.8.2.8.	QA workshop (2023)
LULUCF	Settlements: Completeness	Report in detail the methodologies, parameters, activity data, their sources for the whole time series in the inventory and the carbon pools covered by the inventory.	See detailed description in NID.	Chapter 6, Section 6.8.2.	QA workshop (2023)
LULUCF	Settlements: Completeness	Report that biomass burning (controlled or wildfires) does not occur in the country.	See detailed description in NID.	Chapter 6, Section 6.3.2.	QA workshop (2023)

Sector	Category	Description	Improvement made	Relevant section in NID	Source of improvement
LULUCF	Settlements: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Report detailed information for the cases where sampling is used, including information on the sampling design, uncertainties estimation, sampling size and how representativeness is ensured, per land-use subcategory and carbon pool. Note that basic information should be included in the NID and additional information can be provided in a separate document, which can be referenced in the NID.	See detailed description in NID.	Chapter 6, Section 6.8.2.	QA workshop (2023)
LULUCF	Settlements: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Report how consistency in the time series is ensured with regard to the consistent application of definitions and survey methods throughout time and space.	See detailed description in NID.	Chapter 6, Section 6.2.	QA workshop (2023)
LULUCF	Settlements: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Report detailed information on the stratification used in settlements (e.g. settlement types) and on the reasons for applying such stratification.	See detailed description in NID.	Chapter 6, Section 6.2.5.	QA workshop (2023)
LULUCF	Settlements: Transparency/ documentation	Report the complete time series, the AD, EFs and parameters used, including their reference/ sources in the NID at the most disaggregated level, i.e. the level at which the estimation of emissions has been done. You may consider using Annexes in the NID for this purpose.	See detailed description in NID.	Chapter 6, Section 6.8.2.	QA workshop (2023)
LULUCF	Settlements: Transparency/ documentation	Report detailed information on the process and frequency of AD collection, together with any challenges faced, changes in the process implemented and planned improvements.	See detailed description in NID.	Chapter 6, Section 6.2.	QA workshop (2023)
LULUCF	Settlements: Transparency/ documentation	Report detailed information on the methodologies applied such as equations, assumptions used. When IPCC default methods are applied, you may cross-reference IPCC Guidelines (e.g., equation X, vol.Y, ch.Z, pg. D). Include in the NID all the necessary information as provided during the QA.	See detailed description in NID.	Chapter 6, Section 6.8.2.	QA workshop (2023)
LULUCF	Settlements: Transparency/ documentation	Report detailed information on the methodologies applied, including background information such as equations (e.g. allometric equations), parameters, assumptions, models, verification activities, expert judgment, peer-review publications etc. used and the source of such information.	See detailed description in NID.	Chapter 6, Section 6.8.2.	QA workshop (2023)
LULUCF	Settlements: Settlements remaining settlements	Ensure that when gain-loss method is applied, all carbon gains and all carbon losses should be appropriately taken into account in estimating carbon stock changes.	See detailed description in NID.	Chapter 6, Section 6.8.2.	QA workshop (2023)
LULUCF	Settlements: Land converted to settlements	Report detailed information on how CSCs were estimated in all subcategories of land converted to settlements and for all carbon pools.	See detailed description in NID.	Chapter 6, Section 6.8.2.	QA workshop (2023)
LULUCF	Settlements: Land converted to settlements	Report in detail the parameters used to estimate CSCs in litter and dead wood and their sources.	See detailed description in NID.	Chapter 6, Section 6.8.2.	QA workshop (2023)

Sector	Category	Description	Improvement made	Relevant section in NID	Source of improvement
LULUCF	Settlements: Land converted to settlements	Report in detail the parameters used to estimate CSCs in SOM.	See detailed description in NID.	Chapter 6, Section 6.8.2.	QA workshop (2023)
LULUCF	Settlements: Land converted to settlements	Use the stock-different method to verify the CSCs estimated by the gain-loss method.	The stock difference method is applied for such LUCs.	Chapter 6, Section 6.8.2.	QA workshop (2023)
LULUCF	Aggregate Sources and Non-CO_2 Emissions Sources on Land: Completeness	Report that biomass burning (controlled burning or wildfires) does not occur in the country in any of the inventory years.	See detailed description in NID.	Chapter 6, Section 6.3.2.	QA workshop (2023)
LULUCF	Aggregate Sources and Non-CO_2 Emissions Sources on Land: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Provide detailed information about the stratification used in the inventory for estimating agriculture and LULUCF emissions/removals as per 2006 IPCC guidelines for at least climate, soil, ecological and management characteristics.	See detailed description in NID.	Chapter 6, Section 6.3.	QA workshop (2023)
LULUCF	Aggregate Sources and Non-CO_2 Emissions Sources on Land: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Ensure completeness of the inventory, apply the appropriate stratification based on 2006 IPCC Guidelines (volume 4, chapter 3) and ensure that the sum of AD of the different strata equals the total AD of the source category.	See detailed description in NID.	Chapter 6, Section 6.2.	QA workshop (2023)
LULUCF	Aggregate Sources and Non-CO_2 Emissions Sources on Land: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Report for the complete time series, the AD, EFs and parameters used, including their reference/sources in the NID at the most disaggregated level, i.e. the level at which the estimation of emissions has been done. You may consider using Annexes in the NID for this purpose.	See detailed description in NID.	Chapter 6, Section 6.1.2., 6.3., 6.4.2., 6.5.2., 6.7.2., 6.8.2., 6.10.2.	QA workshop (2023)
LULUCF	Aggregate Sources and Non-CO_2 Emissions Sources on Land: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Report in detail the EFs, including when country-specific ones are applied and provide their reference.	See detailed description in NID.	Chapter 6, Section 6.1.2., 6.3., 6.4.2., 6.5.2., 6.7.2., 6.8.2., 6.10.2.	QA workshop (2023)
LULUCF	Aggregate Sources and Non-CO_2 Emissions Sources on Land: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Report detailed information on the process and frequency of AD collection, together with any challenges faced, changes in the process implemented and planned improvements.	See detailed description in NID.	Chapter 6, Section 6.1.2.	QA workshop (2023)
LULUCF	Aggregate Sources and Non-CO_2 Emissions Sources on Land: Method – Assessment of accuracy, consistency, comparability and allocation within the sector	Report detailed information on the methodologies applied (even if just Tier 1 is applied) such as equations, activity data, assumptions and EF/parameter values used.	See detailed description in NID.	Chapter 6, Section 6.1.2., 6.3., 6.4.2., 6.5.2., 6.7.2., 6.8.2., 6.10.2.	QA workshop (2023)
LULUCF	Aggregate Sources and Non-CO_2 Emissions Sources on Land: Method – Direct N_2O emissions from managed soils	Report direct and indirect N_2O emissions from N mineralisation associated with loss of soil organic matter resulting from land-use or management change of mineral soils ensuring the correct allocation of emissions between the agriculture and LULUCF sectors (see ID#A.274).	The LULUCF sector includes only emissions associated with the loss of soil organic matter resulting from land use change.	Chapter 6, Section 6.5.2., 5.7.2.	QA workshop (2023)
LULUCF	Aggregate Sources and Non-CO_2 Emissions Sources on Land: Method – Direct N_2O emissions from managed soils	Report that drainage of organic soils does not occur.	See detailed description in NID.	Chapter 6, Section 6.4.2.	QA workshop (2023)

Sector	Category	Description	Improvement made	Relevant section in NID	Source of improvement
LULUCF	Aggregate Sources and Non-CO_2 Emissions Sources on Land: Method – Indirect N_2O emissions from managed soils	Report in detail which EFs are used for indirect N_2O emissions together with their source.	See detailed description in NID.	Chapter 6, Section 6.5.2., 5.7.2.	QA workshop (2023)
LULUCF	Aggregate Sources and Non-CO_2 Emissions Sources on Land: Method – Indirect N_2O emissions from managed soils	Ensure proper use of AD (carbon stock changes) for estimating indirect N_2O emissions associated with loss of soil organic matter resulting from the change of land use or management in mineral soils. The AD should be consistent with the AD applied for direct N_2O emissions from this source. Coordinate with the LULUCF expert.	See detailed description in NID.	Chapter 6, Section 6.5.2., 5.7.2.	QA workshop (2023)
Waste	General issues: Waste Generation, Composition and Management	Describe the solid waste management system occurring in Singapore, including the treatment systems installed illustrated by a diagram showing the different flows of waste and outputs.	An overview of solid waste management in Singapore is described in Chapter 1 Section 4A of the first BTR.	Chapter 1 Section 4A of the first BTR	QA workshop (2023)
Waste	General issues: Waste Generation, Composition and Management	Describe the national wastewater system occurring in Singapore, including the plants operated for wastewater treatment (domestic and industrial) with the technological processes.	The national wastewater system with a diagram had been included in the NID.	Chapter 7, Section 7.5.1.	QA workshop (2023)
Waste	General issues: Waste Generation, Composition and Management	Describe the two processes occurring to generate power and heat from the collected methane produced by the digesters.	The two processes that generate power and heat from methane produced by digesters had been reported in NID.	Chapter 7, Section 7.3.1. and 7.5.1.	QA workshop (2023)
Waste	4.C. Incineration and Open Burning of Waste	Estimate the emissions for this category for the entire time series.	The time series of emissions from year 2000 to 2022 had been included in the NID.	Chapter 2.2 in NID 2024	QA workshop (2023)
Waste	4.D. Wastewater Treatment and Discharge	Report on the arguments used to justify that CH_4 emissions are NO in the context of Singapore, referring to the 2006 IPCC table 6.6 in Vol. 5, chapter 6.	A narrative to justify that CH_4 emissions are NO in the context of Singapore had been included in the NID.	Chapter 7, Section 7.5.2.	QA workshop (2023)
Waste	4.D. Wastewater Treatment and Discharge	Describe how all wastewater streams (domestic and industrial) are considered to estimate GHG emissions.	Factors for industrial co-discharge of nitrogen have already been factored into the calculations for N_2O generated at WRPs and treated effluent.	Chapter 7, Section 7.5.2.	QA workshop (2023)
Waste	4.D. Wastewater Treatment and Discharge	Report on the arguments used to justify that CH_4 emissions are NO in the context of Singapore, referring to the 2006 IPCC table 6.6 in Vol. 5, Chapter 6.	Narrative to justify that CH_4 emissions are NO in the context of Singapore had been included in the NID.	Chapter 7, Section 7.5.2.	QA workshop (2023)

8.5.

Areas of improvement and/or capacity-building related to the flexibility provisions applied with self-determined estimated time frames for improvements

Data owners that were not able to provide time series from year 1990 to 1999 are currently working with the relevant stakeholders to obtain the activity data and/or emissions data. In the event that the activity data are not available, projection would be conducted to assess the appropriate splicing techniques to be applied as per 2006 IPCC Guidelines, Volume 1, Chapter 5, Table 5.1.

Annex

Annex I: Key categories

Description of the approach used for identifying key categories, if different from the IPCC Tier 1 approach

In accordance with the 2006 IPCC Guidelines, Approach 1 was used to identify the key categories using a pre-determined cumulative emissions threshold. As inventories had been developed for more than one year, both Level Assessment (Approach 1) and Trend Assessment (Approach 1) were conducted based on the national GHG inventory with and without LULUCF using equations[44] provided.

Level Assessment (Approach 1)

Level assessment (Approach 1) provides information on the group of categories that is considered to be key category, which is identified by summing together the level contribution by each category in descending order of magnitude which adds up to 95 percent of the sum of all level contribution.

Key category level assessment
= | source or sink category estimate | / total contribution

$$L_{x,t} = | E_{x,t} | / \sum_y | E_{y,t}$$

Where:

$L_{x,t}$ = level assessment for source or sink x in latest inventory year (year t)

$| E_{x,t} |$ = absolute value of emission or removal estimate of source or sink category x in year t

$\sum_y | E_{y,t}$ = total contribution, which is the sum of the absolute values of emissions and removals in year t calculated using the aggregation level chosen by the country for KCA. Because both emissions and removals are entered with positive sign[45], the total contribution/level can be larger than a country's total emissions less removals[46]

Trend Assessment (Approach 1)

Trend assessment (Approach 1) is to identify categories that may not be large enough to be identified by level assessment, that is, for categories with trend that is significantly different from the trend of the overall inventory regardless of whether the trend is increasing or decreasing, or if it is a sink or source. Categories whose trend diverge most from the total trend should be identified as key category, when this difference is weighted by the level of emissions or removals of the category in the base year. These categories are identified by summing together the trend contribution by each category in descending order of magnitude which adds up to 95 percent of the sum of all trend contribution.

$$T_{x,t} = \frac{| E_{x,0} |}{\sum_y | E_{y,0} |} \bullet \left| \left[\frac{(E_{x,t} - E_{x,0})}{| E_{x,0} |} \right] - \frac{\left(\sum_y E_{y,t} - \sum_y E_{y,0} \right)}{\left| \sum_y E_{y,0} \right|} \right|$$

Where:

$T_{x,t}$ = trend assessment of source or sink category x in year t as compared to the base year (year 0)

$| E_{x,0} |$ = absolute value of emission or removal estimate of source or sink category x in year 0

$E_{x,t}$ and $E_{x,0}$ = real values of estimates of source or sink category x in years t and 0, respectively

$\sum_y E_{y,t}$ and $\sum_y E_{y,0}$ = total inventory estimates in years t and 0, respectively

In circumstances where the base year emissions for a given category are zero, the expression above may be reformulated into the expression below to avoid zero in the denominator.

$$T_{x,t} = \left| E_{x,t} / \sum_y | E_{y,0} | \right|$$

Information on the level of disaggregation

The level of disaggregation is aligned with 2006 IPCC Guidelines, Volume 1, Chapter 4, Table 4.1 and Table 7 in the CRT.

[44] Refer to 2006 IPCC Guidelines, Volume 1, Chapter 4, Equation 4.1 and Equation 4.2.
[45] Removals are entered as absolute values to avoid an oscillating cumulative value Lx,t as could be the case if removals were entered with negative signs, and thus to facilitate straightforward interpretation of the quantitative analysis.
[46] This equation can be used in any situation, regardless of whether the national GHG inventory is a net source (as is most common) or a net sink.

Tables 4.2–4.3 of Volume 1 of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, including and excluding LULUCF

Level Assessment With and Without LULUCF

Table 173: Year 2000 Key Categories Level Assessment with LULUCF

Category code	IPCC Category	Greenhouse Gas	Emissions (Gg CO_2 eq)	Percentage Contribution	Cumulative Total
1.A.1.	Fuel combustion - Energy Industries - Liquid Fuels	CO_2	17,177.75	43.02%	43.02%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	CO_2	10,397.12	26.04%	69.06%
1.A.3.b.	Road Transportation	CO_2	5,627.65	14.10%	83.16%
1.A.1.	Fuel combustion - Energy Industries - Gaseous Fuels	CO_2	2,766.79	6.93%	90.09%
1.A.1.	Fuel combustion - Energy Industries - Other Fossil Fuels	CO_2	848.81	2.13%	92.22%
2.E.	Electronics Industry	PFCs	764.06	1.91%	94.13%
1.A.4.	Other Sectors - Liquid Fuels	CO_2	366.92	0.92%	95.05%
1.B.2.c.	Fugitive Emissions from Fuels - Venting and flaring	CO_2	303.11	0.76%	95.81%
1.A.4.	Other Sectors - Solid Fuels	CO_2	273.49	0.68%	96.49%
1.A.3.d.	Domestic Navigation - Liquid Fuels	CO_2	212.88	0.53%	97.03%
2.F.1.	Refrigeration and air-conditioning	HFCs	137.16	0.34%	97.37%
2.B.8.	Petrochemical and Carbon Black Production	CO_2	137.14	0.34%	97.71%
1.A.3.b.	Road Transportation	N_2O	113.15	0.28%	98.00%
5.C.	Incineration and Open Burning of Waste	CO_2	103.85	0.26%	98.26%
4.E.2.	Land Converted to Settlements	CO_2	101.74	0.25%	98.51%
2.E.	Electronics Industry	NF_3	67.57	0.17%	98.68%
5.A.	Solid Waste Disposal	CH_4	64.87	0.16%	98.84%
4.A.2.	Land Converted to Forest Land	CO_2	58.60	0.15%	98.99%
5.D.	Wastewater Treatment and Discharge	N_2O	44.23	0.11%	99.10%
1.A.1.	Fuel combustion - Energy Industries - Liquid Fuels	N_2O	35.32	0.09%	99.19%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Other Fossil Fuels	CO_2	33.13	0.08%	99.27%
2.E.	Electronics Industry	N_2O	32.60	0.08%	99.35%
1.A.1.	Fuel combustion - Energy Industries - Other Fossil Fuels	N_2O	30.39	0.08%	99.43%
2.E.	Electronics Industry	SF_6	29.75	0.07%	99.50%
4.A.1.	Forest Land Remaining Forest Land	CO_2	28.61	0.07%	99.58%
4.E.1.	Settlements Remaining Settlements	CO_2	28.34	0.07%	99.65%
1.A.3.b.	Road Transportation	CH_4	26.25	0.07%	99.71%
1.A.1.	Fuel combustion - Energy Industries - Liquid Fuels	CH_4	18.66	0.05%	99.76%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	N_2O	13.66	0.03%	99.79%
1.B.2.c.	Fugitive Emissions from Fuels - Venting and flaring	CH_4	12.48	0.03%	99.82%
2.E.	Electronics Industry	HFCs	9.50	0.02%	99.85%
2.H.	Other	CO_2	9.44	0.02%	99.87%
4(III).	Direct and indirect N_2O emissions from N mineralisation / immobilisation	N_2O	8.85	0.02%	99.89%
2.B.10.	Other	CO_2	8.39	0.02%	99.91%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	CH_4	8.30	0.02%	99.94%
4.D.2.	Land Converted to Wetlands	CO_2	4.71	0.01%	99.95%

Category code	IPCC Category	Greenhouse Gas	Emissions (Gg CO_2 eq)	Percentage Contribution	Cumulative Total
2.G.	Other Product Manufacture and Use	SF_6	2.57	0.01%	99.95%
4.F.2.	Land Converted to Other Land	CO_2	2.50	0.01%	99.96%
3.B.	Manure Management	N_2O	2.16	0.01%	99.97%
3.D.1.	Direct N_2O Emissions From Managed Soils	N_2O	1.72	0.00%	99.97%
3.B.	Manure Management	CH_4	1.56	0.00%	99.97%
1.A.3.d.	Domestic Navigation - Liquid Fuels	N_2O	1.52	0.00%	99.98%
1.A.1.	Fuel combustion - Energy Industries - Gaseous Fuels	CH_4	1.38	0.00%	99.98%
1.A.1.	Fuel combustion - Energy Industries - Gaseous Fuels	N_2O	1.31	0.00%	99.98%
5.C.	Incineration and Open Burning of Waste	N_2O	0.84	0.00%	99.99%
1.A.4.	Other Sectors - Liquid Fuels	CH_4	0.81	0.00%	99.99%
3.A.	Enteric Fermentation	CH_4	0.75	0.00%	99.99%
3.D.2.	Indirect N_2O Emissions From Managed Soils	N2O	0.72	0.00%	99.99%
1.A.4.	Other Sectors - Solid Fuels	CH_4	0.69	0.00%	99.99%
1.B.2.c.	Fugitive Emissions from Fuels - Venting and flaring	N_2O	0.25	0.00%	99.99%
1.A.3.d.	Domestic Navigation - Liquid Fuels	CH_4	0.56	0.00%	100.00%
2.B.8.	Petrochemical and Carbon Black Production	CH_4	0.31	0.00%	100.00%
4.B.2.	Land Converted to Cropland	CO_2	0.24	0.00%	100.00%
2.D.	Non-energy Products from Fuels and Solvent Use	CO_2	0.23	0.00%	100.00%
2.F.4.	Aerosols	HFCs	0.18	0.00%	100.00%
1.A.4.	Other Sectors - Liquid Fuels	N_2O	0.15	0.00%	100.00%
1.A.4.	Other Sectors - Solid Fuels	N_2O	0.13	0.00%	100.00%
2.F.3.	Fire Protection	HFCs	0.12	0.00%	100.00%
3.G.	Liming	CO_2	0.11	0.00%	100.00%
2.B.10.	Other	N_2O	0.06	0.00%	100.00%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Other Fossil Fuels	N_2O	0.05	0.00%	100.00%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Other Fossil Fuels	CH_4	0.02	0.00%	100.00%
4.B.1.	Cropland Remaining Cropland	CO_2	0.02	0.00%	100.00%
1.A.1.	Fuel combustion - Energy Industries - Other Fossil Fuels	CH_4	0.01	0.00%	100.00%
2.B.10.	Other	CH_4	0.00	0.00%	100.00%
5.C.	Incineration and Open Burning of Waste	CH_4	0.00	0.00%	100.00%
3.H.	Urea Application	CO_2	0.00	0.00%	100.00%
2.F.2.	Foam Blowing Agents	HFCs	0.00	0.00%	100.00%
4.D.1.2.	Flooded Land Remaining Flooded Land	CO_2	0.00	0.00%	100.00%

Table 174: Year 2000 Key Categories Level Assessment without LULUCF

Category code	IPCC Category	Greenhouse Gas	Emissions (Gg CO_2 eq)	Percentage Contribution	Cumulative Total
1.A.1.	Fuel combustion - Energy Industries - Liquid Fuels	CO_2	17,177.75	43.28%	43.28%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	CO_2	10,397.12	26.19%	69.47%
1.A.3.b.	Road Transportation	CO_2	5,627.65	14.18%	83.65%
1.A.1.	Fuel combustion - Energy Industries - Gaseous Fuels	CO_2	2,766.79	6.97%	90.62%
1.A.1.	Fuel combustion - Energy Industries - Other Fossil Fuels	CO_2	848.81	2.14%	92.76%
2.E.	Electronics Industry	PFCs	764.06	1.92%	94.68%
1.A.4.	Other Sectors - Liquid Fuels	CO_2	366.92	0.92%	95.61%
1.B.2.c.	Fugitive Emissions from Fuels - Venting and flaring	CO_2	303.11	0.76%	96.37%
1.A.4.	Other Sectors - Solid Fuels	CO_2	273.49	0.69%	97.06%
1.A.3.d.	Domestic Navigation - Liquid Fuels	CO_2	212.88	0.54%	97.60%
2.F.1.	Refrigeration and air-conditioning	HFCs	137.16	0.35%	97.94%
2.B.8.	Petrochemical and Carbon Black Production	CO_2	137.14	0.35%	98.29%
1.A.3.b.	Road Transportation	N_2O	113.15	0.29%	98.57%
5.C.	Incineration and Open Burning of Waste	CO_2	103.85	0.26%	98.83%
2.E.	Electronics Industry	NF_3	67.57	0.17%	99.00%
5.A.	Solid Waste Disposal	CH_4	64.87	0.16%	99.17%
5.D.	Wastewater Treatment and Discharge	N_2O	44.23	0.11%	99.28%
1.A.1.	Fuel combustion - Energy Industries - Liquid Fuels	N_2O	35.32	0.09%	99.37%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Other Fossil Fuels	CO_2	33.13	0.08%	99.45%
2.E.	Electronics Industry	N_2O	32.60	0.08%	99.53%
1.A.1.	Fuel combustion - Energy Industries - Other Fossil Fuels	N_2O	30.39	0.08%	99.61%
2.E.	Electronics Industry	SF_6	29.75	0.07%	99.69%
1.A.3.b.	Road Transportation	CH_4	26.25	0.07%	99.75%
1.A.1.	Fuel combustion - Energy Industries - Liquid Fuels	CH_4	18.66	0.05%	99.80%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	N_2O	13.66	0.03%	99.83%
1.B.2.c.	Fugitive Emissions from Fuels - Venting and flaring	CH_4	12.48	0.03%	99.86%
2.E.	Electronics Industry	HFCs	9.50	0.02%	99.89%
2.H.	Other	CO_2	9.44	0.02%	99.91%
2.B.10.	Other	CO_2	8.39	0.02%	99.93%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	CH_4	8.30	0.02%	99.95%
2.G.	Other Product Manufacture and Use	SF_6	2.57	0.01%	99.96%
3.B.	Manure Management	N_2O	2.16	0.01%	99.97%
3.D.1.	Direct N_2O Emissions From Managed Soils	N_2O	1.72	0.00%	99.97%
3.B.	Manure Management	CH_4	1.56	0.00%	99.97%
1.A.3.d.	Domestic Navigation - Liquid Fuels	N_2O	1.52	0.00%	99.98%
1.A.1.	Fuel combustion - Energy Industries - Gaseous Fuels	CH_4	1.38	0.00%	99.98%
1.A.1.	Fuel combustion - Energy Industries - Gaseous Fuels	N_2O	1.31	0.00%	99.98%
5.C.	Incineration and Open Burning of Waste	N_2O	0.84	0.00%	99.99%
1.A.4.	Other Sectors - Liquid Fuels	CH_4	0.81	0.00%	99.99%
3.A.	Enteric Fermentation	CH_4	0.75	0.00%	99.99%

Category code	IPCC Category	Greenhouse Gas	Emissions (Gg CO_2 eq)	Percentage Contribution	Cumulative Total
3.D.2.	Indirect N_2O Emissions From Managed Soils	N_2O	0.72	0.00%	99.99%
1.A.4.	Other Sectors - Solid Fuels	CH_4	0.69	0.00%	99.99%
1.A.3.d.	Domestic Navigation - Liquid Fuels	CH_4	0.56	0.00%	100.00%
2.B.8.	Petrochemical and Carbon Black Production	CH_4	0.31	0.00%	100.00%
1.B.2.c.	Fugitive Emissions from Fuels - Venting and flaring	N_2O	0.25	0.00%	100.00%
2.D.	Non-energy Products from Fuels and Solvent Use	CO_2	0.23	0.00%	100.00%
2.F.4.	Aerosols	HFCs	0.18	0.00%	100.00%
1.A.4.	Other Sectors - Liquid Fuels	N_2O	0.15	0.00%	100.00%
1.A.4.	Other Sectors - Solid Fuels	N_2O	0.13	0.00%	100.00%
2.F.3.	Fire Protection	HFCs	0.12	0.00%	100.00%
3.G.	Liming	CO_2	0.11	0.00%	100.00%
2.B.10.	Other	N_2O	0.06	0.00%	100.00%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Other Fossil Fuels	N_2O	0.05	0.00%	100.00%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Other Fossil Fuels	CH_4	0.02	0.00%	100.00%
1.A.1.	Fuel combustion - Energy Industries - Other Fossil Fuels	CH_4	0.01	0.00%	100.00%
2.B.10.	Other	CH_4	0.00	0.00%	100.00%
5.C.	Incineration and Open Burning of Waste	CH_4	0.00	0.00%	100.00%
3.H.	Urea Application	CO_2	0.00	0.00%	100.00%
2.F.2.	Foam Blowing Agents	HFCs	0.00	0.00%	100.00%

Table 175: Year 2022 Key Categories Level Assessment with LULUCF

Category code	IPCC Category	Greenhouse Gas	Emissions (Gg CO_2 eq)	Percentage Contribution	Cumulative Total
1.A.1.	Fuel combustion - Energy Industries - Gaseous Fuels	CO_2	17,995.15	30.64%	30.64%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	CO_2	12,694.51	21.61%	52.25%
1.A.3.b.	Road Transportation	CO_2	6,426.02	10.94%	63.19%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Gaseous Fuels	CO_2	6,129.17	10.43%	73.62%
2.F.1.	Refrigeration and air-conditioning	HFCs	3,973.37	6.76%	80.39%
2.E.	Electronics Industry	PFCs	2,518.74	4.29%	84.67%
1.A.1.	Fuel combustion - Energy Industries - Liquid Fuels	CO_2	1,731.51	2.95%	87.62%
1.A.1.	Fuel combustion - Energy Industries - Other Fossil Fuels	CO_2	1,609.27	2.74%	90.36%
2.B.10.	Other	CO_2	814.62	1.39%	91.75%
2.E.	Electronics Industry	NF_3	644.77	1.10%	92.85%
1.B.2.c.	Fugitive Emissions from Fuels - Venting and flaring	CO_2	564.93	0.96%	93.81%
2.B.8.	Petrochemical and Carbon Black Production	CO_2	473.42	0.81%	94.61%
1.A.3.d.	Domestic Navigation - Liquid Fuels	CO_2	431.31	0.73%	95.35%
1.A.4.	Other Sectors - Solid Fuels	CO_2	311.29	0.53%	95.88%
5.C.	Incineration and Open Burning of Waste	CO_2	304.14	0.52%	96.40%
1.A.4.	Other Sectors - Liquid Fuels	CO_2	278.72	0.47%	96.87%
2.E.	Electronics Industry	N_2O	263.88	0.45%	97.32%
1.A.5.	Other (Not specified elsewhere) - Liquid Fuels	CO_2	250.23	0.43%	97.74%

Category code	IPCC Category	Greenhouse Gas	Emissions (Gg CO_2 eq)	Percentage Contribution	Cumulative Total
1.A.4.	Other Sectors - Gaseous Fuels	CO_2	173.23	0.29%	98.04%
1.A.3.b.	Road Transportation	N_2O	135.06	0.23%	98.27%
2.E.	Electronics Industry	SF_6	128.84	0.22%	98.49%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Other Fossil Fuels	CO_2	128.66	0.22%	98.71%
2.E.	Electronics Industry	HFCs	117.45	0.20%	98.91%
4.E.2.	Land Converted to Settlements	CO_2	101.95	0.17%	99.08%
5.D.	Wastewater Treatment and Discharge	N_2O	75.75	0.13%	99.21%
2.F.3.	Fire Protection	HFCs	63.89	0.11%	99.32%
4.A.1.	Forest Land Remaining Forest Land	CO_2	57.36	0.10%	99.42%
1.A.1.	Fuel combustion - Energy Industries - Other Fossil Fuels	N_2O	48.51	0.08%	99.50%
1.B.2.c.	Fugitive Emissions from Fuels - Venting and flaring	CH_4	47.97	0.08%	99.58%
1.A.3.	Road Transportation	CH_4	33.43	0.06%	99.64%
2.G.	Other Product Manufacture and Use	SF_6	25.74	0.04%	99.68%
2.H.	Other	CO_2	21.35	0.04%	99.72%
4.A.2.	Land Converted to Forest Land	CO_2	18.48	0.03%	99.75%
2.B.10.	Other	N_2O	14.94	0.03%	99.78%
2.F.4.	Aerosols	HFCs	13.06	0.02%	99.80%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	N_2O	13.27	0.02%	99.82%
2.B.8.	Petrochemical and Carbon Black Production	CH_4	12.10	0.02%	99.84%
1.A.1.	Fuel combustion - Energy Industries - Gaseous Fuels	CH_4	8.98	0.02%	99.86%
1.A.1.	Fuel combustion - Energy Industries - Gaseous Fuels	N_2O	8.50	0.01%	99.87%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	CH_4	8.38	0.01%	99.88%
4(III).	Direct and indirect N_2O emissions from N mineralisation/immobilisation	N_2O	7.31	0.01%	99.90%
1.A.1.	Fuel combustion - Energy Industries - Biomass	N_2O	6.63	0.01%	99.91%
1.A.1.	Fuel combustion - Energy Industries - Liquid Fuels	N_2O	5.78	0.01%	99.92%
1.A.1.	Fuel combustion - Energy Industries - Biomass	CH_4	5.25	0.01%	99.93%
4.E.1.	Settlements Remaining Settlements	CO_2	3.47	0.01%	99.93%
1.A.3.d.	Domestic Navigation - Gaseous Fuels	CO_2	3.15	0.01%	99.94%
1.A.3.d.	Domestic Navigation - Liquid Fuels	N_2O	3.08	0.01%	99.94%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Gaseous Fuels	CH_4	3.05	0.01%	99.95%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Gaseous Fuels	N_2O	2.88	0.00%	99.95%
3.B.	Manure Management	N_2O	2.75	0.00%	99.96%
5.C.	Incineration and Open Burning of Waste	N_2O	2.50	0.00%	99.96%
3.B.	Manure Management	CH_4	2.36	0.00%	99.97%
1.A.3.a.	Domestic Aviation	CO_2	2.31	0.00%	99.97%
1.A.5.	Other (Not specified elsewhere) - Liquid Fuels	N_2O	1.92	0.00%	99.97%
4.D.2.	Land Converted to Wetlands	CO_2	1.81	0.00%	99.98%
5.A.	Solid Waste Disposal	CH_4	1.80	0.00%	99.98%
3.D.1.	Direct N_2O Emissions From Managed Soils	N_2O	1.78	0.00%	99.98%
1.A.3.d.	Domestic Navigation - Liquid Fuels	CH_4	1.14	0.00%	99.99%
1.A.1.	Fuel combustion - Energy Industries - Liquid Fuels	CH_4	1.12	0.00%	99.99%

Category code	IPCC Category	Greenhouse Gas	Emissions (Gg CO_2 eq)	Percentage Contribution	Cumulative Total
1.B.2.c.	Fugitive Emissions from Fuels - Venting and flaring	N_2O	1.01	0.00%	99.99%
2.D .	Non-energy Products from Fuels and Solvent Use	CO_2	0.99	0.00%	99.99%
2.B.10.	Other	CH_4	0.90	0.00%	99.99%
1.A.4.	Other Sectors - Solid Fuels	CH_4	0.78	0.00%	99.99%
3.D.2.	Indirect N_2O Emissions From Managed Soils	N_2O	0.74	0.00%	99.99%
1.A.4.	Other Sectors - Liquid Fuels	CH_4	0.62	0.00%	100.00%
1.A.4.	Other Sectors - Gaseous Fuels	CH_4	0.43	0.00%	100.00%
3.A.	Enteric Fermentation	CH_4	0.34	0.00%	100.00%
4.B.1.	Cropland Remaining Cropland	CO_2	0.30	0.00%	100.00%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Other Fossil Fuels	N_2O	0.29	0.00%	100.00%
4.B.2.	Land Converted to Cropland	CO_2	0.29	0.00%	100.00%
1.A.5.	Other (Not specified elsewhere) - Liquid Fuels	CH_4	0.21	0.00%	100.00%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Other Fossil Fuels	CH_4	0.16	0.00%	100.00%
1.A.4.	Other Sectors - Solid Fuels	N_2O	0.15	0.00%	100.00%
1.A.4.	Other Sectors - Liquid Fuels	N_2O	0.12	0.00%	100.00%
1.A.1.	Fuel combustion - Energy Industries - Other Fossil Fuels	CH_4	0.09	0.00%	100.00%
1.A.4.	Other Sectors - Gaseous Fuels	N_2O	0.08	0.00%	100.00%
3.G.	Liming	CO_2	0.07	0.00%	100.00%
1.A.3.d.	Domestic Navigation - Gaseous Fuels	N_2O	0.03	0.00%	100.00%
1.A.3.a.	Domestic Aviation	N_2O	0.02	0.00%	100.00%
1.A.3.d.	Domestic Navigation - Gaseous Fuels	CH_4	0.01	0.00%	100.00%
2.F.2.	Foam Blowing Agents	HFCs	0.01	0.00%	100.00%
4.F.2.	Land Converted to Other Land	CO_2	0.00	0.00%	100.00%
5.C.	Incineration and Open Burning of Waste	CH_4	0.00	0.00%	100.00%
1.A.3.a.	Domestic Aviation	CH_4	0.00	0.00%	100.00%
3.H.	Urea Application	CO_2	0.00	0.00%	100.00%
4.D.1.2.	Flooded Land Remaining Flooded Land	CO_2	0.00	0.00%	100.00%

Table 176: Year 2022 Key Categories Level Assessment without LULUCF

Category code	IPCC Category	Greenhouse Gas	Emissions (Gg CO_2 eq)	Percentage Contribution	Cumulative Total
1.A.1.	Fuel combustion - Energy Industries - Gaseous Fuels	CO_2	17,995.15	30.74%	30.74%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	CO_2	12,694.51	21.68%	52.42%
1.A.3.b.	Road Transportation	CO_2	6,426.02	10.98%	63.39%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Gaseous Fuels	CO_2	6,129.17	10.47%	73.86%
2.F.1.	Refrigeration and air-conditioning	HFCs	3,973.37	6.79%	80.65%
2.E.	Electronics Industry	PFCs	2,518.74	4.30%	84.95%
1.A.1.	Fuel combustion - Energy Industries - Liquid Fuels	CO_2	1,731.51	2.96%	87.91%
1.A.1.	Fuel combustion - Energy Industries - Other Fossil Fuels	CO_2	1,609.27	2.75%	90.66%
2.B.10.	Other	CO_2	814.62	1.39%	92.05%
2.E.	Electronics Industry	NF_3	644.77	1.10%	93.15%
1.B.2.c.	Fugitive Emissions from Fuels - Venting and flaring	CO_2	564.93	0.96%	94.11%
2.B.8.	Petrochemical and Carbon Black Production	CO_2	473.42	0.81%	94.92%
1.A.3.d.	Domestic Navigation - Liquid Fuels	CO_2	431.31	0.74%	95.66%
1.A.4.	Other Sectors - Solid Fuels	CO_2	311.29	0.53%	96.19%
5.C.	Incineration and Open Burning of Waste	CO_2	304.14	0.52%	96.71%
1.A.4.	Other Sectors - Liquid Fuels	CO_2	278.72	0.48%	97.19%
2.E.	Electronics Industry	N_2O	263.88	0.45%	97.64%
1.A.5.	Other (Not specified elsewhere) - Liquid Fuels	CO_2	250.23	0.43%	98.06%
1.A.4.	Other Sectors - Gaseous Fuels	CO_2	173.23	0.30%	98.36%
1.A.3.b.	Road Transportation	N_2O	135.06	0.23%	98.59%
2.E.	Electronics Industry	SF_6	128.84	0.22%	98.81%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Other Fossil Fuels	CO_2	128.66	0.22%	99.03%
2.E.	Electronics Industry	HFCs	117.45	0.20%	99.23%
5.D.	Wastewater Treatment and Discharge	N_2O	75.75	0.13%	99.36%
2.F.3.	Fire Protection	HFCs	63.89	0.11%	99.47%
1.A.1.	Fuel combustion - Energy Industries - Other Fossil Fuels	N_2O	48.51	0.08%	99.55%
1.B.2.c.	Fugitive Emissions from Fuels - Venting and flaring	CH_4	47.97	0.08%	99.63%
1.A.3.b.	Road Transportation	CH_4	33.43	0.06%	99.69%
2.G.	Other Product Manufacture and Use	SF_6	25.74	0.04%	99.74%
2.H.	Other	CO_2	21.35	0.04%	99.77%
2.B.10.	Other	N_2O	14.94	0.03%	99.80%
2.F.4.	Aerosols	HFCs	13.06	0.02%	99.82%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	N_2O	13.27	0.02%	99.84%
2.B.8.	Petrochemical and Carbon Black Production	CH_4	12.10	0.02%	99.86%
1.A.1.	Fuel combustion - Energy Industries - Gaseous Fuels	CH_4	8.98	0.02%	99.88%
1.A.1.	Fuel combustion - Energy Industries - Gaseous Fuels	N_2O	8.50	0.01%	99.89%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	CH_4	8.38	0.01%	99.91%
1.A.1.	Fuel combustion - Energy Industries - Biomass	N_2O	6.63	0.01%	99.92%
1.A.1.	Fuel combustion - Energy Industries - Liquid Fuels	N_2O	5.78	0.01%	99.93%
1.A.1.	Fuel combustion - Energy Industries - Biomass	CH_4	5.25	0.01%	99.94%
1.A.3.d.	Domestic Navigation - Gaseous Fuels	CO_2	3.15	0.01%	99.94%
1.A.3.d.	Domestic Navigation - Liquid Fuels	N_2O	3.08	0.01%	99.95%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Gaseous Fuels	CH_4	3.05	0.01%	99.95%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Gaseous Fuels	N_2O	2.88	0.00%	99.96%
3.B.	Manure Management	N_2O	2.75	0.00%	99.96%
5.C.	Incineration and Open Burning of Waste	N_2O	2.50	0.00%	99.97%
3.B.	Manure Management	CH_4	2.36	0.00%	99.97%
1.A.3.a.	Domestic Aviation	CO_2	2.31	0.00%	99.97%
1.A.5.	Other (Not specified elsewhere) - Liquid Fuels	N_2O	1.92	0.00%	99.98%
5.A.	Solid Waste Disposal	CH_4	1.80	0.00%	99.98%
3.D.1.	Direct N_2O Emissions From Managed Soils	N_2O	1.78	0.00%	99.98%
1.A.3.d.	Domestic Navigation - Liquid Fuels	CH_4	1.14	0.00%	99.99%
1.A.1.	Fuel combustion - Energy Industries - Liquid Fuels	CH_4	1.12	0.00%	99.99%

Category code	IPCC Category	Greenhouse Gas	Emissions (Gg CO_2 eq)	Percentage Contribution	Cumulative Total
1.B.2.c.	Fugitive Emissions from Fuels - Venting and flaring	N_2O	1.01	0.00%	99.99%
2.D.	Non-energy Products from Fuels and Solvent Use	CO_2	0.99	0.00%	99.99%
2.B.10.	Other	CH_4	0.90	0.00%	99.99%
1.A.4.	Other Sectors - Solid Fuels	CH_4	0.78	0.00%	99.99%
3.D.2.	Indirect N_2O Emissions From Managed Soils	N_2O	0.74	0.00%	100.00%
1.A.4.	Other Sectors - Liquid Fuels	CH_4	0.62	0.00%	100.00%
1.A.4.	Other Sectors - Gaseous Fuels	CH_4	0.43	0.00%	100.00%
3.A.	Enteric Fermentation	CH_4	0.34	0.00%	100.00%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Other Fossil Fuels	N_2O	0.29	0.00%	100.00%
1.A.5.	Other (Not specified elsewhere) - Liquid Fuels	CH_4	0.21	0.00%	100.00%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Other Fossil Fuels	CH_4	0.16	0.00%	100.00%
1.A.4.	Other Sectors - Solid Fuels	N_2O	0.15	0.00%	100.00%
1.A.4.	Other Sectors - Liquid Fuels	N_2O	0.12	0.00%	100.00%
1.A.1.	Fuel combustion - Energy Industries - Other Fossil Fuels	CH_4	0.09	0.00%	100.00%
1.A.4.	Other Sectors - Gaseous Fuels	N_2O	0.08	0.00%	100.00%
3.G.	Liming	CO_2	0.07	0.00%	100.00%
1.A.3.d.	Domestic Navigation - Gaseous Fuels	N_2O	0.03	0.00%	100.00%
1.A.3.a.	Domestic Aviation	N_2O	0.02	0.00%	100.00%
1.A.3.d.	Domestic Navigation - Gaseous Fuels	CH_4	0.01	0.00%	100.00%
2.F.2.	Foam Blowing Agents	HFCs	0.01	0.00%	100.00%
5.C.	Incineration and Open Burning of Waste	CH_4	0.00	0.00%	100.00%
1.A.3.a.	Domestic Aviation	CH_4	0.00	0.00%	100.00%
3.H.	Urea Application	CO_2	0.00	0.00%	100.00%

Table 177: Trend Assessment with LULUCF

Category code	IPCC Category	Greenhouse Gas	Y2000 Emissions (Gg CO_2 eq)	Y2022 Emissions (Gg CO_2 eq)	Trend Assessment	Percentage contribution to trend assessment	Cumulative Total
1.A.1.	Fuel combustion - Energy Industries - Liquid Fuels	CO_2	17,177.75	1,731.51	0.59	46.26%	46.26%
1.A.1.	Fuel combustion - Energy Industries - Gaseous Fuels	CO_2	2,766.79	17,995.15	0.35	27.36%	73.62%
2.F.1.	Refrigeration and air-conditioning	HFCs	137.16	3,973.37	0.09	7.41%	81.04%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	CO_2	10,397.12	12,694.51	0.07	5.11%	86.15%
1.A.3.b.	Road Transportation	CO_2	5,627.65	6,426.02	0.05	3.64%	89.79%
2.E.	Electronics Industry	PFCs	764.06	2,518.74	0.03	2.74%	92.53%
2.B.10.	Other	CO_2	8.39	814.62	0.02	1.58%	94.11%
2.E.	Electronics Industry	NF_3	67.57	644.77	0.01	1.07%	95.18%
1.A.1.	Fuel combustion - Energy Industries - Other Fossil Fuels	CO_2	848.81	1,609.27	0.01	0.71%	95.89%
2.B.8.	Petrochemical and Carbon Black Production	CO_2	137.14	473.42	0.01	0.53%	96.42%
1.A.4.	Other Sectors - Liquid Fuels	CO_2	366.92	278.72	0.01	0.51%	96.93%
2.E.	Electronics Industry	N_2O	32.60	263.88	0.01	0.42%	97.36%
5.C.	Incineration and Open Burning of Waste	CO_2	103.85	304.14	0.00	0.30%	97.66%
1.B.2.c.	Fugitive Emissions from Fuels - Venting and flaring	CO_2	303.11	564.93	0.00	0.23%	97.89%
1.A.3.d.	Domestic Navigation - Liquid Fuels	CO_2	212.78	431.31	0.00	0.23%	98.12%
2.E.	Electronics Industry	HFCs	9.50	117.45	0.00	0.20%	98.33%
5.A.	Solid Waste Disposal	CH_4	64.87	1.80	0.00	0.18%	98.51%
1.A.4.	Other Sectors - Solid Fuels	CO_2	273.49	311.29	0.00	0.18%	98.69%
2.E.	Electronics Industry	SF_6	29.75	128.84	0.00	0.17%	98.86%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Other Fossil Fuels	CO_2	33.13	128.66	0.00	0.16%	99.01%
4.A.2.	Land Converted to Forest Land	CO_2	58.60	18.48	0.00	0.13%	99.15%
2.F.3.	Fire Protection	HFCs	0.12	63.89	0.00	0.13%	99.27%
4.E.2.	Land Converted to Settlements	CO_2	101.74	101.95	0.00	0.09%	99.37%
1.A.1.	Fuel combustion - Energy Industries - Liquid Fuels	N_2O	35.32	5.78	0.00	0.09%	99.46%
4.E.1.	Settlements Remaining Settlements	CO_2	28.34	3.47	0.00	0.08%	99.53%
1.A.3.b.	Road Transportation	N_2O	113.15	135.06	0.00	0.06%	99.59%
1.B.2.c.	Fugitive Emissions from Fuels - Venting and flaring	CH_4	12.48	47.97	0.00	0.06%	99.65%
1.A.1.	Fuel combustion - Energy Industries - Liquid Fuels	CH_4	18.66	1.12	0.00	0.05%	99.70%
2.G.	Other Product Manufacture and Use	SF_6	2.57	25.74	0.00	0.04%	99.75%
4.A.1.	Forest Land Remaining Forest Land	CO_2	28.61	57.36	0.00	0.03%	99.78%
2.B.10.	Other	N_2O	0.00	14.94	0.00	0.03%	99.81%
2.F.4.	Aerosols	HFCs	0.18	13.06	0.00	0.03%	99.83%

Category code	IPCC Category	Greenhouse Gas	Y2000 Emissions (Gg CO_2 eq)	Y2022 Emissions (Gg CO_2 eq)	Trend Assessment	Percentage contribution to trend assessment	Cumulative Total
2.B.8.	Petrochemical and Carbon Black Production	CH_4	0.31	12.10	0.00	0.02%	99.85%
5.D.	Wastewater Treatment and Discharge	N_2O	44.23	75.75	0.00	0.02%	99.87%
2.H.	Other	CO_2	9.44	21.35	0.00	0.01%	99.89%
1.A.1.	Fuel combustion - Energy Industries - Gaseous Fuels	CH_4	1.38	8.98	0.00	0.01%	99.90%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	N_2O	13.66	13.27	0.00	0.01%	99.92%
1.A.1.	Fuel combustion - Energy Industries - Gaseous Fuels	N_2O	1.31	8.50	0.00	0.01%	99.93%
4(III).	Direct and indirect N_2O emissions from N mineralisation/ immobilisation	N_2O	8.85	7.31	0.00	0.01%	99.94%
1.A.3.b.	Road Transportation	CH_4	26.25	33.43	0.00	0.01%	99.95%
4.D.2.	Land Converted to Wetlands	CO_2	4.71	1.81	0.00	0.01%	99.96%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	CH_4	8.30	8.38	0.00	0.01%	99.97%
1.A.1.	Fuel combustion - Energy Industries - Other Fossil Fuels	N_2O	30.39	48.51	0.00	0.01%	99.98%
4.F.2.	Land Converted to Other Land	CO_2	2.50	0.00	0.00	0.01%	99.98%
5.C.	Incineration and Open Burning of Waste	N_2O	0.84	2.50	0.00	0.00%	99.99%
1.A.3.d.	Domestic Navigation - Liquid Fuels	N_2O	1.52	3.08	0.00	0.00%	99.99%
2.B.10.	Other	CH_4	0.06	0.90	0.00	0.00%	99.99%
3.A.	Enteric Fermentation	CH_4	0.75	0.34	0.00	0.00%	99.99%
3.D.1.	Direct N_2O Emissions From Managed Soils	N_2O	1.72	1.78	0.00	0.00%	99.99%
2.D.	Non-energy Products from Fuels and Solvent Use	CO_2	0.23	0.99	0.00	0.00%	99.99%
1.B.2.c.	Fugitive Emissions from Fuels - Venting and flaring	N_2O	0.25	1.01	0.00	0.00%	99.99%
1.A.4.	Other Sectors - Liquid Fuels	CH_4	0.81	0.62	0.00	0.00%	100.00%
3.B.	Manure Management	N_2O	2.16	2.75	0.00	0.00%	100.00%
3.D.2.	Indirect N_2O Emissions From Managed Soils	N_2O	0.72	0.74	0.00	0.00%	100.00%
1.A.3.d.	Domestic Navigation - Liquid Fuels	CH_4	0.56	1.14	0.00	0.00%	100.00%
4.B.1.	Cropland Remaining Cropland	CO_2	0.02	0.30	0.00	0.00%	100.00%
1.A.4.	Other Sectors - Solid Fuels	CH_4	0.69	0.78	0.00	0.00%	100.00%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Other Fossil Fuels	N_2O	0.05	0.29	0.00	0.00%	100.00%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Other Fossil Fuels	CH_4	0.02	0.16	0.00	0.00%	100.00%
1.A.4.	Other Sectors - Liquid Fuels	N_2O	0.15	0.12	0.00	0.00%	100.00%

Category code	IPCC Category	Greenhouse Gas	Y2000 Emissions (Gg CO_2 eq)	Y2022 Emissions (Gg CO_2 eq)	Trend Assessment	Percentage contribution to trend assessment	Cumulative Total
3.G.	Liming	CO_2	0.11	0.07	0.00	0.00%	100.00%
1.A.1.	Fuel combustion - Energy Industries - Other Fossil Fuels	CH_4	0.01	0.09	0.00	0.00%	100.00%
4.B.2.	Land Converted to Cropland	CO_2	0.24	0.29	0.00	0.00%	100.00%
3.B.	Manure Management	CH_4	1.56	2.36	0.00	0.00%	100.00%
1.A.4.	Other Sectors - Solid Fuels	N_2O	0.13	0.15	0.00	0.00%	100.00%
2.F.2.	Foam Blowing Agents	HFCs	0.00	0.01	0.00	0.00%	100.00%
5.C.	Incineration and Open Burning of Waste	CH_4	0.00	0.00	0.00	0.00%	100.00%
3.H.	Urea Application	CO_2	0.00	0.00	0.00	0.00%	100.00%
1.A.1.	Fuel combustion - Energy Industries - Biomass	CH_4	0.00	5.25	0.00	0.00%	100.00%
1.A.1.	Fuel combustion - Energy Industries - Biomass	N_2O	0.00	6.63	0.00	0.00%	100.00%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Gaseous Fuels	CH_4	0.00	3.05	0.00	0.00%	100.00%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Gaseous Fuels	CO_2	0.00	6,129.17	0.00	0.00%	100.00%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Gaseous Fuels	N_2O	0.00	2.88	0.00	0.00%	100.00%
1.A.3.a.	Domestic Aviation	CH_4	0.00	0.00	0.00	0.00%	100.00%
1.A.3.a.	Domestic Aviation	CO_2	0.00	2.31	0.00	0.00%	100.00%
1.A.3.a.	Domestic Aviation	N_2O	0.00	0.02	0.00	0.00%	100.00%
1.A.3.	Domestic Navigation - Gaseous Fuels	CH_4	0.00	0.01	0.00	0.00%	100.00%
1.A.3.	Domestic Navigation - Gaseous Fuels	CO_2	0.00	3.15	0.00	0.00%	100.00%
1.A.3.	Domestic Navigation - Gaseous Fuels	N_2O	0.00	0.03	0.00	0.00%	100.00%
1.A.4.	Other Sectors - Gaseous Fuels	CH_4	0.00	0.43	0.00	0.00%	100.00%
1.A.4.	Other Sectors - Gaseous Fuels	CO_2	0.00	173.23	0.00	0.00%	100.00%
1.A.4.	Other Sectors - Gaseous Fuels	N_2O	0.00	0.08	0.00	0.00%	100.00%
1.A.5.	Other (Not specified elsewhere) - Liquid Fuels	CH_4	0.00	0.21	0.00	0.00%	100.00%
1.A.5.	Other (Not specified elsewhere) - Liquid Fuels	CO_2	0.00	250.23	0.00	0.00%	100.00%
1.A.5.	Other (Not specified elsewhere) - Liquid Fuels	N_2O	0.00	1.92	0.00	0.00%	100.00%
4.D.1.2.	Flooded Land Remaining Flooded Land	CO_2	0.00	0.00	0.00	0.00%	100.00%

Table 178: Trend Assessment without LULUCF

Category code	IPCC Category	Greenhouse Gas	Y2000 Emissions (Gg CO_2 eq)	Y2022 Emissions (Gg CO_2 eq)	Trend Assessment	Percentage contribution to trend assessment	Cumulative Total
1.A.1.	Fuel combustion - Energy Industries - Liquid Fuels	CO_2	17,177.75	1,731.51	0.59	46.46%	46.46%
1.A.1.	Fuel combustion - Energy Industries - Gaseous Fuels	CO_2	2,766.79	17,995.15	0.35	27.38%	73.84%
2.F.1.	Refrigeration and air-conditioning	HFCs	137.16	3,973.37	0.10	7.42%	81.26%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	CO_2	10,397.12	12,694.51	0.07	5.20%	86.46%
1.A.3.b.	Road Transportation	CO_2	5,627.65	6,426.02	0.05	3.69%	90.15%
2.E.	Electronics Industry	PFCs	764.06	2,518.74	0.04	2.74%	92.89%
2.B.10.	Other	CO_2	8.39	814.62	0.02	1.58%	94.47%
2.E.	Electronics Industry	NF_3	67.57	644.77	0.01	1.07%	95.54%
1.A.1.	Fuel combustion - Energy Industries - Other Fossil Fuels	CO_2	848.81	1,609.27	0.01	0.70%	96.24%
2.B.8.	Petrochemical and Carbon Black Production	CO_2	137.14	473.42	0.01	0.53%	96.78%
1.A.4.	Other Sectors - Liquid Fuels	CO_2	366.92	278.72	0.01	0.52%	97.29%
2.E.	Electronics Industry	N_2O	32.60	263.88	0.01	0.42%	97.72%
5.C.	Incineration and Open Burning of Waste	CO_2	103.85	304.14	0.00	0.30%	98.02%
1.B.2.c.	Fugitive Emissions from Fuels - Venting and flaring	CO_2	303.11	564.93	0.00	0.23%	98.25%
1.A.3.d.	Domestic Navigation - Liquid Fuels	CO_2	212.78	431.31	0.00	0.23%	98.48%
2.E.	Electronics Industry	HFCs	9.50	117.45	0.00	0.20%	98.68%
5.A.	Solid Waste Disposal	CH_4	64.87	1.80	0.00	0.18%	98.87%
1.A.4.	Other Sectors - Solid Fuels	CO_2	273.49	311.29	0.00	0.18%	99.05%
2.E.	Electronics Industry	SF_6	29.75	128.84	0.00	0.17%	99.22%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Other Fossil Fuels	CO_2	33.13	128.66	0.00	0.16%	99.37%
2.F.3.	Fire Protection	HFCs	0.12	63.89	0.00	0.13%	99.50%
1.A.1.	Fuel combustion - Energy Industries - Liquid Fuels	N_2O	35.32	5.78	0.00	0.09%	99.59%
1.A.3.b.	Road Transportation	N_2O	113.15	135.06	0.00	0.06%	99.65%
1.A.2.c.	Fugitive Emissions from Fuels - Venting and flaring	CH_4	12.48	47.97	0.00	0.06%	99.71%
1.A.1.	Fuel combustion - Energy Industries - Liquid Fuels	CH_4	18.66	1.12	0.00	0.05%	99.76%
2.G.	Other Product Manufacture and Use	SF_6	2.57	25.74	0.00	0.04%	99.81%
2.B.10.	Other	N_2O	0.00	14.94	0.00	0.03%	99.83%
2.F.4.	Aerosols	HFCs	0.18	13.06	0.00	0.03%	99.86%
2.B.8.	Petrochemical and Carbon Black Production	CH_4	0.31	12.10	0.00	0.02%	99.88%
5.D.	Wastewater Treatment and Discharge	N_2O	44.23	75.75	0.00	0.02%	99.90%
2.H.	Other	CO_2	9.44	21.35	0.00	0.01%	99.92%
1.A.1.	Fuel combustion - Energy Industries - Gaseous Fuels	CH_4	1.38	8.98	0.00	0.01%	99.93%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	N_2O	13.66	13.27	0.00	0.01%	99.95%
1.A.1.	Fuel combustion - Energy Industries - Gaseous Fuels	N_2O	1.31	8.50	0.00	0.01%	99.96%
1.A.3.b.	Road Transportation	CH_4	26.25	33.43	0.00	0.01%	99.97%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	CH_4	8.30	8.38	0.00	0.01%	99.98%
1.A.1.	Fuel combustion - Energy Industries - Other Fossil Fuels	N_2O	30.39	48.51	0.00	0.01%	99.98%
5.C.	Incineration and Open Burning of Waste	N_2O	0.84	2.50	0.00	0.00%	99.99%
1.A.3.d.	Domestic Navigation - Liquid Fuels	N_2O	1.52	3.08	0.00	0.00%	99.99%
2.B.10.	Other	CH_4	0.06	0.90	0.00	0.00%	99.99%
3.A.	Enteric Fermentation	CH_4	0.75	0.34	0.00	0.00%	99.99%
3.D.1.	Direct N_2O Emissions From Managed Soils	N_2O	1.72	1.78	0.00	0.00%	99.99%
2.D.	Non-energy Products from Fuels and Solvent Use	CO_2	0.23	0.99	0.00	0.00%	99.99%
1.B.2.c.	Fugitive Emissions from Fuels - Venting and flaring	N_2O	0.25	1.01	0.00	0.00%	99.99%
1.A.4.	Other Sectors - Liquid Fuels	CH_4	0.81	0.62	0.00	0.00%	100.00%
3.B.	Manure Management	N_2O	2.16	2.75	0.00	0.00%	100.00%
3.D.2.	Indirect N_2O Emissions From Managed Soils	N_2O	0.72	0.74	0.00	0.00%	100.00%
1.A.3.d.	Domestic Navigation - Liquid Fuels	CH_4	0.56	1.14	0.00	0.00%	100.00%
1.A.4.	Other Sectors - Solid Fuels	CH_4	0.69	0.78	0.00	0.00%	100.00%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Other Fossil Fuels	N_2O	0.05	0.29	0.00	0.00%	100.00%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Other Fossil Fuels	CH_4	0.02	0.16	0.00	0.00%	100.00%
1.A.4.	Other Sectors - Liquid Fuels	N_2O	0.15	0.12	0.00	0.00%	100.00%
3.G.	Liming	CO_2	0.11	0.07	0.00	0.00%	100.00%
1.A.1.	Fuel combustion - Energy Industries - Other Fossil Fuels	CH_4	0.01	0.09	0.00	0.00%	100.00%
3.B.	Manure Management	CH_4	1.56	2.36	0.00	0.00%	100.00%
1.A.4.	Other Sectors - Solid Fuels	N_2O	0.13	0.15	0.00	0.00%	100.00%
2.F.2.	Foam Blowing Agents	HFCs	0.00	0.01	0.00	0.00%	100.00%
5.C.	Incineration and Open Burning of Waste	CH_4	0.00	0.00	0.00	0.00%	100.00%
3.H.	Urea Application	CO_2	0.00	0.00	0.00	0.00%	100.00%
1.A.1.	Fuel combustion - Energy Industries - Biomass	CH_4	0.00	5.25	0.00	0.00%	100.00%
1.A.1.	Fuel combustion - Energy Industries - Biomass	N_2O	0.00	6.63	0.00	0.00%	100.00%

Category code	IPCC Category	Greenhouse Gas	Y2000 Emissions (Gg CO_2 eq)	Y2022 Emissions (Gg CO_2 eq)	Trend Assessment	Percentage contribution to trend assessment	Cumulative Total
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Gaseous Fuels	CH_4	0.00	3.05	0.00	0.00%	100.00%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Gaseous Fuels	CO_2	0.00	6,129.17	0.00	0.00%	100.00%
1.A.2.	Fuel combustion - Manufacturing Industries and Construction - Gaseous Fuels	N_2O	0.00	2.88	0.00	0.00%	100.00%
1.A.3.a.	Domestic Aviation	CH_4	0.00	0.00	0.00	0.00%	100.00%
1.A.3.a.	Domestic Aviation	CO_2	0.00	2.31	0.00	0.00%	100.00%
1.A.3.a.	Domestic Aviation	N_2O	0.00	0.02	0.00	0.00%	100.00%
1.A.3.d.	Domestic Navigation - Gaseous Fuels	CH_4	0.00	0.01	0.00	0.00%	100.00%
1.A.3.d.	Domestic Navigation - Gaseous Fuels	CO_2	0.00	3.15	0.00	0.00%	100.00%
1.A.3.d.	Domestic Navigation - Gaseous Fuels	N_2O	0.00	0.03	0.00	0.00%	100.00%
1.A.4.	Other Sectors - Gaseous Fuels	CH_4	0.00	0.43	0.00	0.00%	100.00%
1.A.4.	Other Sectors - Gaseous Fuels	CO_2	0.00	173.23	0.00	0.00%	100.00%
1.A.4.	Other Sectors - Gaseous Fuels	N_2O	0.00	0.08	0.00	0.00%	100.00%
1.A.5.	Other (Not specified elsewhere) - Liquid Fuels	CH_4	0.00	0.21	0.00	0.00%	100.00%
1.A.5.	Other (Not specified elsewhere) - Liquid Fuels	CO_2	0.00	250.23	0.00	0.00%	100.00%
1.A.5.	Other (Not specified elsewhere) - Liquid Fuels	N_2O	0.00	1.92	0.00	0.00%	100.00%

Annex II: Uncertainty assessment

Description of methodology used for identifying uncertainties

Overall Quantitative Assessment of Uncertainty of Singapore's National Inventory

As Singapore's first BTR submission, this report includes a quantitative uncertainty analysis on the emission and removal estimates for the base and latest reporting year.

Approach 1 – Propagation of Error, as described in the 2006 IPCC Guidelines, was used for combining the overall uncertainties and for most categories, with the exception of a few specific categories which used Approach 2 – Monte Carlo Analysis.

The uncertainty estimates were quantified with a conservative approach, with most categories using default uncertainty values referenced from the 2006 IPCC Guidelines. Uncertainties reported under the CPA uses a framework developed based on a combination of the 2006 IPCC Guidelines, API Compendium, the National Greenhouse and Energy Reporting (NGER) Measurement Determination 2008, and expert judgement.

Data considerations and Methodology for overall uncertainty and trend uncertainty

Uncertainty for emission streams that is indicated as IE is estimated together with uncertainty calculations for the subcategory in which the emission streams are included. This ensures adherence to the methodology used for calculating emissions for the national inventory as well as protection of data confidentiality where applicable.

The emissions of year 2000 from many categories are estimated using backward projection and splicing using manufacturing data output and the emissions data from recent years. Although the current uncertainty estimates for base year only account for the uncertainty from the activity data and emission factor, it is noted that there may be uncertainty associated with the back projection methodology and from the proxy data used. However, the additional quantitative uncertainty from the projection methodology and use of proxy data have not been estimated for this BTR due to lack of capacity. Hence, the uncertainty estimates for base year will be revised to include the additional uncertainty in the subsequent BTR submissions.

Uncertainty contributions from LULUCF sector

While there is high inherent uncertainty in the net GHG emissions/removals in the LULUCF sector, the overall contribution of LULUCF's emissions to the national GHG inventory is comparatively small. Hence, the impact on overall inventory uncertainty as a result of LULUCF sector is capped.

Table 179: Summary of Uncertainties (inclusive of LULUCF)

Emissions (Gg CO_2 eq)	Base Year (2000)	Reporting Year (2022)
Year Uncertainty (%)	7.0	6.9
Trend Uncertainty (%)	5.4	6.5

Uncertainty estimation methodology implemented for Agriculture

Approach 1 – Propagation of Error, as described in the 2006 IPCC Guidelines, was used for combining the overall uncertainties. As Tier 1 methodology was used, default uncertainty values for the default emission factors provided in the 2006 IPCC Guidelines were used. For activity data, uncertainty was estimated based on the data collection methodology.

Uncertainty estimation methodology implemented for LULUCF

The uncertainty analysis for the whole LULUCF sector was carried out using Approach 2 – Monte-Carlo simulations (MCS) – with @Risk software. For 2000 to 2022, the uncertainty of the total LULUCF sector net removals are ±48 Gg CO_2 eq, with Singapore's *Forest Land* and dynamic *Settlements* category contributing the most to the total LULUCF uncertainty. In the *Settlements* category, there were significant carbon gains and losses due to land use changes.

To perform the uncertainty analysis, the uncertainties of all activity data, emission factors, and input parameters for the emission factors were defined. For each subcategory, a bottom-up analysis of the uncertainties of the estimated emissions/removals figures for subcategories was carried out. Almost all pools and gases were included in this analysis, with the exception of inputs that have a negligible contribution to the total uncertainty which were not included. The correlations between parameters were taken into consideration and each simulation was run with 10,000 iteration steps. Subsequently, the uncertainties of all individual subcategories were then merged with the total uncertainty of the LULUCF sector emissions and removals by MCS. The uncertainty values in LULUCF cover the range of the 95% confidence interval (the distance of twice the SD from the mean), which is in line with the 2006 IPCC Guidelines.

Uncertainty estimates for the LULUCF sector are inherently high due to the large number of input parameters, and the nature of parameters used in the sector which may have varying inherent uncertainty and non-normal distributions. MCS was also necessary due to the correlations between activity parameters.

Furthermore, the LULUCF sector is the only sector where the GHG inventory is calculated based on subtractions between emissions and removals (or stocks) in pools, in subcategories and across subcategories. Such subtractions lead to low net results for the GHG emissions or removals, but the uncertainty remains at the same magnitude as the input parameters to the subtractions.

Uncertainty estimates from MCS are expected to remain stable across time and will not change until further methodological improvements are carried out. Therefore, there are only singular uncertainty estimates for each category across both 2000 and 2022.

Table 3.3 of volume 1 of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories

Table 180: Uncertainty assessment for the inventory for base year 2000

				Base year emissions / removals	Base year emissions / removals	Activity data uncertainty		Emission factor/ estimation parameter uncertainty (combined if more than one estimation parameter is used)		Combined uncertainty		Contribution to variance in year t	Inventory trend in national emissions for year t increase with respect to base year	Uncertainty introduced into the trend in total national emissions with respect to base year		Approach and comments
Inventory sector	IPCC category code	IPCC category name	Gas	Gg CO_2 eq	Gg CO_2 eq	(-) %	(+)%	(-) %	(+)%	(-) %	(+)%	(fraction)	(% of base year)	(-) %	(+)%	Approach 1/ Approach 2
Energy	1.A.1.a.i.	Electricity generation, Liquid fuels	CO_2	17,177.75	17,177.75	2	2	2	2	3	3	2	0	1.2	1.2	Approach 1
Energy	1.A.1.a.i.	Electricity generation, Liquid fuels	CH_4	18.66	18.66	2	2	150	150	150	150	0	0	0.0	0.0	Approach 1
Energy	1.A.1.a.i.	Electricity generation, Liquid fuels	N_2O	35.32	35.32	2	2	200	200	200	200	0	0	0.0	0.0	Approach 1
Energy	1.A.1.a.i.	Electricity generation, Gaseous fuels	CO_2	2,766.79	2,766.79	2	2	2	2	3	3	0	0	0.2	0.2	Approach 1
Energy	1.A.1.a.i.	Electricity generation, Gaseous fuels	CH_4	1.38	1.38	2	2	150	150	150	150	0	0	0.0	0.0	Approach 1
Energy	1.A.1.a.i.	Electricity generation, Gaseous fuels	N_2O	1.31	1.31	2	2	200	200	200	200	0	0	0.0	0.0	Approach 1
Energy	1.A.1.a.ii.	Combined heat and power generation, Other fossil fuels	CO_2	848.81	848.81	2	2	2	2	3	3	0	0	0.1	0.1	Approach 1
Energy	1.A.1.a.ii.	Combined heat and power generation, Other fossil fuels	CH_4	0.01	0.01	2	2	150	150	150	150	0	0	0.0	0.0	Approach 1
Energy	1.A.1.a.ii.	Combined heat and power generation, Other fossil fuels	N_2O	30.39	30.39	2	2	200	200	200	200	0	0	0.0	0.0	Approach 1
Energy	1.A.1.a.ii.	Combined heat and power generation, Biomass	CO_2	0.00	0.00	2	2	2	2	3	3	0	NA	0.0	0.0	Approach 1
Energy	1.A.1.a.ii.	Combined heat and power generation, Biomass	CH_4	0.00	0.00	2	2	150	150	150	150	0	NA	0.0	0.0	Approach 1
Energy	1.A.1.a.ii.	Combined heat and power generation, Biomass	N_2O	0.00	0.00	2	2	200	200	200	200	0	NA	0.0	0.0	Approach 1
Energy	1.A.2.c.	Chemicals, Liquid fuels	CO_2	9,143.31	9,143.31	15	15	2	2	15	15	12	0	4.9	4.9	Approach 1

				Base year emissions / removals	Base year emissions / removals	Activity data uncertainty		Emission factor/ estimation parameter uncertainty (combined if more than one estimation parameter is used)		Combined uncertainty		Contribution to variance in year t	Inventory trend in national emissions for year t increase with respect to base year	Uncertainty introduced into the trend in total national emissions with respect to base year		Approach and comments
Inventory sector	IPCC category code	IPCC category name	Gas	Gg CO_2 eq	Gg CO_2 eq	(-) %	(+)%	(-) %	(+)%	(-) %	(+)%	(fraction)	(% of base year)	(-) %	(+)%	Approach 1/ Approach 2
Energy	1.A.2.c.	Chemicals, Liquid fuels	CH_4	6.91	6.91	15	15	150	150	151	151	0	0	0.0	0.0	Approach 1
Energy	1.A.2.c.	Chemicals, Liquid fuels	N_2O	11.03	11.03	15	15	200	200	201	201	0	0	0.0	0.0	Approach 1
Energy	1.A.2.c.	Chemicals, Gaseous fuels	CO_2	0.00	0.00	15	15	2	2	15	15	0	NA	0.0	0.0	Approach 1
Energy	1.A.2.c.	Chemicals, Gaseous fuels	CH_4	0.00	0.00	15	15	150	150	151	151	0	NA	0.0	0.0	Approach 1
Energy	1.A.2.c.	Chemicals, Gaseous fuels	N_2O	0.00	0.00	15	15	200	200	201	201	0	NA	0.0	0.0	Approach 1
Energy	1.A.2.c.	Chemicals, Other fossil fuels	CO_2	33.13	33.13	15	15	2	2	15	15	0	0	0.0	0.0	Approach 1
Energy	1.A.2.c.	Chemicals, Other fossil fuels	CH_4	0.02	0.02	15	15	150	150	151	151	0	0	0.0	0.0	Approach 1
Energy	1.A.2.c.	Chemicals, Other fossil fuels	N_2O	0.05	0.05	15	15	200	200	201	201	0	0	0.0	0.0	Approach 1
Energy	1.A.2.g.viii.	Other, Liquid fuels	CO_2	1,253.81	1,253.81	15	15	2	2	15	15	0	0	0.7	0.7	Approach 1
Energy	1.A.2.g.viii.	Other, Liquid fuels	CH_4	1.39	1.39	15	15	150	150	151	151	0	0	0.0	0.0	Approach 1
Energy	1.A.2.g.viii.	Other, Liquid fuels	N_2O	2.63	2.63	15	15	200	200	201	201	0	0	0.0	0.0	Approach 1
Energy	1.A.2.g.viii.	Other, Gaseous fuels	CO_2	0.00	0.00	15	15	2	2	15	15	0	NA	0.0	0.0	Approach 1
Energy	1.A.2.g.viii.	Other, Gaseous fuels	CH_4	0.00	0.00	15	15	150	150	151	151	0	NA	0.0	0.0	Approach 1
Energy	1.A.2.g.viii.	Other, Gaseous fuels	N_2O	0.00	0.00	15	15	200	200	201	201	0	NA	0.0	0.0	Approach 1
Energy	1.A.3.a.	Domestic aviation, Aviation gasoline	CO_2	0.00	0.00	5	5	5	5	7	7	0	NA	0.0	0.0	Approach 1
Energy	1.A.3.a.	Domestic aviation, Aviation gasoline	CH_4	0.00	0.00	5	5	100	100	100	100	0	NA	0.0	0.0	Approach 1
Energy	1.A.3.a.	Domestic aviation, Aviation gasoline	N_2O	0.00	0.00	5	5	150	150	150	150	0	NA	0.0	0.0	Approach 1
Energy	1.A.3.a.	Domestic aviation, Jet kerosene	CO_2	0.00	0.00	5	5	5	5	7	7	0	NA	0.0	0.0	Approach 1
Energy	1.A.3.a.	Domestic aviation, Jet kerosene	CH_4	0.00	0.00	5	5	100	100	100	100	0	NA	0.0	0.0	Approach 1
Energy	1.A.3.a.	Domestic aviation, Jet kerosene	N_2O	0.00	0.00	5	5	150	150	150	150	0	NA	0.0	0.0	Approach 1
Energy	1.A.3.b.	Road transportation, Gasoline	CO_2	2,081.15	2,081.15	5	5	5	5	7	7	0.1	0	0.4	0.4	Approach 1
Energy	1.A.3.b.	Road transportation, Gasoline	CH_4	21.02	21.02	5	5	223	223	223	223	0.0	0	0.0	0.0	Approach 1
Energy	1.A.3.b.	Road transportation, Gasoline	N_2O	63.67	63.67	5	5	244	244	244	244	0.2	0	0.0	0.0	Approach 1

Inventory sector	IPCC category code	IPCC category name	Gas	Base year emissions / removals	Base year emissions / removals	Activity data uncertainty		Emission factor/ estimation parameter uncertainty (combined if more than one estimation parameter is used)		Combined uncertainty		Contribution to variance in year t	Inventory trend in national emissions for year t increase with respect to base year	Uncertainty introduced into the trend in total national emissions with respect to base year		Approach and comments
				Gg CO_2 eq	Gg CO_2 eq	(-) %	(+)%	(-) %	(+)%	(-) %	(+)%	(fraction)	(% of base year)	(-) %	(+)%	Approach 1/ Approach 2
Energy	1.A.3.b.	Road transportation, Diesel oil	CO_2	3,546.51	3,546.51	5	5	2	2	5	5	0.2	0	0.6	0.6	Approach 1
Energy	1.A.3.b.	Road transportation, Diesel oil	CH_4	5.23	5.23	5	5	144	144	144	144	0.0	0	0.0	0.0	Approach 1
Energy	1.A.3.b.	Road transportation, Diesel oil	N_2O	49.49	49.49	5	5	207	207	207	207	0.1	0	0.0	0.0	Approach 1
Energy	1.A.3.b.	Road transportation, Gaseous fuels	CO_2	0.00	0.00	5	5	4	4	6	6	0.0	NA	0.0	0.0	Approach 1
Energy	1.A.3.b.	Road transportation, Gaseous fuels	CH_4	0.00	0.00	5	5	1,574	1,574	1,574	1,574	0.0	NA	0.0	0.0	Approach 1
Energy	1.A.3.b.	Road transportation, Gaseous fuels	N_2O	0.00	0.00	5	5	2,466	2,466	2,466	2,466	0.0	NA	0.0	0.0	Approach 1
Energy	1.A.3.d.	Domestic navigation, Gas/diesel oil	CO_2	212.78	212.78	5	5	1.5	1.5	5	5	0.0	0	0.0	0.0	Approach 1
Energy	1.A.3.d.	Domestic navigation, Gas/diesel oil	CH_4	0.56	0.56	5	5	50	50	50	50	0.0	0	0.0	0.0	Approach 1
Energy	1.A.3.d.	Domestic navigation, Gas/diesel oil	N_2O	1.52	1.52	5	5	140	140	140	140	0.0	0	0.0	0.0	Approach 1
Energy	1.A.3.d.	Domestic navigation, Gaseous fuels	CO_2	0.00	0.00	5	5	4	4	6	6	0.0	NA	0.0	0.0	Approach 1
Energy	1.A.3.d.	Domestic navigation, Gaseous fuels	CH_4	0.00	0.00	5	5	1,540	1,540	1,540	1,540	0.0	NA	0.0	0.0	Approach 1
Energy	1.A.3.d.	Domestic navigation, Gaseous fuels	N_2O	0.00	0.00	5	5	2,467	2,467	2,467	2,467	0.0	NA	0.0	0.0	Approach 1
Energy	1.A.4.a.	Commercial/ institutional, Liquid fuels	CO_2	123.44	123.44	15	15	1	1	15	15	0.0	0	0.1	0.1	Approach 1
Energy	1.A.4.a.	Commercial/ institutional, Liquid fuels	CH_4	0.27	0.27	15	15	150	150	151	151	0.0	0	0.0	0.0	Approach 1
Energy	1.A.4.a.	Commercial/ institutional, Liquid fuels	N_2O	0.05	0.05	15	15	200	200	201	201	0.0	0	0.0	0.0	Approach 1
Energy	1.A.4.a.	Commercial/ institutional, Solid fuels	CO_2	171.11	171.11	15	15	1	1	15	15	0.0	0	0.1	0.1	Approach 1
Energy	1.A.4.a.	Commercial/ institutional, Solid fuels	CH_4	0.43	0.43	15	15	150	150	151	151	0.0	0	0.0	0.0	Approach 1

Inventory sector	IPCC category code	IPCC category name	Gas	Base year emissions / removals	Base year emissions / removals	Activity data uncertainty		Emission factor/ estimation parameter uncertainty (combined if more than one estimation parameter is used)		Combined uncertainty		Contribution to variance in year t	Inventory trend in national emissions for year t increase with respect to base year	Uncertainty introduced into the trend in total national emissions with respect to base year		Approach and comments
				Gg CO_2 eq	Gg CO_2 eq	(-) %	(+)%	(-) %	(+)%	(-) %	(+)%	(fraction)	(% of base year)	(-) %	(+)%	Approach 1/ Approach 2
Energy	1.A.4.a.	Commercial/ institutional, Solid fuels	N_2O	0.08	0.08	15	15	200	200	201	201	0.0	0	0.0	0.0	Approach 1
Energy	1.A.4.a.	Commercial/ institutional, Gaseous fuels	CO_2	0.00	0.00	15	15	1	1	15	15	0.0	NA	0.0	0.0	Approach 1
Energy	1.A.4.a.	Commercial/ institutional, Gaseous fuels	CH_4	0.00	0.00	15	15	150	150	151	151	0.0	NA	0.0	0.0	Approach 1
Energy	1.A.4.a.	Commercial/ institutional, Gaseous fuels	N_2O	0.00	0.00	15	15	200	200	201	201	0.0	NA	0.0	0.0	Approach 1
Energy	1.A.4.b.	Residential, Liquid fuels	CO_2	243.48	243.48	15	15	1	1	15	15	0.0	0	0.1	0.1	Approach 1
Energy	1.A.4.b.	Residential, Liquid fuels	CH_4	0.54	0.54	15	15	150	150	151	151	0.0	0	0.0	0.0	Approach 1
Energy	1.A.4.b.	Residential, Liquid fuels	N_2O	0.10	0.10	15	15	200	200	201	201	0.0	0	0.0	0.0	Approach 1
Energy	1.A.4.b.	Residential, Solid fuels	CO_2	102.39	102.39	15	15	1	1	15	15	0.0	0	0.1	0.1	Approach 1
Energy	1.A.4.b.	Residential, Solid fuels	CH_4	0.26	0.26	15	15	150	150	151	151	0.0	0	0.0	0.0	Approach 1
Energy	1.A.4.b.	Residential, Solid fuels	N_2O	0.05	0.05	15	15	200	200	201	201	0.0	0	0.0	0.0	Approach 1
Energy	1.A.5.b.	Mobile, Liquid fuels	CO_2	0.00	0.00	0	0	0	0	0	0	0.0	NA	0.0	0.0	Approach 1
Energy	1.A.5.b.	Mobile, Liquid fuels	CH_4	0.00	0.00	0	0	0	0	0	0	0.0	NA	0.0	0.0	Approach 1
Energy	1.A.5.b.	Mobile, Liquid fuels	N_2O	0.00	0.00	0	0	0	0	0	0	0.0	NA	0.0	0.0	Approach 1
Energy	1.B.2.c.	Flaring, Oil	CO_2	303.11	303.11	17	17	75	75	77	77	0.3	0	0.2	0.2	Approach 1
Energy	1.B.2.c.	Flaring, Oil	CH_4	12.48	12.48	17	17	75	75	77	77	0.0	0	0.0	0.0	Approach 1
Energy	1.B.2.c.	Flaring, Oil	N_2O	0.63	0.63	17	17	1,000	1,000	1,000	1,000	0.0	0	0.0	0.0	Approach 1
IPPU	2.B.8.g.	Other	CO_2	137.14	137.14	17	17	75	75	77	77	0.1	0	0.1	0.1	Approach 1
IPPU	2.B.10.b.	Other	CO_2	8.39	8.39	17	17	75	75	77	77	0.0	0	0.0	0.0	Approach 1
IPPU	2.B.10.b.	Other	CH_4	0.31	0.31	17	17	75	75	77	77	0.0	0	0.0	0.0	Approach 1
IPPU	2.B.10.b.	Other	N_2O	0.06	0.06	17	17	1,000	1,000	1,000	1,000	0.0	0	0.0	0.0	Approach 1
IPPU	2.D.1.	Lubricant use	CO_2	0.23	0.23	20	20	50	50	54	54	0.0	0	0.0	0.0	Approach 1
IPPU	2.E.1.	Integrated circuit or semiconductor	CO_2	0.09	0.09	10	10	200	200	200	200	0.0	0	0.0	0.0	Approach 1
IPPU	2.E.1.	Integrated circuit or semiconductor	CH_4	0.00	0.00	10	10	200	200	200	200	0.0	NA	0.0	0.0	Approach 1

				Base year emissions / removals	Base year emissions / removals	Activity data uncertainty		Emission factor/ estimation parameter uncertainty (combined if more than one estimation parameter is used)		Combined uncertainty		Contribution to variance in year t	Inventory trend in national emissions for year t increase with respect to base year	Uncertainty introduced into the trend in total national emissions with respect to base year		Approach and comments
Inventory sector	IPCC category code	IPCC category name	Gas	Gg CO_2 eq	Gg CO_2 eq	(-) %	(+)%	(-) %	(+)%	(-) %	(+)%	(fraction)	(% of base year)	(-) %	(+)%	Approach 1/ Approach 2
IPPU	2.E.1.	Integrated circuit or semiconductor	N_2O	32.51	32.51	10	10	200	200	200	200	0.0	0	0.0	0.0	Approach 1
IPPU	2.E.1.	Integrated circuit or semiconductor	HFC-23	9.50	9.50	10	10	200	200	200	200	0.0	0	0.0	0.0	Approach 1
IPPU	2.E.1.	Integrated circuit or semiconductor	HFC-32	0.00	0.00	10	10	200	200	200	200	0.0	0	0.0	0.0	Approach 1
IPPU	2.E.1.	Integrated circuit or semiconductor	NF_3	67.57	67.57	10	10	200	200	200	200	0.1	0	0.0	0.0	Approach 1
IPPU	2.E.1.	Integrated circuit or semiconductor	PFC-116	269.54	269.54	10	10	200	200	200	200	1.9	0	0.1	0.1	Approach 1
IPPU	2.E.1.	Integrated circuit or semiconductor	PFC-14	492.39	492.39	10	10	200	200	200	200	6.2	0	0.2	0.2	Approach 1
IPPU	2.E.1.	Integrated circuit or semiconductor	PFC-c318	2.13	2.13	10	10	200	200	200	200	0.0	0	0.0	0.0	Approach 1
IPPU	2.E.1.	Integrated circuit or semiconductor	SF_6	29.75	29.75	10	10	200	200	200	200	0.0	0	0.0	0.0	Approach 1
IPPU	2.F.1.a.	Commercial refrigeration, in operating systems	HFC-125	0.00	0.00	1	1	0	0	1	1	0.0	NA	0.0	0.0	Approach 2
IPPU	2.F.1.a.	Commercial refrigeration, in operating systems	HFC-134	0.00	0.00	1	1	0	0	1	1	0.0	NA	0.0	0.0	Approach 2
IPPU	2.F.1.a.	Commercial refrigeration, in operating systems	HFC-134a	21.46	21.46	1	1	0	0	1	1	0.0	0	0.0	0.0	Approach 2
IPPU	2.F.1.a.	Commercial refrigeration, in operating systems	HFC-143a	0.00	0.00	1	1	0	0	1	1	0.0	NA	0.0	0.0	Approach 2
IPPU	2.F.1.a.	Commercial refrigeration, in operating systems	HFC-32	0.00	0.00	1	1	0	0	1	1	0.0	NA	0.0	0.0	Approach 2
IPPU	2.F.1.a.	Commercial refrigeration, remaining at decommissioning	HFC-125	0.00	0.00	1	1	0	0	1	1	0.0	NA	0.0	0.0	Approach 2
IPPU	2.F.1.a.	Commercial refrigeration, remaining at decommissioning	HFC-134	0.00	0.00	1	1	0	0	1	1	0.0	NA	0.0	0.0	Approach 2
IPPU	2.F.1.a.	Commercial refrigeration, remaining at decommissioning	HFC-134a	4.37	4.37	1	1	0	0	1	1	0.0	0	0.0	0.0	Approach 2

				Base year emissions / removals	Base year emissions / removals	Activity data uncertainty		Emission factor/ estimation parameter uncertainty (combined if more than one estimation parameter is used)		Combined uncertainty		Contribution to variance in year t	Inventory trend in national emissions for year t increase with respect to base year	Uncertainty introduced into the trend in total national emissions with respect to base year		Approach and comments
Inventory sector	IPCC category code	IPCC category name	Gas	Gg CO_2 eq	Gg CO_2 eq	(-) %	(+)%	(-) %	(+)%	(-) %	(+)%	(fraction)	(% of base year)	(-) %	(+)%	Approach 1/ Approach 2
IPPU	2.F.1.a.	Commercial refrigeration, remaining at decommissioning	HFC-143a	0.00	0.00	1	1	0	0	1	1	0.0	NA	0.0	0.0	Approach 2
IPPU	2.F.1.a.	Commercial refrigeration, remaining at decommissioning	HFC-32	0.00	0.00	1	1	0	0	1	1	0.0	NA	0.0	0.0	Approach 2
IPPU	2.F.1.a.	Commercial refrigeration, recovery	HFC-125	0.00	0.00	1	1	0	0	1	1	0.0	NA	0.0	0.0	Approach 2
IPPU	2.F.1.a.	Commercial refrigeration, recovery	HFC-134a	0.00	0.00	1	1	0	0	1	1	0.0	NA	0.0	0.0	Approach 2
IPPU	2.F.1.a.	Commercial refrigeration, recovery	HFC-143a	0.00	0.00	1	1	0	0	1	1	0.0	NA	0.0	0.0	Approach 2
IPPU	2.F.1.a.	Commercial refrigeration, recovery	HFC-32	0.00	0.00	1	1	0	0	1	1	0.0	NA	0.0	0.0	Approach 2
IPPU	2.F.1.b.	Domestic refrigeration, in operating systems	HFC-134a	0.24	0.24	3	3	0	0	3	3	0.0	0	0.0	0.0	Approach 2
IPPU	2.F.1.b.	Domestic refrigeration, in operating systems	HFC-152a	0.00	0.00	3	3	0	0	3	3	0.0	0	0.0	0.0	Approach 2
IPPU	2.F.1.b.	Domestic refrigeration, remaining at decommissioning	HFC-134a	3.71	3.71	3	3	0	0	3	3	0.0	0	0.0	0.0	Approach 2
IPPU	2.F.1.b.	Domestic refrigeration, remaining at decommissioning	HFC-152a	0.02	0.02	3	3	0	0	3	3	0.0	0	0.0	0.0	Approach 2
IPPU	2.F.1.c.	Industrial refrigeration, in operating systems	HFC-125	2.02	2.02	10	10	0	0	10	10	0.0	0	0.0	0.0	Approach 2
IPPU	2.F.1.c.	Industrial refrigeration, in operating systems	HFC-134a	13.96	13.96	10	10	0	0	10	10	0.0	0	0.0	0.0	Approach 2
IPPU	2.F.1.c.	Industrial refrigeration, in operating systems	HFC-143a	3.61	3.61	10	10	0	0	10	10	0.0	0	0.0	0.0	Approach 2

Inventory sector	IPCC category code	IPCC category name	Gas	Base year emissions / removals	Base year emissions / removals	Activity data uncertainty		Emission factor/ estimation parameter uncertainty (combined if more than one estimation parameter is used)		Combined uncertainty		Contribution to variance in year t	Inventory trend in national emissions for year t increase with respect to base year	Uncertainty introduced into the trend in total national emissions with respect to base year		Approach and comments
				Gg CO_2 eq	Gg CO_2 eq	(-) %	(+)%	(-) %	(+)%	(-) %	(+)%	(fraction)	(% of base year)	(-) %	(+)%	Approach 1/ Approach 2
IPPU	2.F.1.c.	Industrial refrigeration, in operating systems	HFC-32	0.00	0.00	10	10	0	0	10	10	0.0	NA	0.0	0.0	Approach 2
IPPU	2.F.1.c.	Industrial refrigeration, remaining at decommissioning	HFC-125	0.00	0.00	10	10	0	0	10	10	0.0	NA	0.0	0.0	Approach 2
IPPU	2.F.1.c.	Industrial refrigeration, remaining at decommissioning	HFC-134a	0.00	0.00	10	10	0	0	10	10	0.0	NA	0.0	0.0	Approach 2
IPPU	2.F.1.c.	Industrial refrigeration, remaining at decommissioning	HFC-143a	0.00	0.00	10	10	0	0	10	10	0.0	NA	0.0	0.0	Approach 2
IPPU	2.F.1.c.	Industrial refrigeration, remaining at decommissioning	HFC-32	0.00	0.00	10	10	0	0	10	10	0.0	NA	0.0	0.0	Approach 2
IPPU	2.F.1.d.	Transport refrigeration, in operating systems	HFC-125	0.17	0.17	21	21	0	0	21	21	0.0	0	0.0	0.0	Approach 2
IPPU	2.F.1.d.	Transport refrigeration, in operating systems	HFC-134a	0.46	0.46	21	21	0	0	21	21	0.0	0	0.0	0.0	Approach 2
IPPU	2.F.1.d.	Transport refrigeration, in operating systems	HFC-143a	0.46	0.46	21	21	0	0	21	21	0.0	0	0.0	0.0	Approach 2
IPPU	2.F.1.d.	Transport refrigeration, remaining at decommissioning	HFC-125	0.00	0.00	21	21	0	0	21	21	0.0	NA	0.0	0.0	Approach 2
IPPU	2.F.1.d.	Transport refrigeration, remaining at decommissioning	HFC-134a	0.00	0.00	21	21	0	0	21	21	0.0	NA	0.0	0.0	Approach 2
IPPU	2.F.1.d.	Transport refrigeration, remaining at decommissioning	HFC-143a	0.00	0.00	21	21	0	0	21	21	0.0	NA	0.0	0.0	Approach 2
IPPU	2.F.1.d.	Transport refrigeration, recovery	HFC-125	0.00	0.00	21	21	0	0	21	21	0.0	NA	0.0	0.0	Approach 2

Inventory sector	IPCC category code	IPCC category name	Gas	Base year emissions / removals	Base year emissions / removals	Activity data uncertainty		Emission factor/ estimation parameter uncertainty (combined if more than one estimation parameter is used)		Combined uncertainty		Contribution to variance in year t	Inventory trend in national emissions for year t increase with respect to base year	Uncertainty introduced into the trend in total national emissions with respect to base year		Approach and comments
				Gg CO_2 eq	Gg CO_2 eq	(-) %	(+)%	(-) %	(+)%	(-) %	(+)%	(fraction)	(% of base year)	(-) %	(+)%	Approach 1/ Approach 2
IPPU	2.F.1.d.	Transport refrigeration, recovery	HFC-134a	0.00	0.00	21	21	0	0	21	21	0.0	NA	0.0	0.0	Approach 2
IPPU	2.F.1.d.	Transport refrigeration, recovery	HFC-143a	0.00	0.00	21	21	0	0	21	21	0.0	NA	0.0	0.0	Approach 2
IPPU	2.F.1.e.	Mobile air-conditioning, in operating systems	HFC-134a	77.70	77.70	100	100	0	0	100	100	0.0	0	0.3	0.3	Approach 2
IPPU	2.F.1.e.	Mobile air-conditioning, in operating systems	HFC-152a	0.00	0.00	100	100	0	0	100	100	0.0	0	0.0	0.0	Approach 2
IPPU	2.F.1.e.	Mobile air-conditioning, in operating systems	HFO-1234yf	0.00	0.00	100	100	0	0	100	100	0.0	NA	0.0	0.0	Approach 2
IPPU	2.F.1.e.	Mobile air-conditioning, in operating systems	HFC-32	0.34	0.34	100	100	0	0	100	100	0.0	0	0.0	0.0	Approach 2
IPPU	2.F.1.e.	Mobile air-conditioning, in operating systems	HFC-125	1.75	1.75	100	100	0	0	100	100	0.0	0	0.0	0.0	Approach 2
IPPU	2.F.1.e.	Mobile air-conditioning, remaining at decommissioning	HFC-134a	0.00	0.00	100	100	0	0	100	100	0.0	NA	0.0	0.0	Approach 2
IPPU	2.F.1.e.	Mobile air-conditioning, remaining at decommissioning	HFC-152a	0.00	0.00	100	100	0	0	100	100	0.0	NA	0.0	0.0	Approach 2
IPPU	2.F.1.e.	Mobile air-conditioning, recovery	HFC-134a	0.00	0.00	100	100	0	0	100	100	0.0	NA	0.0	0.0	Approach 2
IPPU	2.F.1.e.	Mobile air-conditioning, recovery	HFC-32	0.00	0.00	100	100	0	0	100	100	0.0	NA	0.0	0.0	Approach 2
IPPU	2.F.1.e.	Mobile air-conditioning, recovery	HFC-125	0.00	0.00	100	100	0	0	100	100	0.0	NA	0.0	0.0	Approach 2
IPPU	2.F.1.f.	Stationary air-conditioning, in operating systems	HFC-125	0.25	0.25	130	130	0	0	130	130	0.0	0	0.0	0.0	Approach 2

Inventory sector	IPCC category code	IPCC category name	Gas	Base year emissions / removals	Base year emissions / removals	Activity data uncertainty		Emission factor/ estimation parameter uncertainty (combined if more than one estimation parameter is used)		Combined uncertainty		Contribution to variance in year t	Inventory trend in national emissions for year t increase with respect to base year	Uncertainty introduced into the trend in total national emissions with respect to base year		Approach and comments
				Gg CO_2 eq	Gg CO_2 eq	(-) %	(+)%	(-) %	(+)%	(-) %	(+)%	(fraction)	(% of base year)	(-) %	(+)%	Approach 1/ Approach 2
IPPU	2.F.1.f.	Stationary air-conditioning, in operating systems	HFC-134a	6.57	6.57	130	130	0	0	130	130	0.0	0	0.0	0.0	Approach 2
IPPU	2.F.1.f.	Stationary air-conditioning, in operating systems	HFC-143a	0.00	0.00	130	130	0	0	130	130	0.0	NA	0.0	0.0	Approach 2
IPPU	2.F.1.f.	Stationary air-conditioning, in operating systems	HFC-32	0.05	0.05	130	130	0	0	130	130	0.0	0	0.0	0.0	Approach 2
IPPU	2.F.1.f.	Stationary air-conditioning, in operating systems	HFO-1336mzz	0.00	0.00	130	130	0	0	130	130	0.0	NA	0.0	0.0	Approach 2
IPPU	2.F.1.f.	Stationary air-conditioning, remaining at decommissioning	HFC-125	0.00	0.00	130	130	0	0	130	130	0.0	NA	0.0	0.0	Approach 2
IPPU	2.F.1.f.	Stationary air-conditioning, remaining at decommissioning	HFC-134a	0.00	0.00	130	130	0	0	130	130	0.0	NA	0.0	0.0	Approach 2
IPPU	2.F.1.f.	Stationary air-conditioning, remaining at decommissioning	HFC-32	0.00	0.00	130	130	0	0	130	130	0.0	NA	0.0	0.0	Approach 2
IPPU	2.F.1.f.	Stationary air-conditioning, recovery	HFC-125	0.00	0.00	130	130	0	0	130	130	0.0	NA	0.0	0.0	Approach 2
IPPU	2.F.1.f.	Stationary air-conditioning, recovery	HFC-134a	0.00	0.00	130	130	0	0	130	130	0.0	NA	0.0	0.0	Approach 2
IPPU	2.F.1.f.	Stationary air-conditioning, recovery	HFC-32	0.00	0.00	130	130	0	0	130	130	0.0	NA	0.0	0.0	Approach 2
IPPU	2.F.2.a.	Closed cells, from stocks	HFC-134a	0.00	0.00	49	49	0	0	49	49	0.0	0	0.0	0.0	Approach 2
IPPU	2.F.2.a.	Closed cells, from stocks	HFC-152a	0.00	0.00	49	49	0	0	49	49	0.0	NA	0.0	0.0	Approach 2
IPPU	2.F.2.a.	Closed cells, from stocks	HFC-227ea	0.00	0.00	49	49	0	0	49	49	0.0	NA	0.0	0.0	Approach 2
IPPU	2.F.2.a.	Closed cells, from stocks	HFC-245fa	0.00	0.00	49	49	0	0	49	49	0.0	NA	0.0	0.0	Approach 2

Inventory sector	IPCC category code	IPCC category name	Gas	Base year emissions / removals	Base year emissions / removals	Activity data uncertainty		Emission factor/ estimation parameter uncertainty (combined if more than one estimation parameter is used)		Combined uncertainty		Contribution to variance in year t	Inventory trend in national emissions for year t increase with respect to base year	Uncertainty introduced into the trend in total national emissions with respect to base year		Approach and comments
				Gg CO_2 eq	Gg CO_2 eq	(-) %	(+)%	(-) %	(+)%	(-) %	(+)%	(fraction)	(% of base year)	(-) %	(+)%	Approach 1/ Approach 2
IPPU	2.F.2.a.	Closed cells, from stocks	HFC-365mfc	0.00	0.00	49	49	0	0	49	49	0.0	NA	0.0	0.0	Approach 2
IPPU	2.F.3.	Fire protection, from stocks	HFC-227ea	0.01	0.01	68	68	0	0	68	68	0.0	0	0.0	0.0	Approach 2
IPPU	2.F.3.	Fire protection, from stocks	HFC-23	0.11	0.11	68	68	0	0	68	68	0.0	0	0.0	0.0	Approach 2
IPPU	2.F.3.	Fire protection, remaining at decommissioning	HFC-227ea	0.00	0.00	68	68	0	0	68	68	0.0	NA	0.0	0.0	Approach 2
IPPU	2.F.3.	Fire protection, recovery	HFC-227ea	0.00	0.00	68	68	0	0	68	68	0.0	NA	0.0	0.0	Approach 2
IPPU	2.F.4.a.	Metered dose inhalers, from stocks	HFC-134a	0.15	0.15	63	63	0	0	63	63	0.0	0	0.0	0.0	Approach 2
IPPU	2.F.4.a.	Metered dose inhalers, from stocks	HFC-227ea	0.03	0.03	63	63	0	0	63	63	0.0	0	0.0	0.0	Approach 2
IPPU	2.G.1.	Electrical equipment	SF_6	2.57	2.57	31	31	30	30	43	43	0.0	0	0.0	0.0	Approach 1
IPPU	2.H.3.	Other, flares, vents, other processes in manufacturing	CO_2	9.44	9.44	17	17	75	75	77	77	0.0	0	0.0	0.0	Approach 1
Agriculture	3.A.	Enteric fermentation	CH_4	0.75	0.75	0	0	37	37	37	37	0.0	0	0.0	0.0	Approach 1
Agriculture	3.B.	Manure management	CH_4	1.56	1.56	19	19	28	28	34	34	0.0	0	0.0	0.0	Approach 1
Agriculture	3.B.	Manure management	N_2O	2.16	2.16	60	60	98	98	126	126	0.0	0	0.0	0.0	Approach 1
Agriculture	3.D.1.a.	Inorganic N fertilisers	N_2O	0.05	0.05	116	116	200	200	393	393	0.0	0	0.0	0.0	Approach 1
Agriculture	3.D.1.b.	Organic N fertilisers	N_2O	1.66	1.66	223	223	200	200	764	764	0.0	0	0.0	0.0	Approach 1
Agriculture	3.D.1.e.	Mineralisation/ iimmobilisation associated with loss/ gain of soil organic matter	N_2O	0.01	0.01	115	115	200	200	391	391	0.0	0	0.0	0.0	Approach 1
Agriculture	3.D.2.a.	Indirect N_2O Emissions from managed soils: Atmospheric deposition	N_2O	0.34	0.34	219	219	400	400	3,212	3,212	0.0	0	0.0	0.0	Approach 1

Inventory sector	IPCC category code	IPCC category name	Gas	Base year emissions / removals	Base year emissions / removals	Activity data uncertainty		Emission factor/ estimation parameter uncertainty (combined if more than one estimation parameter is used)		Combined uncertainty		Contribution to variance in year t	Inventory trend in national emissions for year t increase with respect to base year	Uncertainty introduced into the trend in total national emissions with respect to base year		Approach and comments
				Gg CO_2 eq	Gg CO_2 eq	(-) %	(+)%	(-) %	(+)%	(-) %	(+)%	(fraction)	(% of base year)	(-) %	(+)%	Approach 1/ Approach 2
Agriculture	3.D.2.b.	Indirect N_2O Emissions from managed soils: Nitrogen leaching and run-off	N_2O	0.38	0.38	273	273	233	233	1,349	1,349	0.0	0	0.0	0.0	Approach 1
Agriculture	3.G.	Liming	CO_2	0.11	0.11	22	22	50	50	55	55	0.0	0	0.0	0.0	Approach 1
Agriculture	3.H.	Urea Application	CO_2	0.00	0.00	37	37	50	50	62	62	0.0	0	0.0	0.0	Approach 1
LULUCF	4.	N_2O	N_2O	8.85	8.85	63	63	0	0	63	63	0.0	0	0.0	0.0	Approach 2
LULUCF	4.A.1.	Forest land remaining forest land	CO_2	-28.50	-28.50	64	64	0	0	64	64	0.0	0	0.1	0.1	Approach 2
LULUCF	4.A.2.	Land converted to forest land	CO_2	-58.47	-58.47	37	37	0	0	37	37	0.0	0	0.1	0.1	Approach 2
LULUCF	4.B.1.	Cropland remaining cropland	CO_2	-0.02	-0.02	66	66	0	0	66	66	0.0	0	0.0	0.0	Approach 2
LULUCF	4.B.2.	Land converted to cropland	CO_2	-0.23	-0.23	280	280	0	0	280	280	0.0	0	0.0	0.0	Approach 2
LULUCF	4.D.2.	Land converted to wetland	CO_2	4.71	4.71	34	34	0	0	34	34	0.0	0	0.0	0.0	Approach 2
LULUCF	4.E.1.	Settlements remaining settlements	CO_2	-25.93	-25.93	1,624	1,624	0	0	1,624	1,624	0.0	0	1.5	1.5	Approach 2
LULUCF	4.E.2.	Land converted to settlements	CO_2	107.91	107.91	47	47	0	0	47	47	0.0	0	0.2	0.2	Approach 2
LULUCF	4.H.	Land converted to sea	CO_2	2.50	2.50	23	23	0	0	23	23	0.0	0	0.0	0.0	Approach 2
Waste	5.A.2.	Unmanaged waste disposal sites	CH_4	64.87	64.87	99	99	5	5	99	99	0.0	0	0.2	0.2	Approach 1
Waste	5.C.1.b.ii.2.	Hazardous waste	CO_2	103.36	103	11	11	5	5	12	12	0.0	0	0.0	0.0	Approach 1
Waste	5.C.1.b.ii.2.	Hazardous waste	CH_4	0.00	0.00	11	11	100	100	101	101	0.0	0	0.0	0.0	Approach 1
Waste	5.C.1.b.ii.2.	Hazardous waste	N_2O	0.83	0.83	11	11	100	100	101	101	0.0	0	0.0	0.0	Approach 1
Waste	5.C.1.b.ii.3.	Clinical waste	CO_2	0.49	0.49	11	11	5	5	12	12	0.0	0	0.0	0.0	Approach 1
Waste	5.C.1.b.ii.3.	Clinical waste	CH_4	0.00	0.00	11	11	100	100	101	101	0.0	0	0.0	0.0	Approach 1
Waste	5.C.1.b.ii.3.	Clinical waste	N_2O	0.01	0.01	11	11	100	100	101	101	0.0	0	0.0	0.0	Approach 1
Waste	5.D.1.	Domestic wastewater, from Plants	N_2O	4.27	4.27	30	30	150	150	153	153	0.0	0	0.0	0.0	Approach 1
Waste	5.D.2.	Domestic wastewater, from effluent	N_2O	39.96	39.96	44	44	4,900	4,900	4,900	4,900	24.4	0	0.1	0.1	Approach 1

Table 181: Uncertainty assessment for the inventory for reporting year 2022

Inventory sector	IPCC category code	IPCC category name	Gas	Base year emissions / removals	Year t emissions / removals	Activity data uncertainty		Emission factor/ estimation parameter uncertainty (combined if more than one estimation parameter is used)		Combined uncertainty		Contribution to variance in year t	Inventory trend in national emissions for year t increase with respect to base year	Uncertainty introduced into the trend in total national emissions with respect to base year		Approach and comments
				Gg CO_2 eq	Gg CO_2 eq	(-) %	(+)%	(-) %	(+)%	(-) %	(+)%	(fraction)	(% of base year)	(-) %	(+)%	Approach 1/ Approach 2
Energy	1.A.1.a.i.	Electricity generation, Liquid fuels	CO_2	17,177.75	1,731.51	2.0	2.0	2	2	3	3	0.007	-89.9	1.2	1.2	Approach 1
Energy	1.A.1.a.i.	Electricity generation, Liquid fuels	CH_4	18.66	1.12	2.0	2.0	150	150	150	150	0.000	-94.0	0.1	0.1	Approach 1
Energy	1.A.1.a.i.	Electricity generation, Liquid fuels	N_2O	35.32	5.78	2.0	2.0	200	200	200	200	0.000	-83.6	0.2	0.2	Approach 1
Energy	1.A.1.a.i.	Electricity generation, Gaseous fuels	CO_2	2,766.79	17,995.15	2.0	2.0	2	2	3	3	0.766	550.4	1.5	1.5	Approach 1
Energy	1.A.1.a.i.	Electricity generation, Gaseous fuels	CH_4	1.38	8.98	2.0	2.0	150	150	150	150	0.001	550.4	0.0	0.0	Approach 1
Energy	1.A.1.a.i.	Electricity generation, Gaseous fuels	N_2O	1.31	8.50	2.0	2.0	200	200	200	200	0.001	550.4	0.0	0.0	Approach 1
Energy	1.A.1.a.ii.	Combined heat and power generation, Other fossil fuels	CO_2	848.81	1,609.27	9.9	9.9	2	2	10	10	0.078	89.6	0.6	0.6	Approach 1
Energy	1.A.1.a.ii.	Combined heat and power generation, Other fossil fuels	CH_4	0.01	0.09	8.3	8.3	43	43	44	44	0.000	586.9	0.0	0.0	Approach 1
Energy	1.A.1.a.ii.	Combined heat and power generation, Other fossil fuels	N_2O	30.39	48.51	4.0	4.0	61	61	61	61	0.003	59.6	0.0	0.0	Approach 1
Energy	1.A.1.a.ii.	Combined heat and power generation, Biomass	CO_2	0.00	0.00	8.1	8.1	2	2	8	8	0.000	NA	0.0	0.0	Approach 1
Energy	1.A.1.a.ii.	Combined heat and power generation, Biomass	CH_4	0.00	5.25	2.0	2.0	51	51	51	51	0.000	NA	0.0	0.0	Approach 1
Energy	1.A.1.a.ii.	Combined heat and power generation, Biomass	N_2O	0.00	6.63	2.0	2.0	60	60	60	60	0.000	NA	0.0	0.0	Approach 1
Energy	1.A.2.c.	Chemicals, Liquid fuels	CO_2	9,143.31	11,062.26	1.6	1.6	1	1	2	2	0.132	16.3	0.6	0.6	Approach 1
Energy	1.A.2.c.	Chemicals, Liquid fuels	CH_4	6.91	6.57	1.5	1.5	7	7	7	7	0.000	-9.8	0.0	0.0	Approach 1

Inventory sector	IPCC category code	IPCC category name	Gas	Base year emissions / removals	Year t emissions / removals	Activity data uncertainty		Emission factor/ estimation parameter uncertainty (combined if more than one estimation parameter is used)		Combined uncertainty		Contribution to variance in year t	Inventory trend in national emissions for year t increase with respect to base year	Uncertainty introduced into the trend in total national emissions with respect to base year		Approach and comments
				Gg CO_2 eq	Gg CO_2 eq	(-) %	(+)%	(-) %	(+)%	(-) %	(+)%	(fraction)	(% of base year)	(-) %	(+)%	Approach 1/ Approach 2
Energy	1.A.2.c.	Chemicals, Liquid fuels	N_2O	11.03	9.83	1.2	1.2	7	7	7	7	0.000	-16.3	0.0	0.0	Approach 1
Energy	1.A.2.c.	Chemicals, Gaseous fuels	CO_2	0.00	2,434.74	15.0	15.0	2	2	15	15	0.402	NA	1.3	1.3	Approach 1
Energy	1.A.2.c.	Chemicals, Gaseous fuels	CH_4	0.00	1.22	15.0	15.0	150	150	151	151	0.000	NA	0.0	0.0	Approach 1
Energy	1.A.2.c.	Chemicals, Gaseous fuels	N_2O	0.00	1.15	15.0	15.0	200	200	201	201	0.000	NA	0.0	0.0	Approach 1
Energy	1.A.2.c.	Chemicals, Other fossil fuels	CO_2	33.13	128.66	0.5	0.5	7	7	7	7	0.000	288.4	0.0	0.0	Approach 1
Energy	1.A.2.c.	Chemicals, Other fossil fuels	CH_4	0.02	0.16	0.4	0.4	30	30	30	30	0.000	695.9	0.0	0.0	Approach 1
Energy	1.A.2.c.	Chemicals, Other fossil fuels	N_2O	0.05	0.29	0.4	0.4	22	22	22	22	0.000	493.1	0.0	0.0	Approach 1
Energy	1.A.2.g.viii.	Other, Liquid fuels	CO_2	1,253.81	1,632.25	15.0	15.0	2	2	15	15	0.180	30.2	0.9	0.9	Approach 1
Energy	1.A.2.g.viii.	Other, Liquid fuels	CH_4	1.39	1.82	15.0	15.0	150	150	151	151	0.000	30.6	0.0	0.0	Approach 1
Energy	1.A.2.g.viii.	Other, Liquid fuels	N_2O	2.63	3.44	15.0	15.0	200	200	201	201	0.000	30.6	0.0	0.0	Approach 1
Energy	1.A.2.g.viii.	Other, Gaseous fuels	CO_2	0.00	3,694.43	15.0	15.0	2	2	15	15	0.925	NA	2.0	2.0	Approach 1
Energy	1.A.2.g.viii.	Other, Gaseous fuels	CH_4	0.00	1.83	15.0	15.0	150	150	151	151	0.000	NA	0.0	0.0	Approach 1
Energy	1.A.2.g.viii.	Other, Gaseous fuels	N_2O	0.00	1.73	15.0	15.0	200	200	201	201	0.000	NA	0.0	0.0	Approach 1
Energy	1.A.3.a.	Domestic aviation, Aviation gasoline	CO_2	0.00	0.27	5.0	5.0	5	5	7	7	0.000	NA	0.0	0.0	Approach 1
Energy	1.A.3.a.	Domestic aviation, Aviation gasoline	CH_4	0.00	0.00	5.0	5.0	100	100	100	100	0.000	NA	0.0	0.0	Approach 1
Energy	1.A.3.a.	Domestic aviation, Aviation gasoline	N_2O	0.00	0.00	5.0	5.0	150	150	150	150	0.000	NA	0.0	0.0	Approach 1
Energy	1.A.3.a.	Domestic aviation, Jet kerosene	CO_2	0.00	2.04	5.0	5.0	5	5	7	7	0.000	NA	0.0	0.0	Approach 1
Energy	1.A.3.a.	Domestic aviation, Jet kerosene	CH_4	0.00	0.00	5.0	5.0	100	100	100	100	0.000	NA	0.0	0.0	Approach 1
Energy	1.A.3.a.	Domestic aviation, Jet kerosene	N_2O	0.00	0.02	5.0	5.0	150	150	150	150	0.000	NA	0.0	0.0	Approach 1
Energy	1.A.3.b.	Road transportation, Gasoline	CO_2	2,081.15	2,728.12	5.0	5.0	5	5	7	7	0.110	31.1	0.5	0.5	Approach 1
Energy	1.A.3.b.	Road transportation, Gasoline	CH_4	21.02	27.56	5.0	5.0	223	223	223	223	0.011	31.1	0.0	0.0	Approach 1
Energy	1.A.3.b.	Road transportation, Gasoline	N_2O	63.67	83.46	5.0	5.0	244	244	244	244	0.123	31.1	0.1	0.1	Approach 1

Inventory sector	IPCC category code	IPCC category name	Gas	Base year emissions / removals	Year t emissions / removals	Activity data uncertainty		Emission factor/ estimation parameter uncertainty (combined if more than one estimation parameter is used)		Combined uncertainty		Contribution to variance in year t	Inventory trend in national emissions for year t increase with respect to base year	Uncertainty introduced into the trend in total national emissions with respect to base year		Approach and comments
				Gg CO_2 eq	Gg CO_2 eq	(-) %	(+)%	(-) %	(+)%	(-) %	(+)%	(fraction)	(% of base year)	(-) %	(+)%	Approach 1/ Approach 2
Energy	1.A.3.b.	Road transportation, Diesel oil	CO_2	3,546.51	3,688.41	5.0	5.0	2	2	5	5	0.117	4.0	0.7	0.7	Approach 1
Energy	1.A.3.b.	Road transportation, Diesel oil	CH_4	5.23	5.44	5.0	5.0	144	144	144	144	0.000	4.0	0.0	0.0	Approach 1
Energy	1.A.3.b.	Road transportation, Diesel oil	N_2O	49.49	51.47	5.0	5.0	207	207	207	207	0.034	4.0	0.1	0.1	Approach 1
Energy	1.A.3.b.	Road transportation, Gaseous fuels	CO_2	0.00	9.49	5.0	5.0	4	4	6	6	0.000	NA	0.0	0.0	Approach 1
Energy	1.A.3.b.	Road transportation, Gaseous fuels	CH_4	0.00	0.44	5.0	5.0	1,574	1,574	1,574	1,574	0.000	NA	0.0	0.0	Approach 1
Energy	1.A.3.b.	Road transportation, Gaseous fuels	N_2O	0.00	0.13	5.0	5.0	2,466	2,466	2,466	2,466	0.000	NA	0.0	0.0	Approach 1
Energy	1.A.3.d.	Domestic navigation, Gas/diesel oil	CO_2	212.78	431.31	5.0	5.0	2	2	5	5	0.001	102.6	0.1	0.1	Approach 1
Energy	1.A.3.d.	Domestic navigation, Gas/diesel oil	CH_4	0.56	1.14	5.0	5.0	50	50	50	50	0.000	102.6	0.0	0.0	Approach 1
Energy	1.A.3.d.	Domestic navigation, Gas/diesel oil	N_2O	1.52	3.08	5.0	5.0	140	140	140	140	0.000	102.6	0.0	0.0	Approach 1
Energy	1.A.3.d.	Domestic navigation, Gaseous fuels	CO_2	0.00	3.15	5.0	5.0	4	4	6	6	0.000	NA	0.0	0.0	Approach 1
Energy	1.A.3.d.	Domestic navigation, Gaseous fuels	CH_4	0.00	0.01	5.0	5.0	1,540	1,540	1,540	1,540	0.000	NA	0.0	0.0	Approach 1
Energy	1.A.3.d.	Domestic navigation, Gaseous fuels	N_2O	0.00	0.03	5.0	5.0	2,467	2,467	2,467	2,467	0.000	NA	0.0	0.0	Approach 1
Energy	1.A.4.a.	Commercial/ institutional, Liquid fuels	CO_2	123.44	209.04	15.0	15.0	1	1	15	15	0.003	69.3	0.1	0.1	Approach 1
Energy	1.A.4.a.	Commercial/ institutional, Liquid fuels	CH_4	0.27	0.46	15.0	15.0	150	150	151	151	0.000	69.3	0.0	0.0	Approach 1
Energy	1.A.4.a.	Commercial/ institutional, Liquid fuels	N_2O	0.05	0.09	15.0	15.0	200	200	201	201	0.000	69.3	0.0	0.0	Approach 1
Energy	1.A.4.a.	Commercial/ institutional, Solid fuels	CO_2	171.11	158.57	15.0	15.0	1	1	15	15	0.002	-7.3	0.1	0.1	Approach 1
Energy	1.A.4.a.	Commercial/ institutional, Solid fuels	CH_4	0.43	0.40	15.0	15.0	150	150	151	151	0.000	-7.3	0.0	0.0	Approach 1

Inventory sector	IPCC category code	IPCC category name	Gas	Base year emissions / removals	Year t emissions / removals	Activity data uncertainty		Emission factor/ estimation parameter uncertainty (combined if more than one estimation parameter is used)		Combined uncertainty		Contribution to variance in year t	Inventory trend in national emissions for year t increase with respect to base year	Uncertainty introduced into the trend in total national emissions with respect to base year		Approach and comments
				Gg CO_2 eq	Gg CO_2 eq	(-) %	(+)%	(-) %	(+)%	(-) %	(+)%	(fraction)	(% of base year)	(-) %	(+)%	Approach 1/ Approach 2
Energy	1.A.4.a.	Commercial/ institutional, Solid fuels	N_2O	0.08	0.08	15.0	15.0	200	200	201	201	0.000	-7.3	0.0	0.0	Approach 1
Energy	1.A.4.a.	Commercial/ institutional, Gaseous fuels	CO_2	0.00	173.23	15.0	15.0	1	1	15	15	0.002	NA	0.1	0.1	Approach 1
Energy	1.A.4.a.	Commercial/ institutional, Gaseous fuels	CH_4	0.00	0.43	15.0	15.0	150	150	151	151	0.000	NA	0.0	0.0	Approach 1
Energy	1.A.4.a.	Commercial/ institutional, Gaseous fuels	N_2O	0.00	0.08	15.0	15.0	200	200	201	201	0.000	NA	0.0	0.0	Approach 1
Energy	1.A.4.b.	Residential, Liquid fuels	CO_2	243.48	69.68	15.0	15.0	1	1	15	15	0.000	-71.4	0.0	0.0	Approach 1
Energy	1.A.4.b.	Residential, Liquid fuels	CH_4	0.54	0.15	15.0	15.0	150	150	151	151	0.000	-71.4	0.0	0.0	Approach 1
Energy	1.A.4.b.	Residential, Liquid fuels	N_2O	0.10	0.03	15.0	15.0	200	200	201	201	0.000	-71.4	0.0	0.0	Approach 1
Energy	1.A.4.b.	Residential, Solid fuels	CO_2	102.39	152.73	15.0	15.0	1	1	15	15	0.002	49.2	0.1	0.1	Approach 1
Energy	1.A.4.b.	Residential, Solid fuels	CH_4	0.26	0.38	15.0	15.0	150	150	151	151	0.000	49.2	0.0	0.0	Approach 1
Energy	1.A.4.b.	Residential, Solid fuels	N_2O	0.05	0.07	15.0	15.0	200	200	201	201	0.000	49.2	0.0	0.0	Approach 1
Energy	1.A.5.b.	Mobile, Liquid fuels	CO_2	0.00	250	0.0	0.0	0	0	0	0	0.000	NA	0.0	0.0	Approach 1
Energy	1.A.5.b.	Mobile, Liquid fuels	CH_4	0.00	0.21	0.0	0.0	0	0	0	0	0.000	NA	0.0	0.0	Approach 1
Energy	1.A.5.b.	Mobile, Liquid fuels	N_2O	0.00	1.92	0.0	0.0	0	0	0	0	0.000	NA	0.0	0.0	Approach 1
Energy	1.B.2.c.	Flaring, Oil	CO_2	303.11	564.93	1.0	1.0	2	2	2	2	0.000	86.4	0.0	0.0	Approach 1
Energy	1.B.2.c.	Flaring, Oil	CH_4	12.48	47.97	0.3	0.3	4	4	4	4	0.000	284.2	0.0	0.0	Approach 1
Energy	1.B.2.c.	Flaring, Oil	N_2O	0.63	1.01	0.3	0.3	4	4	4	4	0.000	59.0	0.0	0.0	Approach 1
IPPU	2.B.8.g.	Other	CO_2	137.14	473.42	1.0	1.0	5	5	5	5	0.002	245.2	0.0	0.0	Approach 1
IPPU	2.B.10.b.	Other	CO_2	8.39	814.62	5.0	5.0	3	3	6	6	0.007	9,609.9	0.2	0.2	Approach 1
IPPU	2.B.10.b.	Other	CH_4	0.31	13.00	5.0	5.0	14	14	15	15	0.000	5,716.4	0.0	0.0	Approach 1
IPPU	2.B.10.b.	Other	N_2O	0.06	14.94	9.0	9.0	46	46	47	47	0.000	26,014.9	0.0	0.0	Approach 1
IPPU	2.D.1.	Lubricant use	CO_2	0.23	0.99	1.0	1.0	30	30	30	30	0.000	327.1	0.0	0.0	Approach 1
IPPU	2.E.1.	Integrated circuit or semiconductor	CO_2	0.08	0.35	0.9	0.9	1	1	1	1	0.000	328.9	0.0	0.0	Approach 1
IPPU	2.E.1.	Integrated circuit or semiconductor	CH_4	0.01	0.14	0.0	0.0	3	3	3	3	0.000	1,843.1	0.0	0.0	Approach 1

Inventory sector	IPCC category code	IPCC category name	Gas	Base year emissions / removals	Year t emissions / removals	Activity data uncertainty		Emission factor/ estimation parameter uncertainty (combined if more than one estimation parameter is used)		Combined uncertainty		Contribution to variance in year t	Inventory trend in national emissions for year t increase with respect to base year	Uncertainty introduced into the trend in total national emissions with respect to base year		Approach and comments
				Gg CO_2 eq	Gg CO_2 eq	(-) %	(+)%	(-) %	(+)%	(-) %	(+)%	(fraction)	(% of base year)	(-) %	(+)%	Approach 1/ Approach 2
IPPU	2.E.1.	Integrated circuit or semiconductor	N_2O	32.51	263.39	0.1	0.1	8	8	8	8	0.001	710.1	0.0	0.0	Approach 1
IPPU	2.E.1.	Integrated circuit or semiconductor	HFC-23	9.50	115.63	0.2	0.2	60	60	60	60	0.014	1,117.1	0.2	0.2	Approach 1
IPPU	2.E.1.	Integrated circuit or semiconductor	HFC-32	0.00	1.81	0.0	0.0	182	182	182	182	0.000	1,486,671.9	0.0	0.0	Approach 1
IPPU	2.E.1.	Integrated circuit or semiconductor	NF_3	67.57	645	0.0	0.0	126	126	126	126	1.941	854.3	1.7	1.7	Approach 1
IPPU	2.E.1.	Integrated circuit or semiconductor	PFC-116	269.54	713.01	0.2	0.2	55	55	55	55	0.454	164.5	0.4	0.4	Approach 1
IPPU	2.E.1.	Integrated circuit or semiconductor	PFC-14	492.39	1,600.27	0.1	0.1	55	55	55	55	2.300	225.0	1.2	1.2	Approach 1
IPPU	2.E.1.	Integrated circuit or semiconductor	PFC-c318	2.13	205.46	0.0	0.0	103	103	103	103	0.132	9,538.0	0.5	0.5	Approach 1
IPPU	2.E.1.	Integrated circuit or semiconductor	SF_6	29.75	128.84	0.7	0.7	96	96	96	96	0.045	333.1	0.2	0.2	Approach 1
IPPU	2.F.1.a.	Commercial refrigeration, in operating systems	HFC-125	0.00	181.80	1.0	1.0	0	0	1	1	0.000	NA	0.0	0.0	Approach 2
IPPU	2.F.1.a.	Commercial refrigeration, in operating systems	HFC-134	0.00	0.05	1.0	1.0	0	0	1	1	0.000	NA	0.0	0.0	Approach 2
IPPU	2.F.1.a.	Commercial refrigeration, in operating systems	HFC-134a	21.46	69.78	1.0	1.0	0	0	1	1	0.000	225.2	0.0	0.0	Approach 2
IPPU	2.F.1.a.	Commercial refrigeration, in operating systems	HFC-143a	0.00	301	1.0	1.0	0	0	1	1	0.000	NA	0.0	0.0	Approach 2
IPPU	2.F.1.a.	Commercial refrigeration, in operating systems	HFC-32	0.00	2.76	1.0	1.0	0	0	1	1	0.000	NA	0.0	0.0	Approach 2
IPPU	2.F.1.a.	Commercial refrigeration, remaining at decommissioning	HFC-125	0.00	224.72	1.0	1.0	0	0	1	1	0.000	NA	0.0	0.0	Approach 2
IPPU	2.F.1.a.	Commercial refrigeration, remaining at decommissioning	HFC-134	0.00	0.05	1.0	1.0	0	0	1	1	0.000	NA	0.0	0.0	Approach 2

Inventory sector	IPCC category code	IPCC category name	Gas	Base year emissions / removals	Year t emissions / removals	Activity data uncertainty		Emission factor/ estimation parameter uncertainty (combined if more than one estimation parameter is used)		Combined uncertainty		Contribution to variance in year t	Inventory trend in national emissions for year t increase with respect to base year	Uncertainty introduced into the trend in total national emissions with respect to base year		Approach and comments
				Gg CO_2 eq	Gg CO_2 eq	(-) %	(+)%	(-) %	(+)%	(-) %	(+)%	(fraction)	(% of base year)	(-) %	(+)%	Approach 1/ Approach 2
IPPU	2.F.1.a.	Commercial refrigeration, remaining at decommissioning	HFC-134a	4.37	103.16	1.0	1.0	0	0	1	1	0.000	2,258.4	0.0	0.0	Approach 2
IPPU	2.F.1.a.	Commercial refrigeration, remaining at decommissioning	HFC-143a	0.00	375.32	1.0	1.0	0	0	1	1	0.000	NA	0.0	0.0	Approach 2
IPPU	2.F.1.a.	Commercial refrigeration, remaining at decommissioning	HFC-32	0.00	3.07	1.0	1.0	0	0	1	1	0.000	NA	0.0	0.0	Approach 2
IPPU	2.F.1.a.	Commercial refrigeration, recovery	HFC-125	0.00	1.77	1.0	1.0	0	0	1	1	0.000	NA	0.0	0.0	Approach 2
IPPU	2.F.1.a.	Commercial refrigeration, recovery	HFC-134a	0.00	2.08	1.0	1.0	0	0	1	1	0.000	NA	0.0	0.0	Approach 2
IPPU	2.F.1.a.	Commercial refrigeration, recovery	HFC-143a	0.00	1.31	1.0	1.0	0	0	1	1	0.000	NA	0.0	0.0	Approach 2
IPPU	2.F.1.a.	Commercial refrigeration, recovery	HFC-32	0.00	0.20	1.0	1.0	0	0	1	1	0.000	NA	0.0	0.0	Approach 2
IPPU	2.F.1.b.	Domestic refrigeration, in operating systems	HFC-134a	0.24	0.05	3.0	3.0	0	0	3	3	0.000	-78.6	0.0	0.0	Approach 2
IPPU	2.F.1.b.	Domestic refrigeration, in operating systems	HFC-152a	0.00	0.00	3.0	3.0	0	0	3	3	0.000	-100.0	0.0	0.0	Approach 2
IPPU	2.F.1.b.	Domestic refrigeration, remaining at decommissioning	HFC-134a	3.71	4.33	3.0	3.0	0	0	3	3	0.000	16.9	0.0	0.0	Approach 2
IPPU	2.F.1.b.	Domestic refrigeration, remaining at decommissioning	HFC-152a	0.02	0.00	3.0	3.0	0	0	3	3	0.000	-100.0	0.0	0.0	Approach 2
IPPU	2.F.1.c.	Industrial refrigeration, in operating systems	HFC-125	2.02	144.50	10.0	10.0	0	0	10	10	0.001	7,057.0	0.1	0.1	Approach 2
IPPU	2.F.1.c.	Industrial refrigeration, in operating systems	HFC-134a	13.96	27.65	10.0	10.0	0	0	10	10	0.000	98.1	0.0	0.0	Approach 2

Inventory sector	IPCC category code	IPCC category name	Gas	Base year emissions / removals	Year t emissions / removals	Activity data uncertainty		Emission factor/ estimation parameter uncertainty (combined if more than one estimation parameter is used)		Combined uncertainty		Contribution to variance in year t	Inventory trend in national emissions for year t increase with respect to base year	Uncertainty introduced into the trend in total national emissions with respect to base year		Approach and comments
				Gg CO_2 eq	Gg CO_2 eq	(-) %	(+)%	(-) %	(+)%	(-) %	(+)%	(fraction)	(% of base year)	(-) %	(+)%	Approach 1/ Approach 2
IPPU	2.F.1.c.	Industrial refrigeration, in operating systems	HFC-143a	3.61	200.37	10.0	10.0	0	0	10	10	0.001	5,445.7	0.1	0.1	Approach 2
IPPU	2.F.1.c.	Industrial refrigeration, in operating systems	HFC-32	0.00	3.20	10.0	10.0	0	0	10	10	0.000	NA	0.0	0.0	Approach 2
IPPU	2.F.1.c.	Industrial refrigeration, remaining at decommissioning	HFC-125	0.00	40.62	10.0	10.0	0	0	10	10	0.000	NA	0.0	0.0	Approach 2
IPPU	2.F.1.c.	Industrial refrigeration, remaining at decommissioning	HFC-134a	0.00	16.93	10.0	10.0	0	0	10	10	0.000	NA	0.0	0.0	Approach 2
IPPU	2.F.1.c.	Industrial refrigeration, remaining at decommissioning	HFC-143a	0.00	55.96	10.0	10.0	0	0	10	10	0.000	NA	0.0	0.0	Approach 2
IPPU	2.F.1.c.	Industrial refrigeration, remaining at decommissioning	HFC-32	0.00	1.11	10.0	10.0	0	0	10	10	0.000	NA	0.0	0.0	Approach 2
IPPU	2.F.1.d.	Transport refrigeration, in operating systems	HFC-125	0.17	4.98	21.0	21.0	0	0	21	21	0.000	2,793.4	0.0	0.0	Approach 2
IPPU	2.F.1.d.	Transport refrigeration, in operating systems	HFC-134a	0.46	0.98	21.0	21.0	0	0	21	21	0.000	111.6	0.0	0.0	Approach 2
IPPU	2.F.1.d.	Transport refrigeration, in operating systems	HFC-143a	0.46	8.91	21.0	21.0	0	0	21	21	0.000	1,827.3	0.0	0.0	Approach 2
IPPU	2.F.1.d.	Transport refrigeration, remaining at decommissioning	HFC-125	0.00	0.11	21.0	21.0	0	0	21	21	0.000	NA	0.0	0.0	Approach 2
IPPU	2.F.1.d.	Transport refrigeration, remaining at decommissioning	HFC-134a	0.00	0.05	21.0	21.0	0	0	21	21	0.000	NA	0.0	0.0	Approach 2
IPPU	2.F.1.d.	Transport refrigeration, remaining at decommissioning	HFC-143a	0.00	0.20	21.0	21.0	0	0	21	21	0.000	NA	0.0	0.0	Approach 2

Inventory sector	IPCC category code	IPCC category name	Gas	Base year emissions / removals	Year t emissions / removals	Activity data uncertainty		Emission factor/ estimation parameter uncertainty (combined if more than one estimation parameter is used)		Combined uncertainty		Contribution to variance in year t	Inventory trend in national emissions for year t increase with respect to base year	Uncertainty introduced into the trend in total national emissions with respect to base year		Approach and comments
				Gg CO_2 eq	Gg CO_2 eq	(-) %	(+)%	(-) %	(+)%	(-) %	(+)%	(fraction)	(% of base year)	(-) %	(+)%	Approach 1/ Approach 2
IPPU	2.F.1.d.	Transport refrigeration, recovery	HFC-125	0.00	0.07	21.0	21.0	0	0	21	21	0.000	NA	0.0	0.0	Approach 2
IPPU	2.F.1.d.	Transport refrigeration, recovery	HFC-134a	0.00	2.84	21.0	21.0	0	0	21	21	0.000	NA	0.0	0.0	Approach 2
IPPU	2.F.1.d.	Transport refrigeration, recovery	HFC-143a	0.00	0.13	21.0	21.0	0	0	21	21	0.000	NA	0.0	0.0	Approach 2
IPPU	2.F.1.e.	Mobile air-conditioning, in operating systems	HFC-134a	77.70	205.16	100.0	100.0	0	0	100	100	0.125	164.1	0.7	0.7	Approach 2
IPPU	2.F.1.e.	Mobile air-conditioning, in operating systems	HFC-152a	0.00	0.00	100.0	100.0	0	0	100	100	0.000	2,982.5	0.0	0.0	Approach 2
IPPU	2.F.1.e.	Mobile air-conditioning, in operating systems	HFO-1234yf	0.00	0.00	100.0	100.0	0	0	100	100	0.000	NA	0.0	0.0	Approach 2
IPPU	2.F.1.e.	Mobile air-conditioning, in operating systems	HFC-32	0.34	4.26	100.0	100.0	0	0	100	100	0.000	1,136.2	0.0	0.0	Approach 2
IPPU	2.F.1.e.	Mobile air-conditioning, in operating systems	HFC-125	1.75	21.67	100.0	100.0	0	0	100	100	0.001	1,136.2	0.1	0.1	Approach 2
IPPU	2.F.1.e.	Mobile air-conditioning, remaining at decommissioning	HFC-134a	0.00	48.90	100.0	100.0	0	0	100	100	0.007	NA	0.2	0.2	Approach 2
IPPU	2.F.1.e.	Mobile air-conditioning, remaining at decommissioning	HFC-152a	0.00	0.00	100.0	100.0	0	0	100	100	0.000	NA	0.0	0.0	Approach 2
IPPU	2.F.1.e.	Mobile air-conditioning, recovery	HFC-134a	0.00	0.45	100.0	100.0	0	0	100	100	0.000	NA	0.0	0.0	Approach 2
IPPU	2.F.1.e.	Mobile air-conditioning, recovery	HFC-32	0.00	0.10	100.0	100.0	0	0	100	100	0.000	NA	0.0	0.0	Approach 2
IPPU	2.F.1.e.	Mobile air-conditioning, recovery	HFC-125	0.00	0.50	100.0	100.0	0	0	100	100	0.000	NA	0.0	0.0	Approach 2

Inventory sector	IPCC category code	IPCC category name	Gas	Base year emissions / removals	Year t emissions / removals	Activity data uncertainty		Emission factor/ estimation parameter uncertainty (combined if more than one estimation parameter is used)		Combined uncertainty		Contribution to variance in year t	Inventory trend in national emissions for year t increase with respect to base year	Uncertainty introduced into the trend in total national emissions with respect to base year		Approach and comments
				Gg CO_2 eq	Gg CO_2 eq	(-) %	(+)%	(-) %	(+)%	(-) %	(+)%	(fraction)	(% of base year)	(-) %	(+)%	Approach 1/ Approach 2
IPPU	2.F.1.f.	Stationary air-conditioning, in operating systems	HFC-125	0.25	551.14	130.0	130.0	0	0	130	130	1.519	218,091.5	2.6	2.6	Approach 2
IPPU	2.F.1.f.	Stationary air-conditioning, in operating systems	HFC-134a	6.57	238.54	130.0	130.0	0	0	130	130	0.284	3,529.2	1.1	1.1	Approach 2
IPPU	2.F.1.f.	Stationary air-conditioning, in operating systems	HFC-143a	0.00	8.05	130.0	130.0	0	0	130	130	0.000	NA	0.0	0.0	Approach 2
IPPU	2.F.1.f.	Stationary air-conditioning, in operating systems	HFC-32	0.05	119.76	130.0	130.0	0	0	130	130	0.072	221,908.2	0.6	0.6	Approach 2
IPPU	2.F.1.f.	Stationary air-conditioning, in operating systems	HFO-1336mzz	0.00	0.04	130.0	130.0	0	0	130	130	0.000	NA	0.0	0.0	Approach 2
IPPU	2.F.1.f.	Stationary air-conditioning, remaining at decommissioning	HFC-125	0.00	840.60	130.0	130.0	0	0	130	130	3.532	NA	3.9	3.9	Approach 2
IPPU	2.F.1.f.	Stationary air-conditioning, remaining at decommissioning	HFC-134a	0.00	92.96	130.0	130.0	0	0	130	130	0.043	NA	0.4	0.4	Approach 2
IPPU	2.F.1.f.	Stationary air-conditioning, remaining at decommissioning	HFC-32	0.00	179.42	130.0	130.0	0	0	130	130	0.161	NA	0.8	0.8	Approach 2
IPPU	2.F.1.f.	Stationary air-conditioning, recovery	HFC-125	0.00	39.37	130.0	130.0	0	0	130	130	0.008	NA	0.2	0.2	Approach 2
IPPU	2.F.1.f.	Stationary air-conditioning, recovery	HFC-134a	0.00	51.80	130.0	130.0	0	0	130	130	0.013	NA	0.2	0.2	Approach 2
IPPU	2.F.1.f.	Stationary air-conditioning, recovery	HFC-32	0.00	8.41	130.0	130.0	0	0	130	130	0.000	NA	0.0	0.0	Approach 2
IPPU	2.F.2.a.	Closed cells, from stocks	HFC-134a	0.00	0.00	49.0	49.0	0	0	49	49	0.000	5,181.2	0.0	0.0	Approach 2
IPPU	2.F.2.a.	Closed cells, from stocks	HFC-152a	0.00	0.00	49.0	49.0	0	0	49	49	0.000	NA	0.0	0.0	Approach 2
IPPU	2.F.2.a.	Closed cells, from stocks	HFC-227ea	0.00	0.00	49.0	49.0	0	0	49	49	0.000	NA	0.0	0.0	Approach 2

Inventory sector	IPCC category code	IPCC category name	Gas	Base year emissions / removals	Year t emissions / removals	Activity data uncertainty		Emission factor/ estimation parameter uncertainty (combined if more than one estimation parameter is used)		Combined uncertainty		Contribution to variance in year t	Inventory trend in national emissions for year t increase with respect to base year	Uncertainty introduced into the trend in total national emissions with respect to base year		Approach and comments
				Gg CO_2 eq	Gg CO_2 eq	(-) %	(+)%	(-) %	(+)%	(-) %	(+)%	(fraction)	(% of base year)	(-) %	(+)%	Approach 1/ Approach 2
IPPU	2.F.2.a.	Closed cells, from stocks	HFC-245fa	0.00	0.01	49.0	49.0	0	0	49	49	0.000	NA	0.0	0.0	Approach 2
IPPU	2.F.2.a.	Closed cells, from stocks	HFC-365mfc	0.00	0.00	49.0	49.0	0	0	49	49	0.000	NA	0.0	0.0	Approach 2
IPPU	2.F.3.	Fire protection, from stocks	HFC-227ea	0.01	43.14	68.0	68.0	0	0	68	68	0.003	430,419.8	0.1	0.1	Approach 2
IPPU	2.F.3.	Fire protection, from stocks	HFC-23	0.11	0.00	68.0	68.0	0	0	68	68	0.000	-100.0	0.0	0.0	Approach 2
IPPU	2.F.3.	Fire protection, remaining at decommissioning	HFC-227ea	0.00	31.83	68.0	68.0	0	0	68	68	0.001	NA	0.1	0.1	Approach 2
IPPU	2.F.3.	Fire protection, recovery	HFC-227ea	0.00	11.08	68.0	68.0	0	0	68	68	0.000	NA	0.0	0.0	Approach 2
IPPU	2.F.4.a.	Metered dose inhalers, from stocks	HFC-134a	0.15	11.81	63.0	63.0	0	0	63	63	0.000	7,661.7	0.0	0.0	Approach 2
IPPU	2.F.4.a.	Metered dose inhalers, from stocks	HFC-227ea	0.03	1.25	63.0	63.0	0	0	63	63	0.000	3,782.9	0.0	0.0	Approach 2
IPPU	2.G.1.	Electrical equipment	SF_6	2.57	25.74	1.3	1.3	0	0	1	1	0.000	901.4	0.0	0.0	Approach 1
IPPU	2.H.3.	Other, flares, vents, other processes in manufacturing	CO_2	9.44	21.35	3.0	3.0	3	3	4	4	0.000	126.1	0.0	0.0	Approach 1
Agriculture	3.A.	Enteric fermentation	CH_4	0.75	0.34	0.0	0.0	30	30	30	30	0.000	-54.5	0.0	0.0	Approach 1
Agriculture	3.B.	Manure management	CH_4	1.56	2.36	19.6	19.6	29	29	35	35	0.000	51.3	0.0	0.0	Approach 1
Agriculture	3.B.	Manure management	N_2O	2.16	2.75	50.6	50.6	98	98	120	120	0.000	27.3	0.0	0.0	Approach 1
Agriculture	3.D.1.a.	Inorganic N fertilisers	N_2O	0.05	0.05	116	116	200	200	393	393	0.000	3.0	0.0	0.0	Approach 1
Agriculture	3.D.1.b.	Organic N fertilisers	N_2O	1.66	1.71	223	223	200	200	764	764	0.000	3.0	0.0	0.0	Approach 1
Agriculture	3.D.1.e.	Mineralisation/ immobilisation associated with loss/ gain of soil organic matter	N_2O	0.01	0.02	110	110	200	200	383	383	0.000	54.5	0.0	0.0	Approach 1
Agriculture	3.D.2.a.	Indirect N_2O Emissions from managed soils: Atmospheric deposition	N_2O	0.34	0.35	219	219	400	400	3,212	3,212	0.000	3.0	0.0	0.0	Approach 1

Inventory sector	IPCC category code	IPCC category name	Gas	Base year emissions / removals	Year t emissions / removals	Activity data uncertainty		Emission factor/ estimation parameter uncertainty (combined if more than one estimation parameter is used)		Combined uncertainty		Contribution to variance in year t	Inventory trend in national emissions for year t increase with respect to base year	Uncertainty introduced into the trend in total national emissions with respect to base year		Approach and comments
				Gg CO_2 eq	Gg CO_2 eq	(-) %	(+)%	(-) %	(+)%	(-) %	(+)%	(fraction)	(% of base year)	(-) %	(+)%	Approach 1/ Approach 2
Agriculture	3.D.2.b.	Indirect N_2O Emissions from managed soils: Nitrogen leaching and run-off	N_2O	0.38	0.40	273	273	233	233	1,349	1,349	0.000	3.0	0.0	0.0	Approach 1
Agriculture	3.G.	Liming	CO_2	0.11	0.07	22.0	22.0	50	50	55	22	0.000	-38.2	0.0	0.0	Approach 1
Agriculture	3.H.	Urea Application	CO_2	0.00	0.00	37.0	37.0	50	50	62	37	0.000	3.0	0.0	0.0	Approach 1
LULUCF	4.	N_2O	N_2O	8.85	7.31	37.0	37.0	50	0	62	37	0.000	-17.3	0.0	0.0	Approach 2
LULUCF	4.A.1.	Forest land remaining forest land	CO_2	-28.50	-57.23	37.0	37.0	50	0	62	37	0.004	100.5	0.1	0.1	Approach 2
LULUCF	4.A.2.	Land converted to forest land	CO_2	-58.47	-18.46	37.0	37.0	50	0	62	37	0.000	-68.4	0.0	0.0	Approach 2
LULUCF	4.B.1.	Cropland remaining cropland	CO_2	-0.02	-0.30	37.0	37.0	50	0	62	37	0.000	1,647.8	0.0	0.0	Approach 2
LULUCF	4.B.2.	Land converted to cropland	CO_2	-0.23	-0.29	37.0	37.0	50	0	62	37	0.000	24.9	0.0	0.0	Approach 2
LULUCF	4.D.2.	Land converted to wetland	CO_2	4.71	1.81	37.0	37.0	50	0	62	37	0.000	-61.6	0.0	0.0	Approach 2
LULUCF	4.E.1.	Settlements remaining settlements	CO_2	-25.93	7.18	37.0	37.0	50	0	62	37	0.009	-112	0.2	0.2	Approach 2
LULUCF	4.E.2.	Land converted to settlements	CO_2	107.91	105.41	37.0	37.0	50	0	62	37	0.007	-2.3	0.2	0.2	Approach 2
LULUCF	4.H.	Land converted to sea	CO_2	2.50	0.00	37.0	37.0	50	0	62	37	0.000	-99.8	0.0	0.0	Approach 2
Waste	5.A.2 .	Unmanaged waste disposal sites	CH_4	64.87	1.80	99.0	99.0	5	5	99	99	0.000	-97.2	0.0	0.0	Approach 1
Waste	5.C.1.b.ii.2.	Hazardous waste	CO_2	103.36	300.29	11.0	11.0	5	5	12	12	0.004	190.5	0.1	0.1	Approach 1
Waste	5.C.1.b.ii.2.	Hazardous waste	CH_4	0.00	0.00	11.0	11.0	100	100	101	101	0.000	190.5	0.0	0.0	Approach 1
Waste	5.C.1.b.ii.2.	Hazardous waste	N_2O	0.83	2.41	11.0	11.0	100	100	101	101	0.000	190.5	0.0	0.0	Approach 1
Waste	5.C.1.b.ii.3.	Clinical waste	CO_2	0.49	3.84	11.0	11.0	5	5	12	12	0.000	687.1	0.0	0.0	Approach 1
Waste	5.C.1.b.ii.3.	Clinical waste	CH_4	0.00	0.00	11.0	11.0	100	100	101	101	0.000	687.1	0.0	0.0	Approach 1
Waste	5.C.1.b.ii.3.	Clinical waste	N_2O	0.01	0.09	11.0	11.0	100	100	101	101	0.000	687.1	0.0	0.0	Approach 1
Waste	5.D.1.	Domestic wastewater, from Plants	N_2O	4.27	5.98	30.0	30.0	150	150	153	153	0.000	39.9	0.0	0.0	Approach 1
Waste	5.D.2.	Domestic wastewater, from effluent	N_2O	39.96	69.78	44.0	44.0	4,900	4,900	4,900	4,900	34.58	74.6	1.4	1.4	Approach 1

Annex III: Detailed description of the reference approach and the results of the comparison of national estimates of emissions with those obtained using the reference approach

Singapore is building its capacity in this area. The results will be included in future reports.

Annex IV: QA/QC plan

Refer to Chapter 1.5 of the NID.

Annex V: Any additional information, as applicable, including detailed methodological descriptions of source or sink categories and the national emission balance

An overview of the method applied and the emission factor used for each subcategory for all five sectors can be found in the table below.

GHG source and sink categories	CO_2		CH_4		N_2O		HFCs		PFCs		SF_6		NF_3	
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
1.A. Fuel combustion activities (sectoral approach)														
1.A.1. Energy industries														
1.A.1.a. Public electricity and heat production	T1, T3	D, PS	T1	D	T1, T3	D, PS								
1.A.1.b. Petroleum refining	T1	D	T1	D	T1	D								
1.A.1.c. Manufacture of solid fuels and other energy industries	IE	IE	IE	IE	IE	IE								
1.A.2. Manufacturing industries and construction														
1.A.2.a. Iron and steel	T1	D	T1	D	T1	D								
1.A.2.b. Non-ferrous metals	IE	IE	IE	IE	IE	IE								
1.A.2.c. Chemicals	T1, T3	D, PS	T1	D	T1	D								
1.A.2.d. Pulp, paper and print	IE	IE	IE	IE	IE	IE								
1.A.2.e. Food processing, beverages and tobacco	IE	IE	IE	IE	IE	IE								
1.A.2.f. Non-metallic minerals	IE	IE	IE	IE	IE	IE								
1.A.2.g. Other	T1, T3	D, CS, PS	T1	D	T1, T3	D, PS								
1.A.3. Transport														
1.A.3.a. Domestic aviation	T1	D	T1	D	T1	D								
1.A.3.b. Road transportation	T1	D	T1	D	T1	D								
1.A.3.c. Railways	NO	NO	NO	NO	NO	NO								
1.A.3.d. Domestic navigation	T1	D	T1	D	T1	D								
1.A.3.e. Other transportation	NO	NO	NO	NO	NO	NO								
1.A.4. Other sectors														
1.A.4.a. Commercial/ institutional	T1	D, CS	T1	D	T1	D								
1.A.4.b. Residential	T1	D, CS	T1	D	T1	D								

Legend
T1 - Tier 1 T2 - Tier 2 T3 - Tier 3 D - Default CS - Country-specific PS - Plant-specific IE - Included elsewhere where the emissions have been accounted for in another emission stream NO - Not occurring NE - Not estimated

GHG source and sink categories	CO₂		CH₄		N₂O		HFCs		PFCs		SF₆		NF₃	
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
1.A.4.c. Agriculture/ forestry/fishing	IE	IE	IE	IE	IE	IE								
1.A.5. Other														
1.A.5.a. Stationary	T1	D, CS	T1	D	T1	D								
1.A.5.b. Mobile	T1	D, CS	T1	D	T1	D								
1.B. Fugitive emissions from fuels														
1.B.1. Solid fuels														
1.B.1.a. Coal mining and handling	NO	NO	NO	NO	NO	NO								
1.B.1.b. Fuel transformation	IE	IE	NA	NA	NA	NA								
1.B.1.c. Other	NO	NO	NO	NO	NO	NO								
1.B.2. Oil and natural gas and other emissions from energy production														
1.B.2.a. Oil	T1, T3	D, PS	T1, T3	D, PS	T1	D								
1.B.2.b. Natural gas	NO	NO	NO	NO										
1.B.2.c. Venting and flaring	T1, T3	D, PS	T1, T3	D, PS	T1	D								
1.B.2.d. Other	NO	NO	NO	NO	NO	NO								
1.C. CO2 Transport and storage														
1.C.1. Transport of CO_2	NO	NO	NO	NO	NO	NO								
1.C.2. Injection and storage	NO	NO	NO	NO	NO	NO								
1.C.3. Other	NO	NO	NO	NO	NO	NO								
2. Total industrial processes														
2.A. Mineral industry														
2.A.1. Cement production	NO	NO												
2.A.2. Lime production	NO	NO												
2.A.3. Glass production	NO	NO												
2.A.4. Other process uses of carbonates	NO	NO												
2.B. Chemical industry														
2.B.1. Ammonia production	NO	NO	NO	NO	NO	NO								
2.B.2. Nitric acid production					NO	NO								
2.B.3. Adipic acid production	NO	NO			NO	NO								
2.B.4. Caprolactam, glyoxal and glyoxylic acid production	NO	NO			NO	NO								
2.B.5. Carbide production	NO	NO	NO	NO										
2.B.6. Titanium dioxide production	NO	NO												

GHG source and sink categories	CO₂		CH₄		N₂O		HFCs		PFCs		SF₆		NF₃	
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
2.B.7. Soda ash production	NO	NO												
2.B.8. Petrochemical and carbon black production	T1, T3	D, PS	T1, T3	D, PS										
2.B.9. Fluorochemical production							NO	NO	NO	NO	NO	NO	NO	NO
2.B.10. Other	T1, T3	D, PS	T1, T3	D, PS	T1, T3	D, PS								
2.C. Metal industry														
2.C.1. Iron and steel production	T3	PS	NA	NA										
2.C.2. Ferroalloys production	NO	NO	NO	NO										
2.C.3. Aluminium production	NO	NO	NO	NO										
2.C.4. Magnesium production	NO	NO												
2.C.5. Lead production	NO	NO												
2.C.6. Zinc production	NO	NO												
2.C.7. Other	NO	NO	NO	NO	NO	NO								
2.D. Non-energy products from fuels and solvent use (4)														
2.D.1. Lubricant use	T1, T3	D, PS	NO	NO	NO	NO								
2.D.2. Paraffin wax use	T1	D	NO	NO	NO	NO								
2.D.3. Other	NO	NO	NO	NO	NO	NO								
2.E. Electronics industry														
2.E.1. Integrated circuit or semiconductor	T3	PS	T3	PS	T3	PS	T2a T2b T3	D, PS	T2a T2b T3	D, PS	T2a T2b T3	D, PS	T2a T2b T3	D, PS
2.E.2. TFT flat panel display					NO	NO	NO	NO	T3	PS	T3	PS	T3	PS
2.E.3. Photovoltaics					T3	PS	NO	NO	T2b	D	NO	NO	T3	PS
2.E.4. Heat transfer fluid							NO	NO	NO	NO	NO	NO	NO	NO
2.E.5. Other					NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2.F. Product uses as substitutes for ODS														
2.F.1. Refrigeration and air-conditioning							T2a, T2b	D, CS	NO	NO	NO	NO	NO	NO
2.F.2. Foam blowing agents							T2a	D	NO	NO	NO	NO	NO	NO
2.F.3. Fire protection							T1a	D	NO	NO	NO	NO	NO	NO
2.F.4. Aerosols							T2a	D	NO	NO	NO	NO	NO	NO
2.F.5. Solvents							T2a	PS	NO	NO	NO	NO	NO	NO
2.F.6. Other applications							NO	NO	NO	NO	NO	NO	NO	NO

Legend
T1 - Tier 1 T2 - Tier 2 T3 - Tier 3 D - Default CS - Country-specific PS - Plant-specific IE - Included elsewhere where the emissions have been accounted for in another emission stream NO - Not occurring NE - Not estimated

GHG source and sink categories	CO_2		CH_4		N_2O		HFCs		PFCs		SF_6		NF_3	
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
2.G. Other product manufacture and use														
2.G.1. Electrical equipment							NO	NO	NO	NO	T3	PS	NO	NO
2.G.2. SF_6 and PFCs from other product use									NO	NO	T2	PS		
2.G.3. N_2O from product uses					NE	NE								
2.G.4. Other	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2.H. Other														
2.H.1. Pulp and paper	NO	NO	NO	NO	NO	NO								
2.H.2. Food and beverages industry	T3	PS	NO	NO	NO	NO								
2.H.3. Other *(please specify)*	T3	PS	T3	PS	T3	PS	NO	NO	NO	NO	NO	NO	NO	NO
3. Total agriculture														
3.A. Enteric fermentation														
3.A.1. Cattle			T1	D										
Option A:														
3.A.1.a. Dairy cattle			T1	D										
3.A.1.b. Non-dairy cattle			T1	D										
Option B (country-specific):														
3.A.1.a. Other														
3.A.1.a.i. Mature dairy cattle														
3.A.1.a.ii. Other mature cattle														
3.A.1.a.iii. Growing cattle														
3.A.1.a.iv. Other (please specify)														
3.A.2. Sheep			NO	NO										
3.A.3. Swine			NO	NO										
3.A.4. Other livestock (goats)			T1	D										
3.B. Manure management														
3.B.1. Cattle			T1	D	T1	D								
Option A:														
3.B.1.a. Dairy cattle			T1	D	T1	D								
3.B.1.b. Non-dairy cattle			T1	D	T1	D								
Option B (country-specific):														

GHG source and sink categories	CO_2		CH_4		N_2O		HFCs		PFCs		SF_6		NF_3	
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
3.B.1.a. Other														
3.B.1.a.i. Mature dairy cattle														
3.B.1.a.ii. Other mature cattle														
3.B.1.a.iii. Growing cattle														
3.B.1.a.iv. Other (please specify)														
3.B.2. Sheep			NO	NO	NO	NO								
3.B.3. Swine			NO	NO	NO	NO								
3.B.4. Other livestock (goats)			T1	D	T1	D								
3.B.4. Other livestock (poultry)			T1	D	T1	D								
3.B.4. Other livestock (quail)			T1	D	T1	D								
3.B.5. Indirect N_2O emissions					NE	NE								
3.C. Rice cultivation			NO	NO	NO	NO								
3.D. Agricultural soils														
3.D.1. Direct N_2O emissions from managed soils					T1	D								
3.D.1.a. Inorganic N fertilisers					T1	D								
3.D.1.b. Organic N fertilisers					T1	D								
3.D.1.c. Urine and dung deposited by grazing animals					NO	NO								
3.D.1.d. Crop residues					NO	NO								
3.D.1.e. Mineralisation/ immobilisation associated with loss/gain of soil organic matter					T1	D								
3.D.1.f. Cultivation of organic soils (i.e. histosols)					NO	NO								
3.D.1.g. Other					NO	NO								
3.D.2. Indirect N_2O Emissions from managed soils					T1	D								

Legend
T1 - Tier 1   T2 - Tier 2   T3 - Tier 3   D - Default   CS - Country-specific   PS - Plant-specific   IE - Included elsewhere where the emissions have been accounted for in another emission stream   NO - Not occurring   NE - Not estimated

GHG source and sink categories	CO_2		CH_4		N_2O		HFCs		PFCs		SF_6		NF_3	
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
3.E. Prescribed burning of savannahs			NO	NO	NO	NO								
3.F. Field burning of agricultural residues			NO	NO	NO	NO								
3.G. Liming	T1	D												
3.H. Urea application	T1	D												
3.I. Other carbon-containing fertilisers	NE	NE												
3.J. Other (please specify)	NO	NO	NO	NO	NO	NO								
4. Total LULUCF														
4.A. Forest land														
4.A.1. Forest land remaining forest land	T3	CS	NO	NO	T1	D								
4.A.2. Land converted to forest land	T1,T3	D,CS	NO	NO	T1	D								
4.B. Cropland														
4.B.1. Cropland remaining cropland	T1	D	NO	NO	T1	D								
4.B.2. Land converted to cropland	T1,T3	D,CS	NO	NO	T1	D								
4.C. Grassland														
4.C.1. Grassland remaining grassland	NO	NO	NO	NO	NO	NO								
4.C.2. Land converted to grassland	NO	NO	NO	NO	NO	NO								
4.D. Wetlands														
4.D.1. Wetlands remaining wetlands	T1	D	NO	NO	NO	NO								
4.D.2. Land converted to wetlands	T1,T3	D,CS	NO	NO	NO	NO								
4.E. Settlements														
4.E.1. Settlements remaining settlements	T3	CS	NO	NO	T1	D								
4.E.2. Land converted to settlements	T1,T3	D,CS	NO	NO	T1	D								
4.F. Other land														
4.F.1. Other land remaining other land	NO	NO	NO	NO	NO	NO								
4.F.2. Land converted to other land	NO	NO	NO	NO	NO	NO								
4.G. Harvested wood products	NO	NO	NO	NO	NO	NO								
4.H. Other (Sea)	T3	CS	NO	NO	NO	NO								

GHG source and sink categories	CO_2		CH_4		N_2O		HFCs		PFCs		SF_6		NF_3	
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
5. Total waste														
5.A. Solid waste disposal														
5.A.1. Managed waste disposal sites			NO	NO										
5.A.2. Unmanaged waste disposal sites			T2	D										
5.A.3. Uncategorized waste disposal sites			NO	NO										
5.B. Biological treatment of solid waste														
5.B.1. Composting			T1, NE	D, NE										
5.B.2. Anaerobic digestion at biogas facilities			T1, NO	D, NO										
5.C. Incineration and open burning of waste														
5.C.1. Waste incineration	T1, T2a, T3	D, PS	T1	D	T1, T3	D, PS								
5.C.2. Open burning of waste	NO	NO	NO	NO	NO	NO								
5.D. Wastewater treatment and discharge														
5.D.1. Domestic wastewater			NO	NO	T1	D								
5.D.2. Industrial wastewater			NO	NO	T1	D								
5.D.3. Other			NO	NO	NO	NO								
5.E. Other *(please specify)*	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

Legend
T1 - Tier 1 T2 - Tier 2 T3 - Tier 3 D - Default CS - Country-specific PS - Plant-specific IE - Included elsewhere where the emissions have been accounted for in another emission stream NO - Not occurring NE - Not estimated

Annex VI: Common reporting tables

Common reporting tables had been submitted electronically in the UNFCCC portal.

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