2024

NATIONAL INVENTORY DOCUMENT

Republic of Korea's Submission to the United Nations Framework Convention on Climate Change

The Government of
the Republic of Korea

PREFACE

This is the Republic of Korea's National Inventory Document (NID) compiled on behalf of the Ministry of Environment, by Greenhouse Gas Inventory and Research Center of Korea (GIR). It is submitted to the United Nations Framework Convention on Climate Change (UNFCCC) to fulfill ROK's commitments under the Paris Agreement.

This document contains greenhouse gas emission estimates for the period of 1990–2022 and descriptions of methodologies used.

The national inventory is compiled in accordance with the 2006 Guidelines of the Intergovernmental Panel on Climate Change (IPCC) using Global Warming Potentials presented in the Fifth Assessment Report of IPCC.

All reported estimates in this document have been rounded off to the nearest integer. As a result, the total value may differ slightly from the sum of subtotals of rounded figures.

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ES.1 Background Information on Climate Change and Greenhouse Gas Inventory

Background Information

The average annual temperature in the Republic of Korea (ROK) has continued to increase for the last 110 years. It increased by approximately 1.6°C over the last 30 years (1991–2020) compared to the historical 30-year period (1912–1940). In 2023, the average annual temperature was 1.2°C higher than that in 2022 at 13.7°C which was the highest on record since 1973. The average annual temperatures in the last five years confirmed that the respective years were among ten warmest years recorded, representing a clear indication of the continued rise in temperature. Extreme weather events have occurred more frequently and severely as evidenced by the intensified precipitation and heat waves, tropical nights and extreme temperature variations in winter.

Since ratification of the United Nations Framework Convention on Climate Change (UNFCCC) in 1993, ROK has been committed to contributing to global efforts to address climate change. Following the adoption of the Paris Agreement in 2015, ROK submitted its Intended Nationally Determined Contributions (INDC) to the UNFCCC. In 2020, ROK declared its national vision to achieve carbon neutrality by 2050 and submitted the 2030 Nationally Determined Contributions (NDC) in 2021 which was an enhanced update of the INDC with more ambitious greenhouse gas reduction target.

In 2021, both the 2050 carbon neutrality vision and the 2030 NDC were codified in the *Framework Act on Carbon Neutrality and Green Growth for Coping with Climate Crisis* (hereinafter referred to as *"Carbon Neutrality Act"*) and its Enforcement Decree. The *Carbon Neutrality Act* stipulates the national target to reduce emissions no less than 35 percent from the 2018 levels by 2030 and outlines policy measures to mitigate emissions.

National Greenhouse Gas Inventory

Transitioning from the Measurement, Reporting and Verification (MRV) arrangements for national greenhouse gas inventories to the Enhanced Transparency Framework (ETF) under the Paris Agreement, all Parties are required to submit a National Inventory Document (NID) and the Common Reporting Tables (CRT) to the UNFCCC either as a standalone report or as part of a Biennial Transparency Report (BTR) due by the end of 2024.[1]

In accordance with Articles 48 and 49 of the *Modalities, procedures and guidelines for the transparency framework for action and support referred to in Article 13 of the Paris Agreement* (hereinafter referred to as the "MPGs"), this document summarizes the inventory of emissions and removals of seven gases which include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6) and nitrogen trifluoride (NF_3).

In accordance with Article 20 of the MPGs, anthropogenic emissions and removals were estimated using the methodologies in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (hereinafter referred to as the "*2006 IPCC Guidelines*") and, where appropriate, the *2019 Refinement to the 2006 IPCC Guidelines* (hereinafter referred to as the "*2019 Refinement*") was applied. For metrics, this document reflects CO_2-equivalents using 100-year time-horizon global warming potential (GWP) values from the *IPCC Fifth Assessment Report* as specified in Article 37 of the MPGs.

In accordance with Article 50 of the MPGs, the national greenhouse gas inventory consists of five sectors including Energy, Industrial Processes and Product Use (IPPU), Agriculture, Land Use, Land-Use Change and Forestry (LULUCF)[2], and Waste. The time series of this inventory cover 33 years from 1990 to 2022.

The sources of activity data used in national greenhouse gas inventory include national statistics published by statistical agencies[3] that are designated under the Statistics Act, data provided by Statistics Korea and relevant associations, and reports

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1) *Modalities, procedures and guidelines for the transparency framework for action and support referred to in Article 13 of the Paris Agreement (Decision 18/CMA.1)*, UNFCCC (2018)

2) The *2006 IPCC Guidelines* integrate Agriculture and LULUCF into a single sector of AFOLU.

3) Entities including government ministries, public organizations, relevant associations and research institutes that compile numerical data for purposes of the establishment and evaluation of policies, research and analysis of economic and social phenomena are designated as statistical agencies in accordance with Article 15 of the *Statistics Act* to promote the production, dissemination, and use of statistics.

submitted by entities under the Greenhouse Gas Target Management System (TMS) and Korea Emissions Trading System (K-ETS).

To supplement the activity data from aforementioned sources, non-national statistics including surveys independently conducted by designated agencies and reports on Clean Development Mechanism (CDM) were also used.

ROK will continue to refine its QA/QC procedures that involve examining data sources and the verification process to further increase the accuracy of national emission estimates.

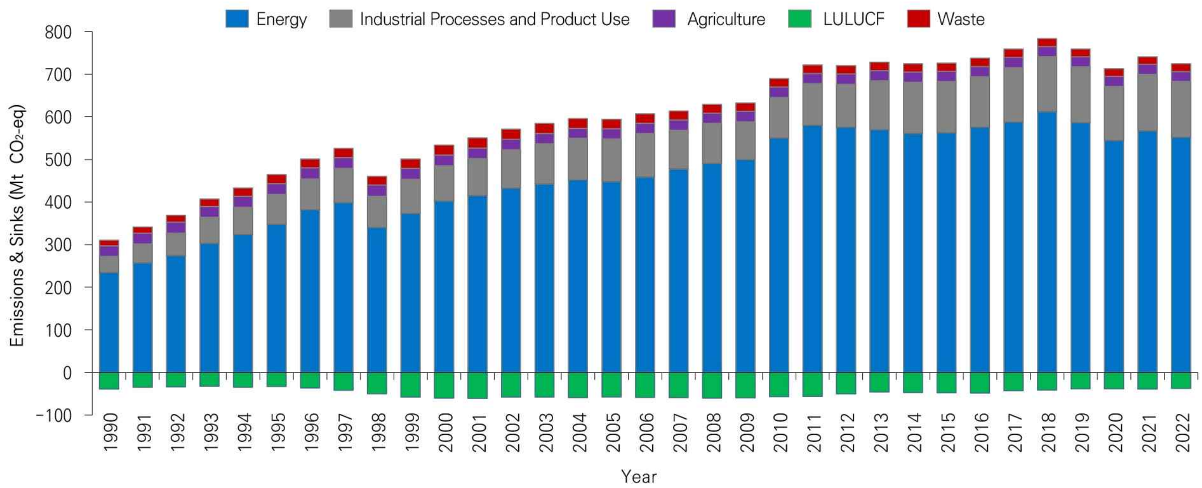
ES.2 Greenhouse Gas Emissions and Sinks Trends

Overview

In 2022, ROK's total gross emissions excluding LULUCF were 724.3 Mt CO2−eq, representing a 133.2 percent increase from 310.6 Mt CO_2−eq in 1990.[4] As illustrated in Figure ES−1 and Table ES−1, total gross emissions decreased by 2.3 percent from 741.0 Mt CO_2−eq in 2021, and by 7.6 percent from 783.9 Mt CO_2−eq in 2018 in which emissions peaked. Net emissions including LULUCF were 686.5 Mt CO_2−eq in 2022, showing a 152.7 percent increase from 271.6 Mt CO2−eq in 1990.[5] Between 2021 and 2022, net emissions decreased by 2.2 percent from 702.0 Mt CO_2−eq. Net emissions in 2018 were 742.3 Mt CO_2−eq which decreased by 7.5 percent in 2022.

National greenhouse gas emissions continued to increase in the 1990s which was driven largely by economic growth. From the late 2000s, the slowdown in emissions growth was observed until emissions reached its peak in 2018 which was then followed by a decreasing trend in the 2018 through 2022 years. In 2020, emissions temporarily decreased by 6.1 percent from 2019 due to the impacts of the global pandemic. Although emissions in 2021 increased relative to the previous year with the easing of the pandemic and rebound of economic activity, emissions declined in 2022, continuing the downward trend. In the pre−pandemic period, the decreases in emissions were observed in some years which were largely driven by economic crisis. The Asian Financial Crisis in 1997 contributed to a sharp decrease of 12.5 percent in emissions in 1998 which was followed by the upward trend with an average annual emissions growth of 2.6 percent until 2009 when the economy was hit by the Great Recession which resulted in only a slight increase of 0.6 percent in 2009.

4) The total gross emissions in this report excludes emissions and removals from LULUCF.
5) The net emissions in this report includes emissions and removals from LULUCF.



| Figure ES-1 | Trends in Greenhouse Gas Emissions and Removals by Sector (1990-2022)

| Table ES-1 | Greenhouse Gas Emissions and Percentage by Sector

(Unit: Mt CO_2-eq)

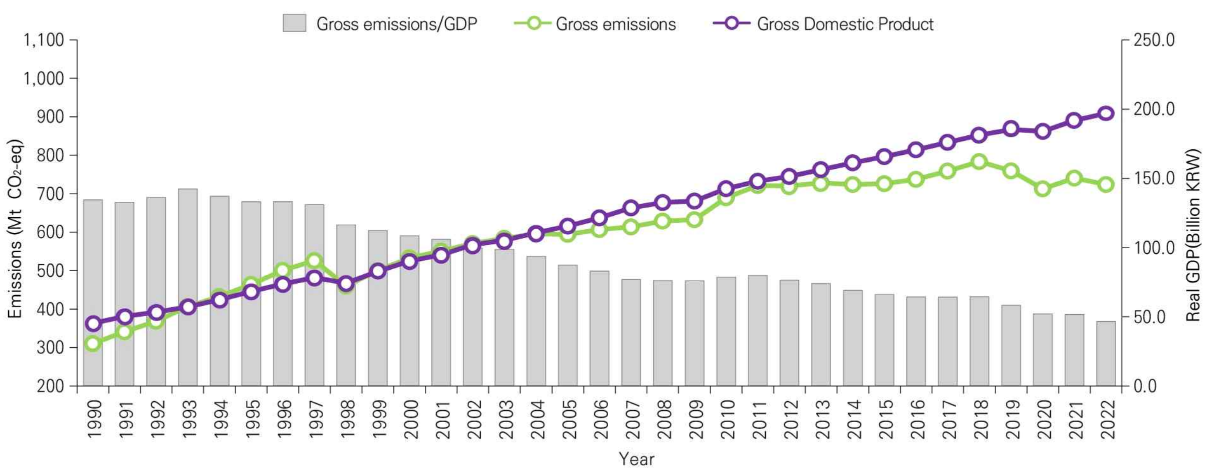
Sector		1990	2000	2010	2018	2021	2022	Emissions Change (%)	
								From 1990	From 2021
Energy	Emissions	234.5	402.2	550.3	612.1	566.8	551.9	135.4	-2.6
	Percentage (%)	75.5	75.4	79.8	78.1	76.5	76.2		
IPPU	Emissions	37.8	83.1	95.0	128.9	132.8	131.3	247.3	-1.1
	Percentage (%)	12.2	15.6	13.8	16.4	17.9	18.1		
Agriculture	Emissions	24.9	24.7	24.7	23.5	23.1	23.0	-7.7	-0.5
	Percentage (%)	8.0	4.6	3.6	3.0	3.1	3.2		
LULUCF	Emissions	-39.0	-60.4	-57.4	-41.6	-39.0	-37.8	Note1)	
Waste	Emissions	13.4	23.4	19.7	19.4	18.3	18.2	35.3	-0.8
	Percentage (%)	4.3	4.4	2.9	2.5	2.5	2.5		
Gross Emissions (excl. LULUCF)	Emissions	310.6	533.5	689.8	783.9	741.0	724.3	133.2	-2.3
	Percentage (%)	100	100	100	100	100	100		
Net Emissions (incl. LULUCF)	Emissions	271.6	473.1	632.4	742.3	702.0	686.5	152.7	-2.2

Note: 1) The percentage change in emissions from 1990 and 2021 is not indicated for LULUCF as the sector has been a sink of net removals for the entire time series.

Greenhouse Gas Emissions per Unit of Gross Domestic Product (GDP)

Emissions per unit of total gross domestic product (GDP)[6] in 2022 was 367.9 tonnes CO_2−eq/billion KRW, showing a 46.2 percent decrease from 683.9 tonnes CO_2−eq/billion KRW in 1990, and a 4.7 percent decrease from 386.2 tonnes CO_2−eq/billion KRW in 2021.

Since 1990, ROK's emissions per unit of GDP have been consistently declining. After emissions peaked in 2018, a decoupling of emissions and GDP was observed with the increase of GDP and the decrease in emissions. In the 1990s, the growth rate of both the GDP and total emissions were between 5 and 10 percent. From the 2000s, the emissions growth of which the annual average of the 2000 to 2009 period was 1.9 percent became lower than the GDP growth of which the respective average of the same period was 4.4 percent, showing weak signs of a decoupling between emissions and GDP growth. In the 2010 to 2017 period, the annual average growth of emissions continued to decline to 1.4 percent which led to a negative figure of 3.1 percent in the growth of gross emissions in 2018. Increases in both GDP and emissions were observed temporarily only when there were rebounds in economic activity after economic crisis such as financial crisis and economic crisis in 1998, 2008 and the COVID−19 pandemic in 2019.



| Figure ES−2 | Total Greenhouse Gas Emissions per Unit of Gross Domestic Product (GDP) (1990−2022)

| Table ES−2 | Total Greenhouse Gas Emissions per Unit of Gross Domestic Product (GDP)

Category	1990	2000	2010	2018	2021	2022
Total Emissions (Mt CO_2−eq)	310.6	533.5	689.8	783.9	741.0	724.3
GDP (Trillion KRW)	4,541.5	9,035.5	14,266.2	18,120.1	19,187.1	19,688.4
Total Emission per GDP (Tonnes CO_2−eq/Billion KRW)	683.9	590.4	483.5	432.6	386.2	367.9

6) *Real GDP and real GNI in chained 2015 KRW, National Accounts*, Bank of Korea (2023) (Accessed on June 20, 2025)

ES.3 Trends in Emissions and Sinks by Gas and Sector

Trends in Emissions and Sinks by Gas

Carbon dioxide (CO_2) accounted for the largest share of 87.8 percent of total emissions in 2022, followed by fluorinated gases (5.9 percent) which include hydrofluorocarbons (HFCs), sulfur hexafluoride (SF_6), perfluorocarbons (PFCs) and nitrogen trifluoride (NF_3) representing 4.5 percent, 0.55 percent, 0.56 percent and 0.2 percent respectively. Methane (CH_4) emissions accounted for 4.9 percent while nitrous oxide (N_2O) represented 1.5 percent. Emissions of all gases have been increasing except CH_4 which have consistently been decreasing since 1990 due to reduced coal production in the Energy sector and reduced rice cultivation area in the Agriculture sector. Fluorinated gases increased significantly in 2022 compared to 1990 largely due to an increase in the use of HFCs which are commonly used as refrigerants in air conditioning and refrigeration systems, and also PFCs, SF_6 as well as NF_3 which are used in semiconductor and display industries.

| Table ES-3 | Recent Trends in Emissions and Percentage by Gas

(Unit: Mt CO_2-eq)

Gas Type		1990	2000	2010	2018	2021	2022	Emissions Change (%)	
								From 1990	From 2021
CO_2	Emissions	256.2	462.6	618.0	701.1	652.5	635.8	148.2	-2.6
	Percentage (%)	82.5	86.7	89.6	89.4	88.1	87.8		
CH_4	Emissions	46.8	44.6	40.6	37.2	35.3	35.2	-24.9	-0.5
	Percentage (%)	15.1	8.4	5.9	4.7	4.8	4.9		
N_2O	Emissions	6.3	14.9	10.6	10.9	10.8	10.7	68.9	-0.9
	Percentage (%)	2.0	2.8	1.5	1.4	1.5	1.5		
HFCs	Emissions	1.0	6.0	7.6	23.6	30.3	32.9	3,062.5	8.8
	Percentage (%)	0.3	1.1	1.1	3.0	4.1	4.5		
PFCs[1)]	Emissions	IE,NE,NO	2.5	2.5	3.9	4.7	4.1	116.6	-14.4
	Percentage (%)	-	0.5	0.4	0.5	0.6	0.6		
SF_6	Emissions	0.2	2.8	10.0	6.3	5.5	4.0	2,243.3	-28.4
	Percentage (%)	0.1	0.5	1.4	0.8	0.7	0.5		
NF_3[2)]	Emissions	IE,NO	IE,NO	0.4	1.0	1.8	1.7	359.7	-7.7
	Percentage (%)	-	-	0.1	0.1	0.2	0.2		
Total Emissions (excl. LULUCF)		310.6	533.5	689.8	783.9	741.0	724.3	133.2	-2.3
Percentage (%)		100	100	100	100	100	100		

Note: 1) The percentage change of PFCs was calculated based on data for 1997 from which data were available.
2) The percentage change of NF_3 was calculated based on data for 2008 from which data were available.

Trends in Emissions and Sinks by Sector

Energy

In 2022, emissions from the Energy sector were 551.9 Mt CO_2−eq, accounting for 76.2 percent of total national emissions. From 1990, sectoral emissions increased by 135.4 percent from 234.5 Mt CO_2−eq, and decreased by 2.6 percent from 566.8 Mt CO_2−eq in 2021.

Emissions from the Energy sector continued to increase in the 1990 to 2011 period except in 1998 in which a sharp decrease was temporarily observed due to the economic crisis. It was followed by some fluctuation between -1.5 percent and 5.4 percent in emissions until it peaked in 2018.

Emissions from the Energy sector are largely divided into Fuel combustion (1.A.) and Fugitive emissions (1.B.). In 2022, emissions from fuel combustion were 548.5 Mt CO_2−eq, representing 99.4 percent of sectoral emissions while fugitive emissions accounted for 0.6 percent with 3.4 Mt CO_2−eq. From fuel combustion, Energy industries (1.A.1.) was the largest contributor accounting for 46.7 percent, followed by Manufacturing industries and construction (1.A.2.) (25.5 percent), Transport (1.A.3.) (17.8 percent), Other sectors (1.A.4.) (8.8 percent), Other (1.A.5.) (0.6 percent), Solid fuels of fugitive emissions (1.B.1.) (0.4 percent) and Oil and natural gas of fugitive emissions (1.B.2.) (0.2 percent).

| Table ES−4 | Greenhouse Gas Emissions from Energy Sector

(Unit: Mt CO_2−eq)

(Sub)Category	1990	2000	2010	2018	2021	2022	Emissions Change (%)	
							From 1990	From 2021
1.A. Fuel Combustion	**223.5**	**396.5**	**545.9**	**608.4**	**563.4**	**548.5**	**145.4**	**−2.6**
1.A.1. Energy Industries	42.0	136.3	254.6	300.0	260.0	257.5	512.7	−1.0
1.A.2. Manufacturing Industries and Construction	72.2	115.4	142.8	153.5	152.9	141.0	95.4	−7.8
1.A.3. Transport	36.5	71.9	86.7	98.8	99.5	98.5	170.2	−1.0
1.A.4. Other Sectors	72.6	70.5	58.9	53.0	48.0	48.4	−33.3	0.9
1.A.5. Other	0.2	2.4	3.0	3.1	2.9	3.0	1,561.0	3.3
1.B. Fugitive Emissions from Fuels	**11.0**	**5.7**	**4.4**	**3.7**	**3.4**	**3.4**	**−69.1**	**−0.5**
1.B.1. Solid Fuels	10.9	5.2	3.6	2.7	2.5	2.4	−77.8	−2.3
1.B.2. Oil and Natural Gas	0.1	0.5	0.9	1.0	0.9	1.0	1,456.3	4.1
Total	234.5	402.2	550.3	612.1	566.8	551.9	135.4	−2.6

Industrial Processes and Product Use (IPPU)

In 2022, emissions from the IPPU sector were 131.3 Mt CO_2-eq, accounting for 18.1 percent of national totals which increased by 247.3 percent from 37.8 Mt CO_2-eq in 1990 and decreased by 1.1 percent from 132.8 Mt CO_2-eq in 2021.

Emissions from all categories except for Product uses as substitutes for ODS (2.F.) and Non-energy products from fuels and solvent use (2.D.) decreased from 2021. In 2022, categories of Electronics industry (2.E.) and Chemical industry (2.B.) produced less emissions from 2021 by 21.6 percent (1.9 Mt CO_2-eq) and 3.0 percent (1.0 Mt CO_2-eq) respectively which were contributed by the reduced input in the naphtha cracking process in the chemistry industry and the enhanced efficacy of emission control equipment in industries across the IPPU sector.

In 2022, the subcategory of product uses as substitutes from ODS was the largest source, representing 24.5 percent followed by the chemical industry of 24.2 percent, the mineral industry of 21.7 percent, the metal industry of 21.3 percent, the electronics industry of 5.3 percent, other product manufacture and use of 2.5 percent and non-energy products and solvent use of 0.5 percent.

Emissions from the IPPU sector were estimated using activity data from a range of sources, but mostly from the Target Management System (TMS) and Emissions Trading Scheme (K-ETS). Data from TMS and K-ETS are verified by the third party and reviewed for its validity as activity data to ensure the completeness and time-series consistency, and adequacy of methodologies and emission factors. Categories that use TMS and K-ETS data include : Mineral industry (2.A.), Chemical industry (2.B.), Metal industry (2.C.), Electronics industry (2.E.) and Other product manufacture and use (2.G.). Since TMS and K-ETS data were available from 2007, activity data for emissions in years prior to 2007 were derived from other sources such as national statistics and field survey.

| Table ES-5 | Greenhouse Gas Emissions from IPPU Sector

(Unit: Mt CO_2-eq)

Category	1990	2000	2010	2018	2021	2022	Emissions Change (%)	
							From 1990	From 2021
2.A. Mineral Industry	16.4	26.1	28.3	30.5	29.0	28.4	73.4	−2.0
2.B. Chemical Industry	7.8	30.1	25.1	31.4	32.8	31.8	306.9	−3.0
2.C. Metal Industry	13.1	18.5	20.5	31.7	28.2	28.0	114.1	−0.8
2.D. Non-Energy Products from Fuels and Solvent Use	0.4	0.5	0.5	0.6	0.6	0.6	72.0	7.0
2.E. Electronics Industry	IE,NA,NO	3.3	8.9	8.7	8.9	7.0	212.5	−21.6
2.F. Product Uses as Substitutes for ODS	IE,NO	2.5	7.4	23.1	29.4	32.2	2,053,154.8	9.5
2.G. Other Product Manufacture and Use	0.2	2.2	4.3	2.9	3.9	3.3	1,835.1	−16.9
Total	**37.8**	**83.1**	**95.0**	**128.9**	**132.8**	**131.3**	**247.3**	**−1.1**

Note: 1) The percentage change of the electronics industry was calculated based on data for 1997 from which data were available.
2) The percentage change of product uses as substitutes for ODS was calculated based on data for 1992 from which data were available.

○ Agriculture

In 2022, total greenhouse gas emissions from the Agriculture sector were 23.0 Mt CO_2-eq, accounting for 3.2 percent of national total emissions which represented decreases of 7.7 percent from 1990 and 0.5 percent from 2021.

Emissions from rice cultivation in 2022 decreased by 4.1 percent (0.3 Mt CO_2-eq) from 2021 which was contributed by changes in water regime practices as well as reduced areas of rice cultivation and of organic amendments applied. The area of rice cultivation as well as the area to which organic amendments were applied decreased by 0.1 percent and 16.3 percent respectively. In contrast, emissions from enteric fermentation increased by 2.8 percent (0.2 Mt CO_2-eq) from 2021 due to the increased livestock population of cattle, chicken and horse. The population of *Hanwoo* (Korean native cattle) and beef cattle increased by 4.4 percent[7] while chicken and horse populations increased by 1.9 percent and 0.5 percent respectively.[8]

In 2022, Rice cultivation (3.C.) was the largest source in the Agriculture sector, accounting for 31.0 percent of total sectoral emissions followed by Enteric fermentation (3.A.)

7) The population of *Hanwoo* (Korean native cattle) and beef cattle in 2021 was 3,538,000 which increased to 3,693,000 in 2022. (*Livestock Statistics*, KOSTAT)
8) The population of chicken in 2021 was 174,498,000 which increased to 177,733,000 in 2022 (*Livestock Statistics*, KOSTAT)

(29.4 percent), Manure management (3.B.) (26.4 percent), Agricultural soils (3.D.) (12.7 percent), Urea application (3.H.) (0.4 percent), Field burning of agricultural residues (3.F.) (0.1 percent), and Liming (3.G.) (0.01 percent).

| Table ES-6 | Greenhouse Gas Emissions from Agriculture Sector

(Unit: Mt CO_2-eq)

Category	1990	2000	2010	2018	2021	2022	Emissions Change (%)	
							From 1990	From 2021
3.A. Enteric Fermentation	3.8	4.3	5.6	6.0	6.6	6.7	79.7	2.8
3.B. Manure Management	3.3	4.7	5.5	6.0	6.0	6.1	82.9	0.8
3.C. Rice cultivation	14.1	12.0	10.6	8.5	7.4	7.1	−49.5	−4.1
3.D. Agricultural soils	3.2	3.3	2.8	2.8	3.0	2.9	−9.7	−1.0
3.F. Field Burning of Agricultural Residues	0.06	0.06	0.05	0.04	0.03	0.03	−53.2	−22.4
3.G. Liming	0.003	0.003	0.003	0.003	0.002	0.002	−2.4	0.7
3.H. Urea Application	0.43	0.28	0.12	0.12	0.11	0.09	−78.8	−16.7
Total	24.9	24.7	24.7	23.5	23.1	23.0	−7.7	−0.5

Land Use, Land-Use Change and Forestry (LULUCF)

In 2022, net removals from the LULUCF sector were 37.8 Mt CO_2-eq, representing decreases of 2.9 percent from 1990 and 3.0 percent from 2021.

Forest land (4.A.) was the largest sink in the LULUCF sector with net removals of 39.3 Mt CO_2-eq, followed by Settlements (4.E.) with 1.2 Mt CO_2-eq and the Harvested Wood Products (HWP) (4.G.) with 0.5 Mt CO_2-eq. Emission sources including Cropland (4.B.), Wetlands (4.D.) and Grassland (4.C.) emitted 2.9 Mt CO_2-eq, 0.38 Mt CO_2-eq and 0.001 Mt CO_2-eq respectively.

Net removals of forest land which accounted for the largest share of the LULUCF sector increased since 1995 as a result of continued reforestation and forest management until it peaked in 2008 removing 61.6 Mt CO_2-eq of carbon. However due to the declining annual net growth of trees caused by aging forests and the reduced area of forest land, net removals have been declining since 2010. Although removals by living biomass have been stable in recent three years from 2020 to 2022, emissions from wildfire increased. In 2022, the burned area was 24,797 ha which was considerably larger than the average burned area of 1,087 ha of the last decade from 2012 to 2021. As a result, net removals from forest land in 2022 was 1.1 Mt CO_2-eq less than that in 2021.

| Table ES-7 | Greenhouse Gas Emissions and Removals from LULUCF Sector

(Unit: Mt CO_2-eq)

Category	1990	2000	2010	2018	2021	2022	Emissions/Removals Change (Mt CO_2-eq)	
							From 1990	From 2021
4.A. Forest land	-38.2	-60.5	-58.8	-42.6	-40.4	-39.3	-1.1	1.1
4.B. Cropland	0.1	1.9	3.0	2.6	2.9	2.9	2.8	-0.02
4.C. Grassland	-0.67	-0.74	-0.21	-0.04	-0.01	0.001	0.7	0.008
4.D. Wetlands	0.34	0.39	0.37	0.39	0.40	0.38	0.03	-0.03
4.E. Settlements	-0.7	-0.9	-1.1	-1.2	-1.2	-1.2	-0.5	0.005
4.G. Harvested Wood Products	0.2	-0.5	-0.6	-0.7	-0.7	-0.5	-0.7	0.1
Total Net Emissions	**-39.0**	**-60.4**	**-57.4**	**-41.6**	**-39.0**	**-37.8**	**1.1**	**1.2**

Waste

In 2022, greenhouse gas emissions from the Waste sector were 18.2 Mt CO_2-eq and accounted for 2.5 percent of total national emissions, representing an increase of 35.3 percent from 1990, and a 0.8 percent decrease from 2021. Since 1990, emissions from the Waste sector increased until it peaked in 2001 which was then followed by a declining trend. Such decrease was contributed by less emissions from solid waste disposal which was the largest source in the sector. Emissions from the remaining subcategories continued to increase in the 1990s and remained steady since the mid-2000s.

Solid waste disposal (5.A.) in 2022 was the largest source in the Waste sector, representing 63.8 percent of total sectoral emissions, followed by Waste incineration (5.C.) (24.6 percent), Wastewater treatment and discharge (5.D.) (10.0 percent) and Biological treatment of solid waste (5.B.) (1.6 percent).

Emissions from solid waste disposal which was the biggest contributor in this sector peaked in 1997 with 18.1 Mt CO_2-eq and have been consistently decreasing which was contributed by the law prohibiting the direct landfilling of food wastes enacted in 2005. The law led to a shift from landfill to food waste treatment such as composting and waste-to-energy solutions which resulted in a continued decrease in emissions.

The largest increase in emissions was observed from waste incineration as emissions increased by 699.4 percent (3.9 Mt CO_2-eq) from 1990. This was largely due to the growing population and economic growth resulting in the increased volume of wastes incinerated. After establishing the *National Plan for Circular Economy* in 2018, the volume of waste recycled as well as energy recovery from municipal solid waste incineration have consistently increasing which contributed to the decrease in emissions.

| Table ES-8 | Greenhouse Gas Emissions from Waste Sector

(Unit: Mt CO_2-eq)

Category	1990	2000	2010	2018	2020	2021	Emissions Change (%)	
							From 1990	From 2021
5.A. Solid Waste Disposal	12.1	17.3	13.8	12.3	11.8	11.6	-4.5	-1.4
5.B. Biological Treatment of Solid Waste	NE	0.03	0.09	0.28	0.30	0.29	6,593.4[1)]	-3.8
5.C. Waste Incineration	0.6	4.3	4.0	5.1	4.7	4.5	699.4	-4.5
5.D. Wastewater Treatment and Discharge	0.7	1.8	1.9	1.7	1.6	1.8	149.9	15.2
Total	**13.4**	**23.4**	**19.7**	**19.4**	**18.3**	**18.2**	**35.3**	**-0.8**

Note: 1) The percentage change of biological treatment of solid waste was calculated based on data for 1994 from which data were available.

ES.4 Other Information

As it is encouraged to provide information on precursor gases of carbon monoxide (CO), nitrogen oxides (NOx) and non-methane volatile organic compounds (NMVOCs), sulphur oxides (SOx) as well as indirect CO_2 and N_2O emissions in accordance with Article 51 and 52 of MPGs, ROK will make additional efforts to include emissions of respective gases in its Biennial Transparency Report and National Inventory Document in the upcoming years.

ES.5 Key Category Analysis

In accordance with Article 25 of the MPGs, key categories were identified using the level assessment and trend assessment of approach 1 from the *2006 IPCC Guidelines* considering both scenarios that include and exclude the LULUCF sector.

For key category analysis, emission sources and carbon sinks were disaggregated into 94 categories including LULUCF[9] using the online reporting tool (ETF reporting tool) of the UNFCCC. Categories that cumulatively accounted for 95% of total emissions based on the absolute values of emissions and removals (both including and excluding LULUCF) in 1990 and 2022 were identified as key categories.

The level assessment evaluates the contribution of each source or sink category to the total national inventory level in accordance with the *2006 IPCC Guidelines*. As removals by sinks are expressed as negative values in the national inventory, absolute values were used to calculate both the total contributions and the individual contributions of sink categories.

The trend assessment was conducted in accordance with the *2006 IPCC Guidelines,* examining the change in the source or sink category over time from the base year of 1990 to the latest inventory year of 2022 in this document. For categories with zero emissions in the base year, the trend assessment was conducted using *Equation 4.3 of the 2006 IPCC Guidelines.*

The 2022 level assessment identified 23 out of 94 categories as key which included energy industries (solid fuel, CO_2), manufacturing industries and construction (solid fuel, CO_2), road transportation (CO_2), energy industries (gaseous fuel, CO_2), and forest land remaining forest land (CO_2).

The 1990 level assessment identified 21 key categories, indicating that there were categories newly identified as key in 2022 from which significant trends from 1990 to 2022 were observed. Such categories include refrigeration and air conditioning (fluorinated gases), manufacturing industries and construction (gaseous fuel, CO_2), electronics industry (fluorinated gases), and manufacturing industries and construction (other fossil fuels, CO_2). Conversely, there were some categories that were identified as key in 1990 but not in 2022.

9) Using the ETF Tool, 94 source and sink categories were identified from which key categories were also analyzed.

The trend assessment for the 1990 to 2022 period indicates that key categories in 2022 include energy industries (solid fuel, CO_2), other sectors (solid fuel, CO_2), manufacturing industries and construction (liquid fuel, CO_2), and other sectors (liquid fuel, CO_2).

| Table ES-9 | Key Category Analysis (including LULUCF)

* Key categories in grey shaded cells ( )

CRT code	Source and Sink Category	GHG	Incl. LULUCF			2022 Emissions (kt CO_2-eq)	Level Assessment ($L_{x,t}$)	Cumulative Total ($L_{x,t}$)
			2022 Level	1990 Level	Trend			
1.A.1	Energy industries: solid fuels	CO_2	•	•	•	169,441	0.220	0.220
1.A.2	Manufacturing industries and construction: solid fuels	CO_2	•	•	•	100,287	0.130	0.351
1.A.3.b	Road transportation	CO_2	•	•	•	92,736	0.121	0.471
1.A.1	Energy industries: gaseous fuels	CO_2	•	•	•	68,905	0.090	0.561
4.A.1	Forest land remaining forest land	CO_2	•	•	•	-39,540	0.051	0.612
1.A.4	Other sectors: gaseous fuels	CO_2	•	•	•	31,698	0.041	0.653
2.B.8	Petrochemical and carbon black production	CO_2	•	•	•	31,276	0.041	0.694
2.F.1	Refrigeration and air conditioning	Fluorinated gases	•	-	•	29,238	0.038	0.732
2.C.1	Iron and steel production	CO_2	•	•	•	27,710	0.036	0.768
2.A.1	Cement production	CO_2	•	•	•	23,227	0.030	0.798
1.A.2	Manufacturing industries and construction: gaseous fuels	CO_2	•	-	•	20,699	0.027	0.825
1.A.1	Energy industries: liquid fuels	CO_2	•	•	•	17,691	0.023	0.848
1.A.4	Other sectors: liquid fuels	CO_2	•	•	•	15,023	0.020	0.868
1.A.2	Manufacturing industries and construction: liquid fuels	CO_2	•	•	•	12,839	0.017	0.885
5.A	Solid waste disposal	CH_4	•	•	•	11,597	0.015	0.900
3.C	Rice Cultivation	CH_4	•	•	•	7,112	0.009	0.909
2.E	Electronics industry	Fluorinated gases	•	-	•	6,956	0.009	0.918
3.A	Enteric fermentation	CH_4	•	•	•	6,742	0.009	0.927
1.A.2	Manufacturing industries and construction: Other fossil fuels	CO_2	•	-	•	6,489	0.008	0.935
5.C	Incineration and open burning of waste	CO_2	•	-	•	4,263	0.006	0.941
2.A.2	Lime Production	CO_2	•	-	•	3,962	0.005	0.946
3.B	Manure Management	CH_4	•	•	-	3,490	0.005	0.950

CRT code	Source and Sink Category	GHG	Incl. LULUCF			2022 Emissions (kt CO_2-eq)	Level Assessment ($L_{x,t}$)	Cumulative Total ($L_{x,t}$)
			2022 Level	1990 Level	Trend			
2.G	Other product manufacture and use	Fluorinated gases	•	–	•	3,153	0.004	0.954
1.B.1	Solid fuels	CH_4	–	•	•	2,417	–	–
3.D.1	Direct N_2O emissions from managed soils	N_2O	–	•	–	1,677	–	–
1.A.3.d	Domestic Navigation: liquid fuels	CO_2	–	•	•	1,378	–	–
1.A.4	Other sectors: solid fuels	CO_2	–	•	•	785	–	–
1.A.4	Other sectors: solid fuels	CH_4	–	•	•	62	–	–

Notes: 1) Sources and sinks that add up to 95% of the sum of all level assessment are indicated with a bullet point (•).
2) Categories are in descending order of magnitude from the 2022 level assessment.
3) Fluorinated gases in this table indicate the sum of HFCs, PFCs, SF_6, and NF_3.

SECTION 01

Introduction

1 Introduction

1.1 Background Information on Climate Change and Greenhouse Gas Inventory

1.1.1 National Responses to Climate Change

The average annual temperature in the Republic of Korea (ROK) has continued to increase for the last 110 years. It increased by approximately 1.6°C over the last 30 years (1991–2020) compared to the historical 30-year period (1912–1940). Among the ten warmest years recorded between 1912 and 2020, six occurred in the last decade (2011–2020).[1] In 2023, the average annual temperature was 1.2°C higher than that in 2022 at 13.7°C which was the highest on record since 1973. The average annual temperatures in the last five years indicated that the respective years were among ten warmest years recorded, representing a clear indication of the continued rise in temperature. Extreme weather events have occurred more frequently and severely as evidenced by the intensified precipitation and heat waves, tropical nights and extreme temperature variations in winter. By the end of the 21st century (2081–2100), ROK's average annual temperature is projected to increase by between 2.3°C and 6.3°C compared to the period from 2000 to 2019.[2]

1) *Analysis report on climate change in Korea over 109 years (1912-2020)*, Korea Meteorological Administration & National Institute of Meteorological Sciences. (2021). [in Korean]

2) *Comprehensive climate change projection report for South Korea: Climate change projections under four SSP scenarios,* National Institute of Meteorological Sciences. (2022). [in Korean]

* National Institute of Meteorological Sciences (2022) developed detailed climate change scenarios for ROK based on the latest greenhouse gas pathways from the *IPCC Sixth Assessment Report* under the Shared Socioeconomic Pathways (SSP). These scenarios include SSP1–2.6, SSP2–4.5, SSP3–7.0, and SSP5–8.5, and the National Institute of Meteorological Sciences (2022) presents the projected annual average temperature increases for the years 2081–2100 for each scenario.

- SSP1–2.6 assumes minimal fossil fuel use and sustainable economic growth, driven by advancements in renewable energy technologies.
- SSP2–4.5 assumes a moderate level of climate change mitigation and socioeconomic development.
- SSP3–7.0 assumes a society with limited climate change mitigation efforts and slow technological development, leading to vulnerability to climate change.
- SSP5–8.5 assumes rapid industrial development, high fossil fuel use, and uncontrolled urban expansion.

National Commitments and Domestic Mitigation Policies

Since ratification of the United Nations Framework Convention on Climate Change (UNFCCC) in 1993, ROK has been committed to contributing to global efforts to address climate change. Following the adoption of the Paris Agreement in 2015, ROK submitted its Intended Nationally Determined Contributions (INDC) to the UNFCCC. In 2020, ROK declared its national vision to achieve carbon neutrality by 2050 and submitted the 2030 Nationally Determined Contributions (NDC) in 2021 which was an enhanced update of the INDC with more ambitious greenhouse gas reduction target.

In 2021, both the 2050 carbon neutrality vision and the 2030 NDC were codified in the *Framework Act on Carbon Neutrality and Green Growth for Coping with Climate Crisis* (hereinafter referred to as *"Carbon Neutrality Act"*) and its Enforcement Decree. The *Carbon Neutrality Act* stipulates the national target to reduce emissions no less than 35 percent from the 2018 levels by 2030 and outlines policy measures to mitigate emissions.

Implementation of Policies and Measures

To achieve carbon neutrality and the 2030 NDC, ROK established the *National Framework Plan for Carbon Neutrality and Green Growth* in 2023 which is a legally mandated plan spanning 20 years with quinquennial updates. It outlines mid- and long-term national and sectoral reduction targets on an annual basis with associated policies and measures which include enhancing the Korea Emissions Trading System (K-ETS), expanding zero-carbon electricity generation, strengthening building energy efficiency standards, promoting low emission technology in agriculture and fisheries, reducing wastes through circular economy actions, recovering and expanding carbon sinks in forests and the ocean, and increasing new carbon sinks such as urban forests. Each local government develops their own plan for carbon neutrality and green growth to implement climate change response policies specifically shaped for local circumstances.

1.1.2 National Greenhouse Gas Inventory

Transitioning from the Measurement, Reporting and Verification (MRV) arrangements for national greenhouse gas inventories to the Enhanced Transparency Framework (ETF) under the Paris Agreement, all Parties are required to submit a National Inventory Document (NID) and the Common Reporting Tables (CRT) to the UNFCCC either as a standalone report or as part of a Biennial Transparency Report (BTR) due by the end of 2024.[3)]

Gases

In accordance with Articles 48 and 49 of the *Modalities, procedures and guidelines for the transparency framework for action and support referred to in Article 13 of the Paris Agreement* (hereinafter referred to as the "MPGs"), this document summarizes the inventory of emissions and removals of seven gases which include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6) and nitrogen trifluoride (NF_3).

Methodology and Metrics

In accordance with Article 20 of the MPGs, anthropogenic emissions and removals were estimated using the methodologies in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (hereinafter referred to as the "*2006 IPCC Guidelines*") and, where appropriate, the *2019 Refinement to the 2006 IPCC Guidelines* (hereinafter referred to as the "*2019 Refinement*") was applied (Section 1.3).

For metrics, this document reflects CO_2-equivalents using 100-year time-horizon global warming potential (GWP) values from the *IPCC Fifth Assessment Report* as specified in Article 37 of the MPGs (see Section 1.8).

Sector and Time Series

In accordance with Article 50 of the MPGs, the national greenhouse gas inventory consists of five sectors including Energy, Industrial Processes and Product Use (IPPU), Agriculture, Land Use, Land-Use Change and Forestry (LULUCF)[4], and Waste. The time series of this inventory cover 33 years from 1990 to 2022.

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3) *Modalities, procedures and guidelines for the transparency framework for action and support referred to in Article 13 of the Paris Agreement (Decision 18/CMA.1)*, UNFCCC (2018)

4) The *2006 IPCC Guidelines* integrate Agriculture and LULUCF into a single sector of AFOLU.

1.2 National Inventory Arrangements

1.2.1 Institutional Arrangements

The Greenhouse Gas Inventory and Research Center of Korea (GIR) was established in 2010 under the Ministry of Environment for management of the national greenhouse gas inventory data through an integrated information system. GIR has defined its responsibilities which include establishing a *Master Plan for National Greenhouse Gas Inventory Management* and *National MRV Guidelines*; verifying greenhouse gas data and country-specific emission and removal factors; managing the national greenhouse gas reporting system; and enhancing international cooperation on climate mitigation.

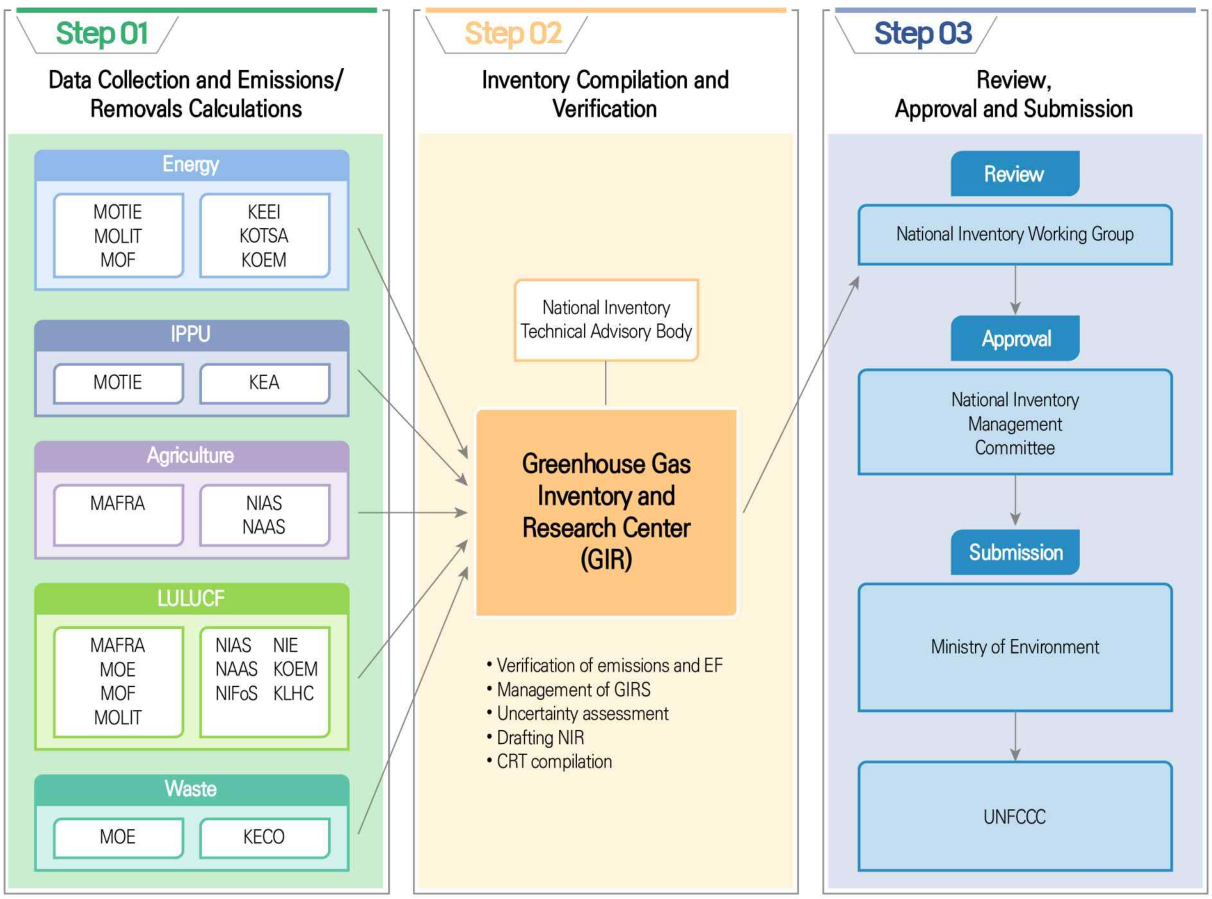
GIR organizes and coordinates the *National Inventory Technical Advisory Body* (hereafter referred to as the *"Technical Advisory Body"*), the *National Inventory Working Group* (*"Working Group"*), and the *National Inventory Management Committee* (*"Management Committee"*).

The *Technical Advisory Body* which is composed of national greenhouse gas inventory experts recommended by government ministries provides technical advice on the inventory and country-specific emission and removal factors.

The *Working Group* is an inter-ministerial coordination body responsible for the establishment and revision of national MRV guidelines as well as the development and verification of country-specific emission and removal factors. Chaired by the GIR president, the *Working Group* members include director-level officials from the Office for Government Policy Coordination, Ministry of Agriculture, Food and Rural Affairs, Ministry of Trade, Industry and Energy, Ministry of Environment, Ministry of Land, Infrastructure and Transport, Ministry of Oceans and Fisheries, Rural Development Administration, Korea Forest Service, and Statistics Korea.

The *Management Committee* is the decision-making body for national MRV guidelines as well as country-specific emission and removal factors. Chaired by the Assistant Minister of Environment, the *Management Committee* members include director-general-level officials from the Office for Government Policy Coordination, Ministry of Agriculture, Food and Rural Affairs, Ministry of Trade, Industry and Energy, Ministry of Environment, Ministry of Land, Infrastructure and Transport, Ministry of Oceans and Fisheries, Statistics Korea, and experts with extensive knowledge and experience in sector-specific greenhouse gas inventories. GIR serves as a coordinating body for the *Management Committee*.

Each respective government ministry manages sector-specific greenhouse gas inventories as a focal point and designates its subsidiary agencies to delegate duties of developing country-specific emission and removal factors, and estimating associated emissions and removals. Ministries review and submit sectoral inventories prepared by the designated agencies to GIR for verification.



| Figure 1-1 | National Greenhouse Gas Inventory Arrangements and Process

Note: Statistical information is consulted with Statistics Korea to ensure integrity and reliability of the national inventories.

| Table 1-1 | Overview of National Greenhouse Gas Inventory Arrangements

Sector and Category		Governing Ministry	Designated Agency
Energy	Fuel Combustion (Energy industries and manufacturing industries and construction) and Fugitive Emissions	Ministry of Trade, Industry and Energy (MOTIE)	Korea Energy Economics Institute (KEEI)
	Transportation (Aviation, Road, Rail) and Buildings	Ministry of Land, Infrastructure and Transport (MOLIT)	Korea Transportation Safety Authority (KOTSA)
	Transportation (Maritime) and Fisheries	Ministry of Oceans and Fisheries (MOF)	Korea Marine Environment Corporation (KOEM)
IPPU		Ministry of Trade, Industry and Energy (MOTIE)	Korea Energy Agency (KEA)
Agriculture	Livestock	Ministry of Agriculture, Food, and Rural Affairs (MAFRA)	National Institute of Animal Science (NIAS)
	Cultivation		National Academy of Agricultural Science (NAAS)
LULUCF	Forest Land, Harvested Wood Products		National Institute of Forest Science (NIFOS)
	Cropland		National Academy of Agricultural Science (NAAS)
	Grassland		National Institute of Animal Science (NIAS)
	Wetlands-Inland	Ministry of Environment (MOE)	National Institute of Ecology (NIE)
	Wetlands-Coastal	Ministry of Oceans and Fisheries (MOF)	Korea Marine Environment Corporation (KOEM)
	Settlements, Other Land	Ministry of Land, Infrastructure and Transport (MOLIT)	Korea Land and Housing Corporation (KLHC)
Waste		Ministry of Environment (MOE)	Korea Environment Corporation (KECO)

Note: As it is encouraged to provide information on precursor gases of carbon monoxide (CO), nitrogen oxides (NOx) and non-methane volatile organic compounds (NMVOCs), sulphur oxides (SOx) as well as indirect CO_2 and N_2O emissions in accordance with Article 51 and 52 of MPGs, ROK will make additional efforts to include emissions of respective gases in its Biennial Transparency Report and National Inventory Document in the upcoming years.

1.2.2 Inventory Preparation Process

1.2.2.1 Preparation

GIR and relevant ministries jointly develop a five-year plan, a *Master Plan for National Greenhouse Gas Inventory* (hereinafter referred to as the *"Master Plan"*)[5] to ensure the quality and consistency of national inventory data, providing a guidance for implementing planned improvements. Areas for improvement include updated methodologies, developing and managing country-specific emission and removal factors as well as collecting activity data, and managing a *Greenhouse Gas Inventory Reporting System* (GIRS).

5) *The First Master Plan for National Greenhouse Gas Inventory (2015-2019)* and the *Second Master Plan for National Greenhouse Gas Inventory (2020-2024)* were published in 2015 and 2020 respectively.

GIR prepares annual amendments to the national MRV guidelines, incorporating requirements from the *Master Plan* and areas for improvements identified during the inventory verification process from the previous year. Once these amendments are finalized following a review by the *Working Group* and deliberation by the *Management Committee*, GIR releases the revised guidelines to governing ministries by December for submission of the sectoral greenhouse gas inventory in the following year.

The governing ministries develop an annual work plan for estimating emissions and removals based on the methodologies outlined in the annual amendments to the national MRV guidelines distributed by GIR. Responsibilities of each ministry include reviewing activity data and tracking any data changes, designating its subsidiary agencies with relevant expertise to delegate duties of developing country-specific emission and removal factors and of estimating emissions as well as removals.

1.2.2.2 Measurement, Reporting and Verification (MRV)

The designated agencies collect data for estimating sectoral emissions and removals by sources and sinks in cooperation with data providers, and estimate national emissions in accordance with the national MRV guidelines released by GIR. The governing ministries conduct quality assurance (QA) and quality control (QC) activities for the entire process of estimating emissions and removals which include collection of activity data, development of country-specific emission and removal factors as well as assessment on the use of methodologies. After QA/QC procedures are implemented, respective ministries submit sectoral estimates of emissions and removals and inventory reports along with supporting documentation to GIR by March every year.

Upon receipt of such sectoral greenhouse gas inventories and associated reports submitted by governing ministries, GIR verifies activity data, emission and removal factors, methodological approaches as well as calculation errors. If any error or areas for improvement are identified, GIR requests the respective ministry to make corrections. After confirming the revised inventory resubmitted by the ministry, GIR prepares a final draft of the national greenhouse gas inventory report and its datasets that cover all sectors.

1.2.2.3 Finalization, Publication and Improvement

The national greenhouse gas inventory report prepared by GIR is officially announced after consultation with the *Working Group* and deliberation by the *Management*

Committee. The final inventory is publicly released online through the websites of GIR and Statistics Korea. The report is used to prepare the National Communication (NC), Biennial Update Report (BUR), and BTR submitted to the UNFCCC.

Areas for improvement identified during the process of inventory preparation are incorporated into either the national MRV guidelines for the following year or the next *Master Plan* depending on whether such improvements can be made in the short or long term. This process ensures a continued improvement in the quality of national greenhouse gas inventories.

| Table 1-2 | National Greenhouse Gas Inventory Preparation Timeline

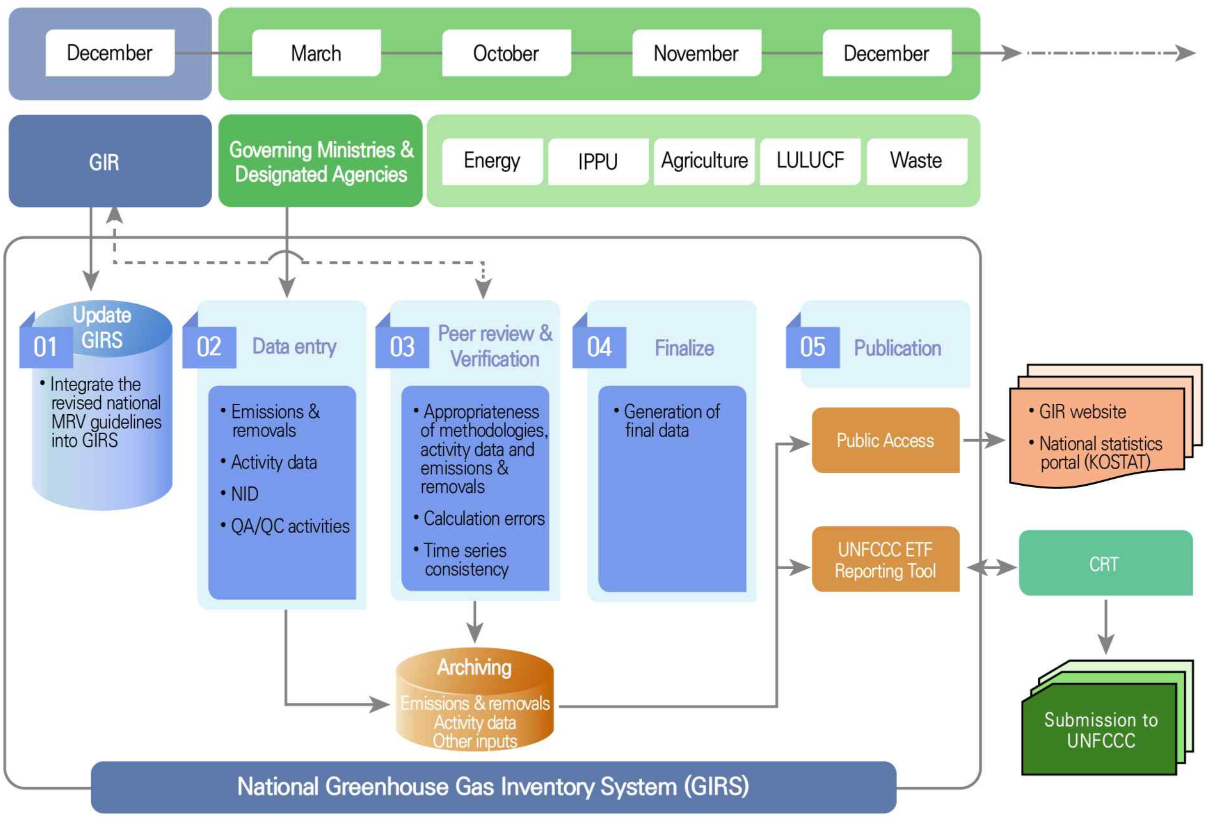
Process	Implemented by	Task	*t*+1	*t*+2			
				Jan	Mar	Oct	Dec
Preparation							
Prepare updated MRV guidelines	GIR	• Draft and prepare updated MRV guidelines					
Establish an annual work plan	Governing Ministries	• Review data for GHG emissions and removals estimation					
Estimation and Reporting							
Estimate and report GHG emissions and removals	Governing Ministries, Designated Agencies	• Estimate emissions and removals by sector • Implement internal QA/QC procedures and report to GIR					
Verification							
Compile and verify sectoral inventories	GIR	• Compile sectoral inventories and prepare aggregated data tables • Review a draft of the inventory report and aggregated data tables • Request for corrections and improvements					
	Governing Ministries	• Make correction and resubmit sector-specific inventories					
Finalization							
Review	Working Group	• Review a draft of national GHG emissions and removals • Prepare a national inventory improvement plan					
Finalize and approve	Management Committee	• Finalize and approve the national GHG inventory					
Publication							
Public release	GIR	• Release the national GHG inventory					

Note: The national greenhouse gas inventory for the 1990 through the inventory year *t* is completed in year *t*+2 as per the *National MRV Guidelines for Greenhouse Gas Inventory.*

1.2.3 Archiving of Information

To facilitate integrated data management and ensure continuity of the national inventory, all of the essential information on emissions and removals of ROK are compiled in the Greenhouse Gas Inventory Reporting System (GIRS). GIRS provides a platform for the efficient collection and archiving of data files on activity data, emissions and removal estimates, methodological approaches as well as electronic documents on report preparation, data entry and historical records thereof.

GIR annually updates data entry files on activity data and methodologies in accordance with the national MRV guidelines which are released through GIRS for designated agencies. Designated agencies complete the given data files and upload them in GIRS along with reports on the sectoral inventory and QA/QC activities for a review by governing ministries and submission to GIR. GIR compiles all sectoral inventories to prepare the national greenhouse gas inventory for deliberation and final approval by the *Working Group* and *Management Committee*. Following approval, the national inventory is released as ROK's official emissions and removal data and is automatically populated by GIRS in the format of CRT for data entry in the online reporting tool (ETF reporting tool) of the UNFCCC.[6]



| Figure 1-2 | Data Compilation and Archiving Procedures

6) Functional testing of GIRS to generate entry files that could be directly imported to the ETF reporting tool is in progress.

1.3 Methodology and Data Sources

1.3.1 Methodology

The national greenhouse gas inventory in this document applied methodologies consistent with the *2006 IPCC Guidelines* in accordance with the Article 20 of MPGs. The *2013 Supplement (Wetlands)* and the *2019 Refinement* were also used to supplement methodologies for sub-sectors where detailed activity data and updated emission and removal factors are available. The *2013 Supplement (Wetlands)* were used for methodologies for CO_2 emissions and removal from coastal wetlands (4.D.1.c.i.) and CO_2 emission factor for tidal marshes. Similarly, the *2019 Refinement* was used for emission factors for fugitive CO_2 and CH_4 from underground mines including abandoned ones in the Energy sector, methodology for N_2O emissions from manure management in the Agriculture sector, and methodologies for CO_2 emissions and carbon stock in harvested wood products (HWP) in the LULUCF sector.

1.3.2 Sources of Activity Data

The sources of activity data used in national greenhouse gas inventory include national statistics published by statistical agencies[7)] that are designated under the Statistics Act, data provided by Statistics Korea and relevant associations, and reports submitted by entities under the Greenhouse Gas Target Management System (TMS) and K-ETS.

To supplement the activity data from aforementioned sources, non-national statistics including surveys independently conducted by designated agencies and reports on Clean Development Mechanism (CDM) were also used.

ROK will continue to refine its QA/QC procedures that involve examining data sources and the verification process to further increase the accuracy of national emission estimates (see Section 1.5 for QA/QC).

7) Entities including government ministries, public organizations, relevant associations and research institutes that compile numerical data for purposes of the establishment and evaluation of policies, research and analysis of economic and social phenomena are designated as statistical agencies in accordance with Article 15 of the *Statistics Act* to promote the production, dissemination, and use of statistics.

| Table 1-3 | Data Sources by Sector

* National Statistics in grey shaded cells ( )

Sector	Data and Statistics	Statistics Agency
Energy	*Yearbook of Energy Statistics*	Korea Energy Economics Institute
	Oil Supply Statistics	Korea National Petroleum Corporation
	Energy Census	Ministry of Trade, Industry and Energy
	Reports under Emissions Trading System (K-ETS) and Target Management System (TMS)	Ministry of Environment
	Aviation fuel consumption	Korea Transportation Safety Authority
	Number of takeoffs and landings per aircraft type	Korea Transportation Safety Authority
	Urea water sales	Ministry of Environment
	Lubricants industry resources	Korea Lubricating Oil Industry Association
	Ship LNG supply	LNG suppliers
	Number of mines closed by year	Korea Mine Rehabilitation and Mineral Resources Corporation
IPPU	Volume of glass production, shipments, inventory, imports, exports	Korea Energy Agency
	Import and Export Statistics	Korea Customs Service
	Reports under Target Management System (TMS) and Emissions Trading System (K-ETS)	Ministry of Environment
	Company-specific survey on activity data in mineral and chemical sectors	Korea Energy Agency
	Clinker production	Korea Cement Association
	Lime production	Korea Limestone Processing Cooperative
	Bottle glass production	Korea Glass Industry Cooperative
	Limestone, dolomite consumption	Korea Iron and Steel Association
	Aluminium production	Korea Nonferrous Metal Association
	Volume of lubricants and grease production, imports and exports	Korea Lubricating Oil Industry Association
	Gas consumption	Korea Semiconductor Industry Association
	Gas consumption	Korea Display Industry Association
	Reports on manufacturing and import volume of pharmaceuticals	Ministry of Food and Drug Safety
	Petrochemical Statistics	Korea Chemical Industry Association
	CDM monitoring reports	UNFCCC
	Yearbook of Energy Statistics	Korea Energy Economics Institute
Agriculture	*Livestock Statistics*	Statistics Korea
	Statistical Yearbook of Agriculture, Food and Rural Affairs	Ministry of Agriculture, Food and Rural Affairs
	Annual Agriculture, Forestry and Fisheries Survey	Statistics Korea
	Agricultural Area Statistics	
	Census of Agriculture, Forestry and Fisheries	

Sector	Data and Statistics	Statistics Agency
	Crop Production Survey	Statistics Korea
	Agricultural and livestock production cost survey	
	Fertilizer Use Statistics Yearbook	National Agricultural Cooperative Federation
	Fertilizer Yearbook	Korea Fertilizer Industry Association
LULUCF	*Statistical Yearbook of Forestry*	Korea Forest Service
	Basic Forest Statistics	Korea Forest Service
	Market Survey of Timber Products	
	Agricultural Area Statistics	Statistics Korea
	Research on Development of Fruit Farming (1992)	Rural Development Administration
	Soil Classification and Explanation of ROK (2011)	
	Cadastral Statistics	Ministry of Land, Infrastructure and Transport
	Number of ice cover days	Korea Meteorological Administration
	National Blue Carbon Inventory System (K-BIS)	Ministry of Oceans and Fisheries
Waste	*National Waste Generation and Treatment Report*	Ministry of Environment
	National Waste Management Survey	
	Sewer Statistics	
	Generation and treatment of industrial wastewater	
	Sudokwon Landfill Statistics Yearbook	*Sudokowon* Landfill Site Management Corporation

BOX 1. Korea Emissions Trading System (K-ETS)

1. Introduction

- Emissions Trading System (ETS) is a market-based emission reduction scheme that allocates annual emission allowances to business entities of which average annual emissions exceed a certain level in order to allow emissions within the given cap.
- ROK enacted the *Act on the Allocation and Trading of Greenhouse Gas Emissions Allowances* in May 2012 and its *Enforcement Decree* in November 2012 (hereinafter referred to as the "*Act*" and "*Decree*") to provide a legal framework for the scheme.
- K-ETS was introduced in 2015 based on the *Basic Plan for the Emissions Trading System*, the *National Allowances Allocation Plan : Phase I (2015-2017)* and related guidelines that align with national reduction target.

2. Entities subject to K-ETS

- An entity with an average annual total emissions exceeding 125,000 t CO_2-eq, or of which at least one business site emitting more than 25,000 t CO_2-eq over 3 consecutive years
  * A total of 707 entities are participating in K-ETS as of 2022.

3. Emissions Estimation, Verification and Submission

- Emissions from participating entities under K-ETS are estimated and verified following the *Guidance on Emissions Reporting and Certification for the Greenhouse Gas Emissions Trading System* and the *Guidance on Verification for Greenhouse Gas Emissions Trading System Operations*.
- Participating entities estimate emissions in compliance with the guidelines below depending on the size and activities of facilities.
  * A total of 572 Mt CO_2-eq of direct and indirect emissions were estimated in 2022.

Emissions	Methodological Choice
Over 500,000 t CO_2-eq	Tier 3 methodology with plant-specific emission factor (PS-EF)
50,000 - 500,000 t CO_2-eq	Tier 2 or 3 methodology with country-specific emission factor (CS-EF)
Less than 50,000 t CO_2-eq	Tier 1 methodology with default emission factor (D-EF)

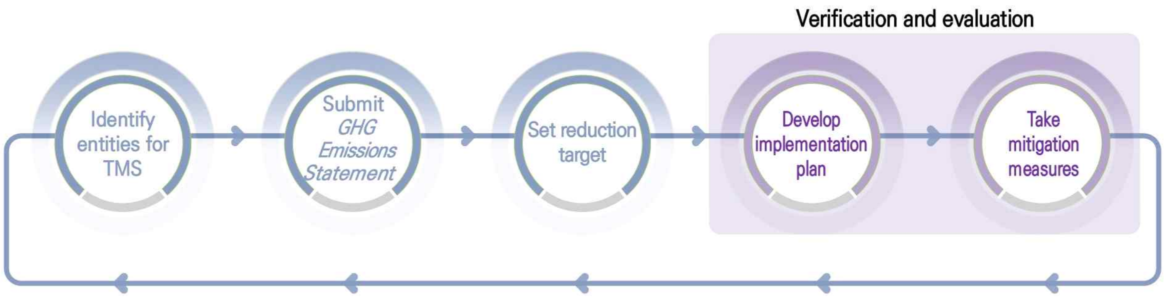
※ Direct emissions in the context of K-ETS refer to emissions from onsite combustion or processes of fuel owned by the entity while indirect emissions refer to emissions from activities associated with fuel purchased from another entity.

- Emission allowances are verified by a third-party body that is accredited to implement the respective procedures as designated by Minister of Environment.

BOX 2. Korea Target Management System (TMS)

1. Introduction

- The Target Management System (TMS) is a quantity-based system that annually identifies business entities of which average annual emissions exceed a certain level to be subject to the system with the aim of setting mitigation targets and reducing emissions.



- TMS was introduced in 2012 in accordance with the *Framework Act on Low Carbon, Green Growth* which was enacted in 2010.

2. Entities subject to TMS

- An entity with an average annual total emissions exceeding 50,000 t CO_2-eq, or of which a business site emitting more than 15,000 t CO_2-eq over 3 consecutive years
  ※ If emissions from the entity under TMS increase to the extent that it becomes subject to K-ETS, the respective entity is switched to the entity under K-ETS.

3. Emissions Estimation, Verification and Submission

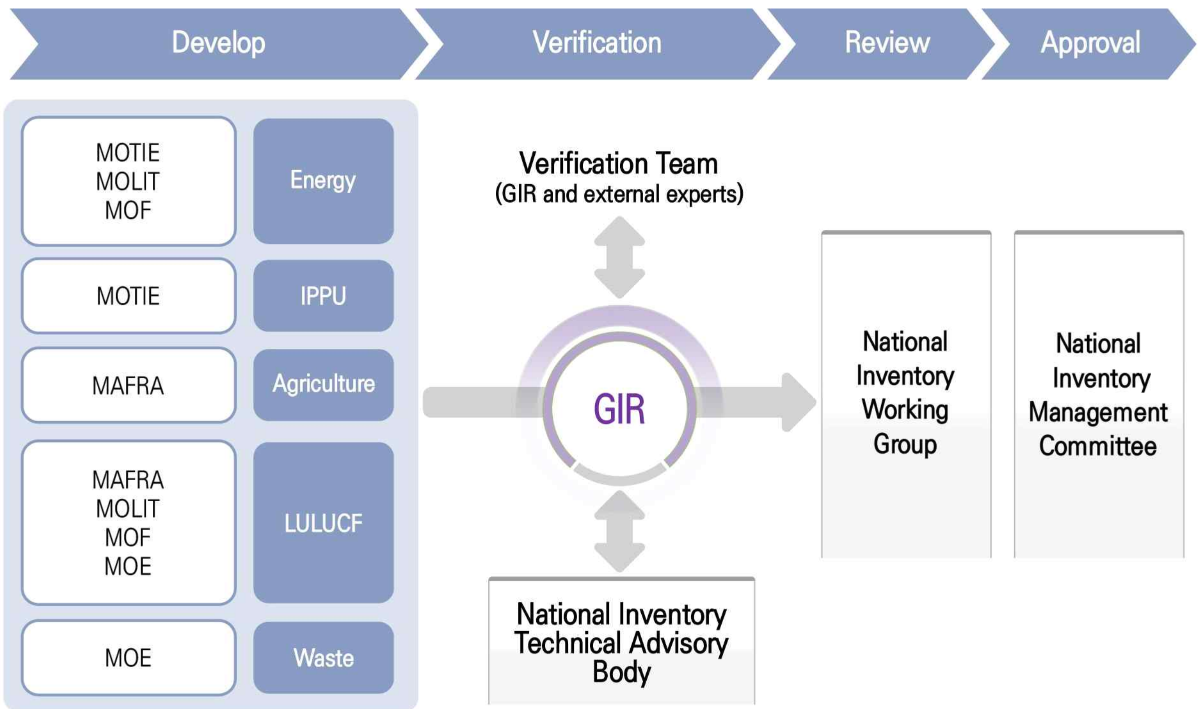
- Emissions from participating entities under TMS are estimated and verified following the *Guidelines for Greenhouse Gas Target Management Operations* and the *Guidelines on Verification for Greenhouse Gas Emissions Trading System Operations*.
- Each entity is required to electronically report emissions in the TMS/K-ETS information system in compliance with applicable laws and regulations together with the results of third-party verification on the respective report to the governing ministry by the end of March.

1.3.3 Country-specific Emission and Removal Factors (CS-EF)

To increase the accuracy of the national greenhouse gas inventory, ROK establishes the *Master Plan* every five years and updates the *National Guidelines for Country-Specific Emission and Removal Factors* (hereinafter referred to as the *"National CS-EF Guidelines"*) to systematically develop, verify, and manage country-specific emission and removal factors.

The governing ministries develop respective factors that reflect domestic circumstances in accordance with the *National CS-EF Guidelines* using methodologies presented in the IPCC guidelines and the national MRV guidelines for K-ETS and TMS as well as academically recognized methodological approaches such as those published in SCI(E)-indexed journals.

Country-specific emission and removal factors developed by designated agencies are verified by GIR and finalized after deliberation and review by the *Working Group* and approval by the *Management Committee*. Such emission and removal factors are reflected in the updated MRV guidelines and used for the national inventory.



| Figure 1-3 | Country-Specific Emission and Removal Factor Development Process

1.4 Key Category Analysis

1.4.1 Methodology

In accordance with Article 25 of the MPGs, key categories were identified using the level assessment and trend assessment of Approach 1 from the *2006 IPCC Guidelines* considering both scenarios that include and exclude the LULUCF sector.

For key category analysis, emission sources and carbon sinks were disaggregated into 94 categories including LULUCF[8] using the online reporting tool (ETF reporting tool) of the UNFCCC. Categories that cumulatively accounted for 95% of total emissions based on the absolute values of emissions and removals (both including and excluding LULUCF) in 1990 and 2022 were identified as key categories.

The level assessment evaluated the contribution of each source or sink category to the total national inventory level in accordance with the *2006 IPCC Guidelines*. As removals by sinks were expressed as negative values in the national inventory, absolute values were used to calculate both the total contributions and the individual contributions of sink categories.

Level Assessment (Approach 1)

$$L_{x,\ t} = \frac{|E_{x,t}|}{\sum_y |E_{y,t}|}$$

L_x, t	: Level evaluation of emission (absorption) source item x of inventory year (t)
$\|E_{x,\ t}\|$	: The absolute value of the emission (absorption) amount of the t year item x (contribution of item x total contribution)
$\Sigma y \mid E_{y,t} \mid$	: The sum of the absolute value of the number of emissions (absorption) by item in the t year (total contribution)

Source: *2006 IPCC Guidelines, Vol.1, Ch.4, Equation 4.1*

The trend assessment was conducted in accordance with the *2006 IPCC Guidelines*, examining the change in emissions from the source or sink category over time from the base year of 1990 to the latest inventory year of 2022 in this document. For categories with zero emissions in the base year, the trend assessment was conducted using Equation 4.3 of the *2006 IPCC Guidelines*.

8) Using the ETF Tool, 94 source and sink categories were identified from which key categories were also analyzed.

Trend Assessment (Approach 1)

$$T_{x,t} = \frac{|E_{x,0}|}{\sum_y |E_{y,0}|} \times \left| \left[\frac{(E_{x,t} - E_{x,0})}{|E_{x,0}|} \right] - \frac{\left(\sum_y E_{y,t} - \sum_y E_{y,0}\right)}{\left|\sum_y E_{y,0}\right|} \right|$$

$T_{x,t}$ = 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

Source: *2006 IPCC Guidelines, Vol.1, Ch.4, Equation 4.2*

Trend Assessment with zero base year emissions

$$T_{x,t} = \left| \frac{E_{x,t}}{\sum_y |E_{y,0}|} \right|$$

Source: *2006 IPCC Guidelines, Vol.1, Vol.4, Equation 4.3*

1.4.2 Key Category Analysis Results

The 2022 level assessment identified 23 out of 94 categories as key which included energy industries (solid fuel, CO_2), manufacturing industries and construction (solid fuel, CO_2), road transportation (CO_2), energy industries (gaseous fuel, CO_2), and forest land remaining forest land (CO_2).

The 1990 level assessment identified 21 key categories, indicating that there were categories newly identified as key in 2022 from which significant trends from 1990 to 2022 were observed. Such categories include refrigeration and air conditioning (fluorinated gases), manufacturing industries and construction (gaseous fuel, CO_2), electronics industry (fluorinated gases), and manufacturing industries and construction (other fossil fuels, CO_2). Conversely, there were some categories that were identified as key in 1990 but not in 2022.

The trend assessment for the 1990 to 2022 period indicates that key categories in 2022 include energy industries (solid fuel, CO_2), other sectors (solid fuel, CO_2), manufacturing industries and construction (liquid fuel, CO_2), and other sectors (liquid fuel, CO_2).

| Table 1-4 | Key Category Analysis (including LULUCF)

※ Key categories in grey shaded cells ( )

CRT code	Source and Sink Category	GHG	Incl. LULUCF			2022 Emissions (kt CO_2-eq)	Level Assessment ($L_{x,t}$)	Cumulative Total ($L_{x,t}$)
			2022 Level	1990 Level	Trend			
1.A.1	Energy industries: solid fuels	CO_2	•	•	•	169,441	0.220	0.220
1.A.2	Manufacturing industries and construction: solid fuels	CO_2	•	•	•	100,287	0.130	0.351
1.A.3.b	Road transportation	CO_2	•	•	•	92,736	0.121	0.471
1.A.1	Energy industries: gaseous fuels	CO_2	•	•	•	68,905	0.090	0.561
4.A.1	Forest land remaining forest land	CO_2	•	•	•	-39,540	0.051	0.612
1.A.4	Other sectors: gaseous fuels	CO_2	•	•	•	31,698	0.041	0.653
2.B.8	Petrochemical and carbon black production	CO_2	•	•	•	31,276	0.041	0.694
2.F.1	Refrigeration and air conditioning	Fluorinated gases	•	–	•	29,238	0.038	0.732
2.C.1	Iron and steel production	CO_2	•	•	•	27,710	0.036	0.768
2.A.1	Cement production	CO_2	•	•	•	23,227	0.030	0.798
1.A.2	Manufacturing industries and construction: gaseous fuels	CO_2	•	–	•	20,699	0.027	0.825
1.A.1	Energy industries: liquid fuels	CO_2	•	•	•	17,691	0.023	0.848
1.A.4	Other sectors: liquid fuels	CO_2	•	•	•	15,023	0.020	0.868
1.A.2	Manufacturing industries and construction: liquid fuels	CO_2	•	•	•	12,839	0.017	0.885
5.A	Solid waste disposal	CH4	•	•	•	11,597	0.015	0.900
3.C	Rice Cultivation	CH4	•	•	•	7,112	0.009	0.909
2.E	Electronics industry	Fluorinated gases	•	–	•	6,956	0.009	0.918
3.A	Enteric fermentation	CH4	•	•	•	6,742	0.009	0.927
1.A.2	Manufacturing industries and construction: Other fossil fuels	CO_2	•	–	•	6,489	0.008	0.935
5.C	Incineration and open burning of waste	CO_2	•	–	•	4,263	0.006	0.941
2.A.2	Lime Production	CO_2	•	–	•	3,962	0.005	0.946
3.B	Manure Management	CH_4	•	•	–	3,490	0.005	0.950

CRT code	Source and Sink Category	GHG	Incl. LULUCF			2022 Emissions (kt CO_2-eq)	Level Assessment ($L_{x,t}$)	Cumulative Total ($L_{x,t}$)
			2022 Level	1990 Level	Trend			
2.G	Other product manufacture and use	Fluorinated gases	•	–	•	3,153	0.004	0.954
1.B.1	Solid fuels	CH_4	–	•	•	2,417	–	–
3.D.1	Direct N_2O emissions from managed soils	N_2O	–	•	–	1,677	–	–
1.A.3.d	Domestic Navigation: liquid fuels	CO_2	–	•	•	1,378	–	–
1.A.4	Other sectors: solid fuels	CO_2	–	•	•	785	–	–
1.A.4	Other sectors: solid fuels	CH_4	–	•	•	62	–	–

Note: 1) Sources and sinks that add up to 95% of the sum of all level assessment are indicated with a bullet point (•).
2) Categories are in descending order of magnitude from the 2022 level assessment.
3) Fluorinated gases in this table indicate the sum of HFCs, PFCs, SF_6, and NF_3.

Table 1-5 shows the level assessments in 1990 and 2022 as well as the trend assessment *excluding* LULUCF.

| Table 1-5 | Key Category Analysis (excluding LULUCF)

* Key categories in grey shaded cells ( )

CRT code	Source and Sink Category	GHG	Excl. LULUCF			2022 Emissions (kt CO_2-eq)	Level Assessment ($L_{x,t}$)	Cumulative Total ($L_{x,t}$)
			2022 Level	1990 Level	Trend			
1.A.1	Energy industries: solid fuels	CO_2	•	•	•	169,441	0.234	0.234
1.A.2	Manufacturing industries and construction: solid fuels	CO_2	•	•	•	100,287	0.138	0.372
1.A.3.b	Road transportation	CO_2	•	•	•	92,736	0.128	0.500
1.A.1	Energy industries: gaseous fuels	CO_2	•	•	•	68,905	0.095	0.596
1.A.4	Other sectors: gaseous fuels	CO_2	•	•	•	31,698	0.044	0.639
2.B.8	Petrochemical and carbon black production	CO_2	•	•	•	31,276	0.043	0.683
2.F.1	Refrigeration and air conditioning	Fluorinated gases	•	–	•	29,238	0.040	0.723
2.C.1	Iron and steel production	CO_2	•	•	–	27,710	0.038	0.761
2.A.1	Cement Production	CO_2	•	•	•	23,227	0.032	0.793
1.A.2	Manufacturing industries and construction: gaseous fuels	CO_2	•	–	•	20,699	0.029	0.822

CRT code	Source and Sink Category	GHG	Excl. LULUCF			2022 Emissions (kt CO_2-eq)	Level Assessment ($L_{x,t}$)	Cumulative Total ($L_{x,t}$)
			2022 Level	1990 Level	Trend			
1.A.1	Energy industries: liquid fuels	CO_2	•	•	•	17,691	0.024	0.846
1.A.4	Other sectors: liquid fuels	CO_2	•	–	•	15,023	0.021	0.867
1.A.2	Manufacturing industries and construction: liquid fuels	CO_2	•	•	•	12,839	0.018	0.885
5.A	Solid waste disposal	CH_4	•	•	•	11,597	0.016	0.901
3.C	Rice Cultivation	CH_4	•	•	•	7,112	0.010	0.911
2.E	Electronics industry	Fluorinated gases	•	–	•	6,956	0.010	0.920
3.A	Enteric Fermentation	CH_4	•	•	–	6,742	0.009	0.929
1.A.2	Manufacturing industries and construction: Other fossil fuels	CO_2	•	–	•	6,489	0.009	0.938
5.C	Incineration and open burning of waste	CO_2	•	–	•	4,263	0.006	0.944
2.A.2	Lime Production	CO_2	•	–	•	3,962	0.005	0.950
3.B	Manure Management	CH_4	•	•	–	3,490	0.005	0.955
2.G	Other product manufacture and use	Fluorinated gases	–	–	•	3,153	–	–
1.B.1	Solid Fuels	CH_4	–	•	•	2,417	–	–
3.D.1	Direct N_2O emissions from managed soils	N_2O	–	•	–	1,677	–	–
1.A.3.d	Domestic Navigation	CO_2	–	•	•	1,378	–	–
1.A.4	Other sectors: solid fuels	CO_2	–	•	•	785	–	–
1.A.4	Other sectors: solid fuels	CH_4	–	•	•	62	–	–

Note: 1) Sources and sinks that add up to 95% of the sum of all level assessment are indicated with a bullet point (•).
2) Categories are in descending order of magnitude from the 2022 level assessment.
3) Fluorinated gases in this table indicate the sum of HFCs, PFCs, SF_6, and NF_3.

1.5 Quality Assurance and Quality Control (QA/QC)

1.5.1 QA/QC Procedures

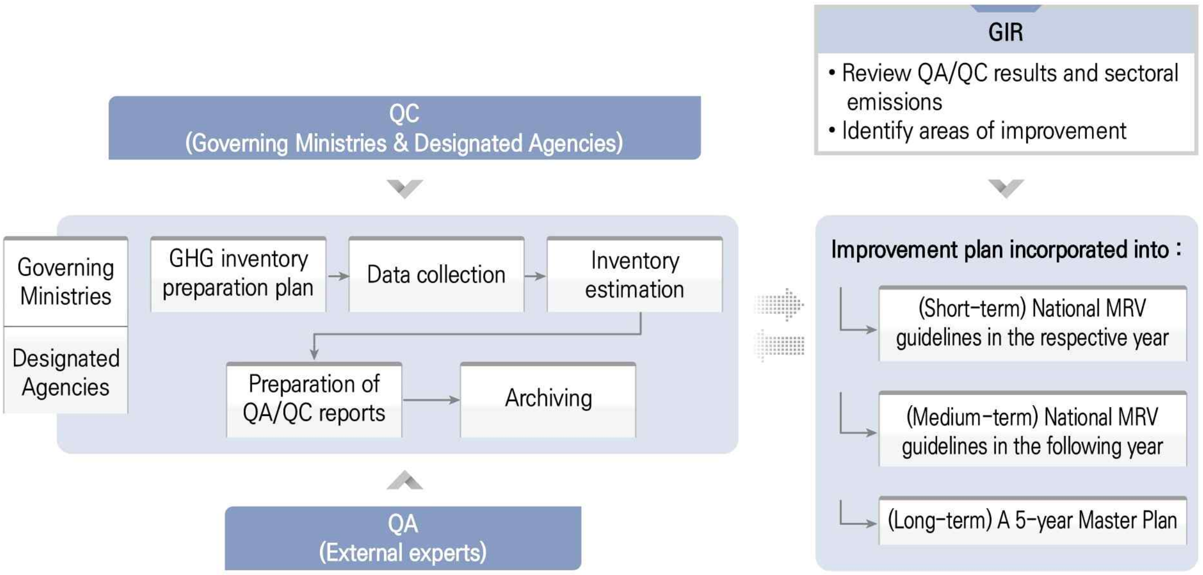
To ensure and enhance transparency, accuracy, consistency, completeness and comparability (TACCC) of the national greenhouse gas inventory, quality assurance and quality control procedures were implemented in accordance with the *2006 IPCC Guidelines*.

The governing ministries, designated agencies and external experts conducted QA/QC activities as per general and category-specific procedures.

The general QC procedures involve technical elements that must be examined to ensure the accuracy of emission estimates such as activity data, emission and removal factors and methodologies. Category-specific QC criteria include elements specifically needed for estimation of emissions from each subcategory.

The general QA procedures include elements that need to be reviewed in general during the planning, estimation and reporting processes of sectoral emissions. External experts who did not participate in estimation of emissions and removals conducted general QA activities to verify the appropriateness of activity data, compliance of emission and removal factors as well as methodologies with relevant guidelines, and the time series consistency of activity data and estimates of emissions and removals.

The governing ministries and designated agencies submit reports on QA/QC procedures to GIR. GIR reviews QA/QC reports as well as sectoral emissions and removals to verify the accuracy of emission estimates to improve the quality of the inventory. Areas of improvement identified during QA/QC and verification processes that could be addressed immediately are incorporated into the updates of the national MRV guidelines in the respective year while those that could be addressed in the short term are reflected in the following update of the national MRV guidelines. Areas for long-term improvement are incorporated into the five-year *Master Plan*. This process ensures continuous improvement in the quality of the national greenhouse gas inventory.



| Figure 1-4 | QA/QC and Verification Framework

QA/QC and verification procedures are implemented for national statistics and country-specific emission and removal factors in order to further enhance the accuracy of the inventory as explained below.

1.5.2 QA/QC and Verification of Country-Specific Emission and Removal Factors (CS-EF)

The governing ministries develop country-specific emission and removal factors (CS-EF) which are submitted to GIR. GIR organizes a verification team comprising both internal and external experts, and a technical advisory body primarily composed of external experts to assess the appropriateness, representativeness and accuracy of methodologies as well as sources and sinks used for the development of emission and removal factors.

In the development and verification process of emission and removal factors, six major criteria and fourteen key elements are considered (see Table 1-6). To verify the methodology used and representativeness of CS-EF, it is considered whether methodologies applied are from appropriate and reliable sources such as the *IPCC Guidelines*, and whether sample groups are reasonably selected. When verifying the accuracy of measurement and analysis, GIR examines whether methodologies take into account characteristics of emission sources and sinks, and whether extreme values or missing values in raw data are appropriately addressed. QA/QC procedures and uncertainty assessments are also implemented as part of the verification process. CS-EF that are thoroughly verified are then reviewed by the *Working Group* with relevant ministries and approved by the *Management Committee*. CS-EF are then ultimately incorporated into the updated national MRV guidelines and used as fundamental data for national greenhouse gas inventory.

| Table 1-6 | Verification Criteria for Country-Specific Emission and Removal Factor

Criteria	Key elements
Methodology	① Consistency with national and IPCC guidelines on emission and removal estimation
	② Appropriateness of methodology
	③ Consideration of characteristics of emission and removal sources
Representativeness	④ Appropriateness of sample group
	⑤ Adequacy of the sample size
Accuracy	⑥ Appropriateness of types and methodologies of measurement and analysis
	⑦ Reliability of entities implementing measurement and analysis
	⑧ Reliability of measurement and analysis tools
Data management	⑨ Appropriateness of data management
	⑩ Time series consistency in data
QA/QC	⑪ Adequacy of QA/QC activities
	⑫ Factor equivalence evaluation
Uncertainty assessment	⑬ Appropriateness of uncertainty assessment method
	⑭ Uncertainty assessment

Source: *National Guidelines for Development and Verification of Greenhouse Gas Emission and Removal Factors* (GIR, 2020)

1.6 Uncertainty Assessment

In accordance with the *2006 IPCC Guidelines*, uncertainty assessment of national greenhouse gas inventory is conducted using either linear error propagation method for which key factors (i.e. emission factors and activity data) are propagated linearly, or a Monte Carlo simulation technique which utilizes the probability distribution functions of individual factors. For national emissions in 1990 and 2022 as well as trend analysis, ROK used a Monte Carlo simulation technique.

ROK primarily used default uncertainty estimates for emission factors and activity data for each sector presented in the *2006 IPCC Guidelines*[9] while country-specific uncertainty estimates were used for some sectors. In cases where uncertainty data are available for country-specific emission factors, either a normal or lognormal assumption was made for the distribution of emission factors. Emissions from fossil fuel combustion in the Energy sector which accounts for the majority of national emissions were based on national statistics on energy consumption. Accordingly, uncertainty was assumed to be low according to the *2006 IPCC Guidelines* and thus normal distributions were used. As there is high uncertainty associated with N_2O and CH_4, as noted in the *2006 IPCC Guidelines*, lognormal distributions were assumed for respective gases because normal distributions may lead to the negative value of emissions factors.

The uncertainty of each sector (Level 1) was estimated by calculating the uncertainty of subcategories (Level 3-5). Emissions from subcategories were simulated repeatedly by generating random values of emission factors and activity data. Emissions from each subcategory were then aggregated by either the category or national level. Using the probability distribution of emissions corresponding to the number of iterations, the uncertainty was calculated.

At the 95 percent confidence interval level, uncertainties of total gross emissions in 2022 were -5.0 percent to 6.4 percent which were lower than that in 1990. This is primarily driven by the improvement of emission factors from default to country-specific factors.

ROK will continue to improve the completeness and increase the accuracy of an uncertainty analysis by including the estimates of uncertainties associated with country-specific emission and removal factors as well as activity data by subcategories.

9) If the estimates of uncertainty of emission factors or activity data are not available, the corresponding subcategory is excluded from the calculation of the uncertainty estimates of both the category and the total national inventory.

1.7 Completeness

In line with Articles 30, 31 and 32 of the MPGs, Parties may use notation keys for sources and sinks for which methodologies are available in the IPCC Guidelines but are not considered in the national inventory report (see Table 1-7). For such emissions and removals, Parties should explain the reasons for exclusion.

Accordingly, ROK reported emissions from categories or processes that do not exist in ROK as "NO" (Not Occurring) which include Non-metallurgical magnesium production (2.A.4.c.) of Mineral industry, and Glyoxal (2.B.4.b.) of Chemical industry in the IPPU sector.

The notation key of "IE" (Included Elsewhere) is used for emissions that are not estimated under the expected source or sink category but instead included elsewhere. One of such sources in ROK from which emissions were included elsewhere is Road transportation (1.A.3.) in the Energy sector. Although emissions are required to be reported under the corresponding vehicle type (i.e. cars, light-duty trucks, heavy-duty trucks and buses, and motorcycles), ROK's national statistics on fuel consumption are not disaggregated by vehicle types. As a result, aggregated emissions were reported under the subcategory of 'Cars (1.A.3.b.i.)' and emissions from light-duty trucks, heavy-duty trucks and buses, and motorcycles were reported as "IE".

| Table 1-7 | CRT Notation Keys

NE	Not Estimated	Emissions and/or removals may occur within a Party but have not been estimated
IE	Included Elsewhere	Emissions and/or removals are estimated but reported elsewhere in the inventory instead of under the expected category
C	Confidential	Emissions and/or removals that would involve the disclosure of confidential information
NA	Not Applicable	Activities occur within the Party but do not result in emissions or removals of a specific gas
NO	Not Occurring	Categories or processes do not exist within a Party

1.8 Metrics

Greenhouse gases vary in the ability to trap heat in the atmosphere and potential impact on global warming. For comparability of all gases subject to reporting, Parties shall use 100-year Global Warming Potential (GWP) values[10) from the *IPCC Fifth Assessment Report* to estimate emissions in CO_2-equivalents (hereinafter referred to as "CO_2-eq") in their national reports in compliance with Article 37 of MPGs of the Paris Agreement. Accordingly, all estimates in this document are presented in units of CO_2-eq.

| Table 1-8 | Global Warming Potentials (GWP)

Gas		Chemical formula	GWP100
Carbon dioxide		CO_2	1
Methane		CH_4	28
Nitrous oxide		N_2O	265
Hydrofluorocarbons (HFCs)	HFC-23	CHF_3	12,400
	HFC-32	CH_2F_2	677
	HFC-41	CH_3F	116
	HFC-125	CHF_2CF_3	3,170
	HFC-134	CHF_2CHF_2	1,120
	HFC-134a	CH_2FCF_3	1,300
	HFC-143	CH_2FCHF_2	328
	HFC-143a	CH_3CF_3	4,800
	HFC-152	CH_2FCH_2F	16
	HFC-152a	CH_3CHF_2	138
	HFC-161	CH_3CH_2F	4
	HFC-227ea	CF_3CHFCF_3	3,350
	HFC-236cb	$CH_2FCF_2CF_3$	1,210
	HFC-236ea	CHF_2CHFCF_3	1,330
	HFC-236fa	$CF_3CH_2CF_3$	8,060
	HFC-245ca	$CH_2FCF_2CHF_2$	716
	HFC-245fa	$CHF_2CH_2CF_3$	858
	HFC-365mfc	$CH_3CF_2CH_2CF_3$	804
	HFC-43-10mee	$CF_3CHFCHFCF_2CF_3$	1,650
Perfluorinated compounds (PFCs)	PFC-14	CF_4	6,630
	PFC-116	C_2F_6	11,100
	PFC-218	C_3F_8	8,900
	PFC-318	$c-C_4F_8$	9,540
	PFC-31-10	C_4F_{10}	9,200
	PFC-41-12	C_5F_{12}	8,550
	PFC-51-14	C_6F_{14}	7,910
	PCF-91-18	$C_{10}F_{18}$	7,190
	Trifluoromethyl sulfur pentafluoride	SF_5CF_3	17,400
	Perfluorocyclopropane	$c-C_3F_6$	9,200
Sulfur hexafluoride		SF_6	23,500
Nitrogen trifluoride		NF_3	16,100

10) Greenhouse gas emissions = activity data × emission factor × GWP

SECTION

02 Trends in Greenhouse Gas Emissions and Removals

2 Trends in Greenhouse Gas Emissions and Removals

2.1 Greenhouse Gas Emissions and Sinks Trends

2.1.1 Overview

In 2022, ROK's total gross emissions excluding LULUCF were 724.3 Mt CO_2-eq, representing a 133.2 percent increase from 310.6 Mt CO_2-eq in 1990.[1)] As illustrated in Figure 2-1 and Table 2-1, total gross emissions decreased by 2.3 percent from 741.0 Mt CO_2-eq in 2021, and by 7.6 percent from 783.9 Mt CO_2-eq in 2018 in which emissions peaked. Net emissions including LULUCF were 686.5 Mt CO_2-eq in 2022, showing a 152.7 percent increase from 271.6 Mt CO_2-eq in 1990.[2)] Between 2021 and 2022, net emissions decreased by 2.2 percent from 702.0 Mt CO_2-eq. Net emissions in 2018 were 742.3 Mt CO_2-eq which decreased by 7.5 percent in 2022.

National greenhouse gas emissions continued to increase in the 1990s which was driven largely by economic growth. From the late 2000s, the slowdown in emissions growth was observed until emissions reached its peak in 2018 which was then followed by a decreasing trend in the 2018 through 2022 years. In 2020, emissions temporarily decreased by 6.1 percent from 2019 due to the impacts of the global pandemic. Although emissions in 2021 increased relative to the previous year with the easing of the pandemic and rebound of economic activity, emissions declined in 2022, continuing the downward trend. In the pre-pandemic period, the decreases in emissions were observed in some years which were largely driven by economic crisis. The Asian Financial Crisis in 1997 contributed to a sharp decrease of 12.5 percent in emissions in 1998 which was followed by the upward trend with an average annual emissions growth of 2.6 percent until 2009 when the economy was hit by the Great Recession which resulted in only a slight increase of 0.6 percent in 2009.

In 2022, the largest contributor to national greenhouse gas emissions was the Energy sector, representing 76.2 percent of total emissions, followed by the Industrial Processes and Product Use (IPPU) sector of 18.1 percent. The Agriculture and Waste sectors

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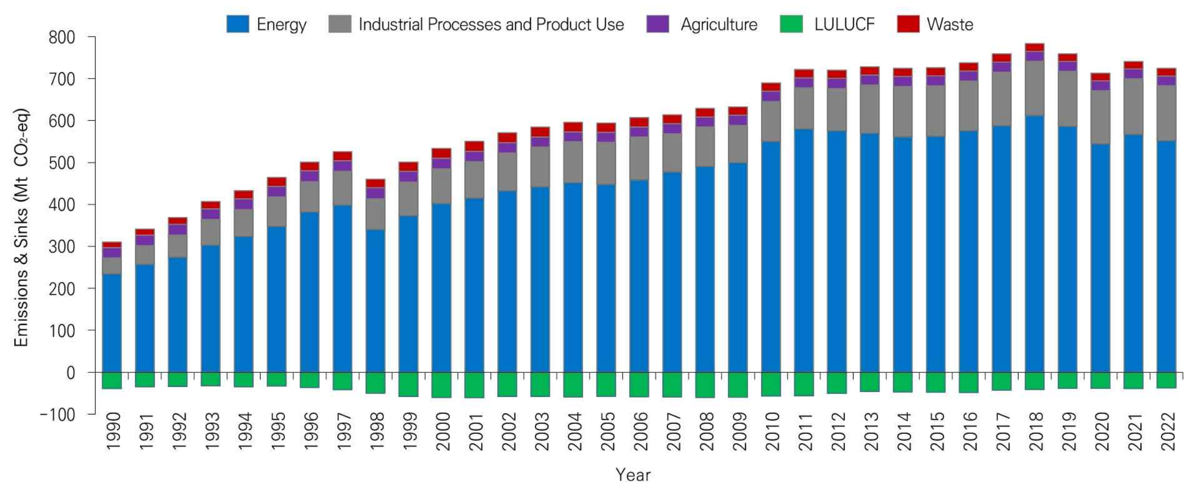
1) The total gross emissions in this document exclude emissions and removals from LULUCF.

2) The net emissions in this document include emissions and removals from LULUCF.

accounted for 3.2 percent and 2.5 percent respectively. As the manufacturing industry makes up a significant part of the industrial structure of ROK, emissions from the Energy sector have consistently accounted for between 74 and 80 percent of national total emissions since 1990.



| Figure 2-1 | Trends in Greenhouse Gas Emissions and Removals by Sector (1990-2022)

| Table 2-1 | Greenhouse Gas Emissions and Percentage by Sector

(Unit: Mt CO_2-eq)

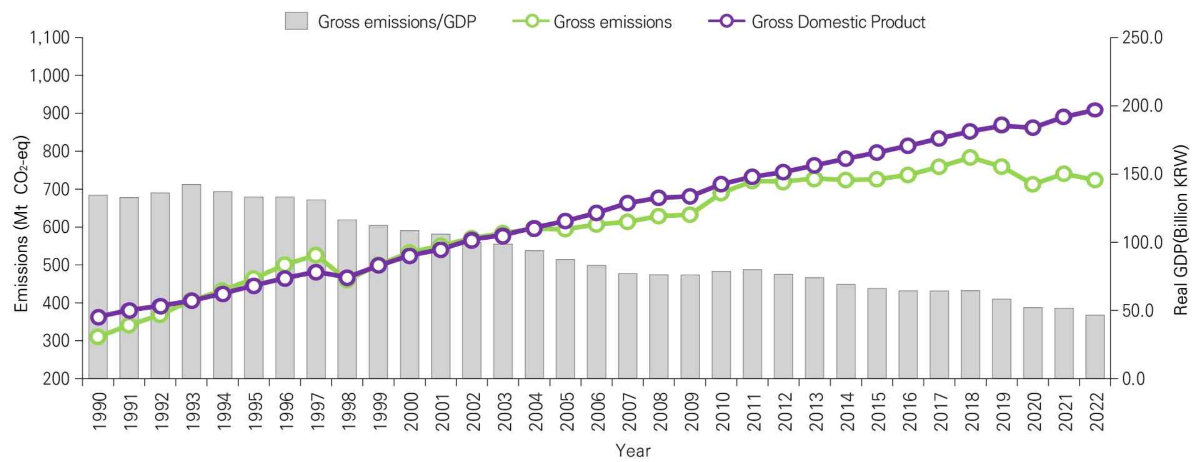
Sector		1990	2000	2010	2018	2021	2022	Emissions Change (%) From 1990	Emissions Change (%) From 2021
Energy	Emissions	234.5	402.2	550.3	612.1	566.8	551.9	135.4	-2.6
	Percentage (%)	75.5	75.4	79.8	78.1	76.5	76.2		
IPPU	Emissions	37.8	83.1	95.0	128.9	132.8	131.3	247.3	-1.1
	Percentage (%)	12.2	15.6	13.8	16.4	17.9	18.1		
Agriculture	Emissions	24.9	24.7	24.7	23.5	23.1	23.0	-7.7	-0.5
	Percentage (%)	8.0	4.6	3.6	3.0	3.1	3.2		
LULUCF	Emissions	-39.0	-60.4	-57.4	-41.6	-39.0	-37.8	Note1)	
Waste	Emissions	13.4	23.4	19.7	19.4	18.3	18.2	35.3	-0.8
	Percentage (%)	4.3	4.4	2.9	2.5	2.5	2.5		
Gross Emissions (excl. LULUCF)	Emissions	310.6	533.5	689.8	783.9	741.0	724.3	133.2	-2.3
	Percentage (%)	100	100	100	100	100	100		
Net Emissions (incl. LULUCF)	Emissions	271.6	473.1	632.4	742.3	702.0	686.5	152.7	-2.2

Note: 1) The percentage change in emissions from 1990 and 2021 is not indicated for LULUCF as the sector has been a sink of net removals for the entire time series.

2.1.2 Greenhouse Gas Emissions per Unit of Gross Domestic Product (GDP)

Emissions per unit of total gross domestic product (GDP)[3] in 2022 was 367.9 tonnes CO_2−eq/billion KRW, showing a 46.2 percent decrease from 683.9 tonnes CO_2−eq/billion KRW in 1990, and a 4.7 percent decrease from 386.2 tonnes CO_2−eq/billion KRW in 2021.

Since 1990, ROK's emissions per unit of GDP have been consistently declining. After emissions peaked in 2018, a decoupling of emissions and GDP was observed with the increase of GDP and the decrease in emissions. In the 1990s, the growth of both the GDP and total emissions were between 5 and 10 percent. From the 2000s, the emissions growth of which the annual average of the 2000 to 2009 period was 1.9 percent became lower than the GDP growth of which the respective average of the same period was 4.4 percent, showing weak signs of a decoupling between emissions and GDP growth. In the 2010 to 2017 period, the annual average growth of emissions continued to decline to 1.4 percent which led to a negative figure of 3.1 percent in the growth of gross emissions in 2018. Increases in both GDP and emissions were observed only temporarily when there were rebounds in economic activity after economic crisis such as financial crisis and economic crisis in 1998, 2008 and the COVID−19 pandemic in 2019.



| Figure 2−2 | Total Greenhouse Gas Emissions per Unit of Gross Domestic Product (GDP) (1990−2022)

| Table 2−2 | Total Greenhouse Gas Emissions per Unit of Gross Domestic Product (GDP)

Category	1990	2000	2010	2018	2021	2022
Total Emissions (Mt CO_2−eq)	**310.6**	**533.5**	**689.8**	**783.9**	**741.0**	**724.3**
GDP (trillion KRW)	4,541.5	9,035.5	14,266.2	18,120.1	19,187.1	19,688.4
Total Emission per GDP (tonnes CO_2−eq/Billion KRW)	683.9	590.4	483.5	432.6	386.2	367.9

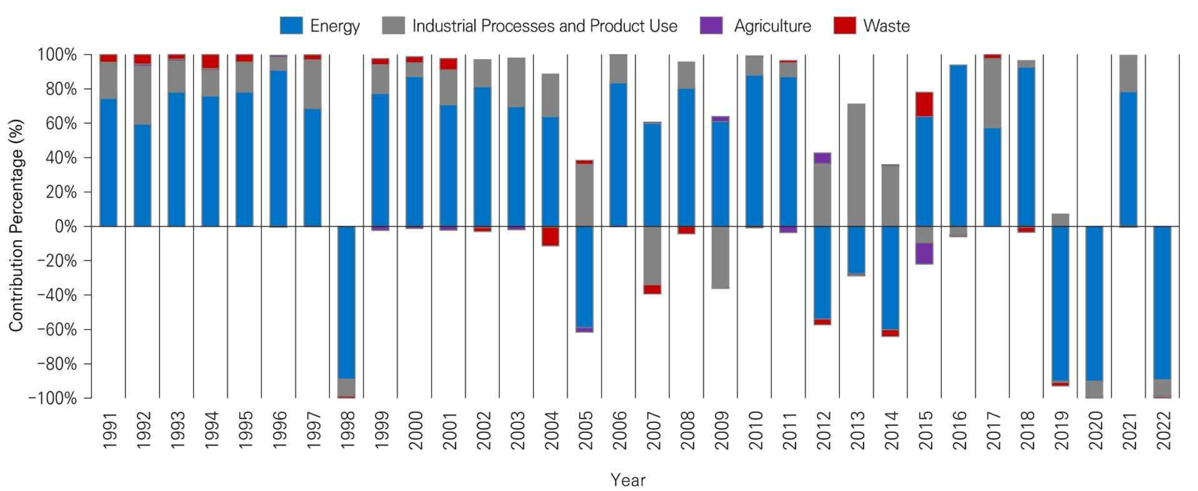
3) *Real GDP and real GNI in chained 2015 KRW, National Accounts*, Bank of Korea (2023) (Accessed on June 20, 2025)

2.1.3 Change in Emissions and Sinks by Sector

The biggest contributing sector to the decrease of 2.3 percent in total emissions in 2022 from 2021 was the Energy sector which accounted for the largest portion of national emissions. The Energy sector contributed to a 2.0 percentage point of a 2.3 percent decrease as the Iron and steel industry (1.A.2.a.) emitted 10.9 percent (5.7 Mt CO_2−eq) less emissions from 2021. Such decrease was attributable to a temporary shutdown of steel plants due to the typhoon Hinnamnor which resulted in the reduced production volume.[4)]

The remaining sectors including IPPU, Agriculture and Waste contributed to 0.2, 0.02 and 0.02 percentage points of a 2.3 percent decrease in national totals respectively. The installation of the abatement technology in the electronics industry which led to a reduction in emissions were the major driver in the IPPU sector while the three−year average area of rice paddy fields as well as the cultivation area with organic amendments which reduced by 0.1 percent[5)] and 16.3 percent respectively[6)] in the Agriculture sector contributed to a decrease in total emissions. Emissions from municipal solid wastes of the Waste sector decreased by 4.5 percent which was another contributor.

In 2022, the net removal in the LULUCF sector decreased to 37.8 Mt CO_2−eq from 39.0 Mt CO_2−eq, largely driven by wildfire of the forest land which caused an increase of 24,031 ha of the area burned from 2021.[7)]



| Figure 2−3 | Contribution to Overall Trends by Sector (1991−2022)

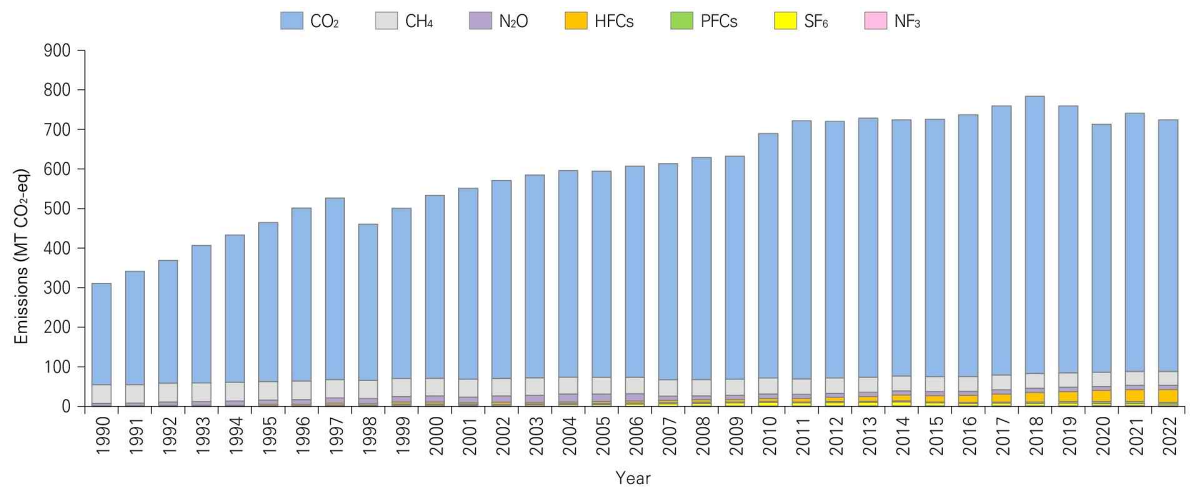
4) *Annual Crude Steel Production*, Korea Iron and Steel Association (2024)
5) *2019−2022 Agricultural Area Statistics,* Statistics Korea (KOSTAT) (2023)
6) *2021−2022 Annual Agriculture, Forestry and Fisheries Survey,* KOSTAT (2023)
7) *Forest Basic Statistics,* Korea Forest Service (KFS) (2023)

| Table 2-3 | Contribution to Emissions Change relative to Previous Year and to Overall Trends by Sector

Sector		1991	2000	2010	2018	2021	2022
Energy	Contribution to Emissions Change (%p)	7.4	5.9	8.1	3.2	3.1	−2.0
	Contribution to Overall Trend (%)	74.5	89.2	89.6	99.5	79.2	89.3
IPPU	Contribution to Emissions Change (%p)	2.1	0.6	1.0	0.1	0.8	−0.2
	Contribution to Overall Trend (%)	20.8	8.4	10.7	4.2	21.4	9.1
Agriculture	Contribution to Emissions Change (%p)	0.02	−0.09	0.1	−0.02	−0.002	−0.02
	Contribution to Overall Trend (%)	0.2	−1.3	0.6	−0.7	−0.1	0.7
Waste	Contribution to Emissions Change (%p)	0.4	0.2	−0.1	−0.1	−0.02	−0.02
	Contribution to Overall Trend (%)	4.5	3.7	−0.9	−3.1	−0.5	0.9
Total Emissions (excl. LULUCF)	Contribution to Emissions Change (%p)	9.9	6.6	9.0	3.3	3.9	−2.3
	Contribution to Overall Trend (%)	100.0	100.0	100.0	100.0	100.0	100.0

2.2 Trends in Emissions and Sinks by Gas

Carbon dioxide (CO_2) accounted for the largest share of 87.8 percent of total emissions in 2022, followed by fluorinated gases (5.9 percent) which include hydrofluorocarbons (HFCs), sulfur hexafluoride (SF_6), perfluorocarbons (PFCs) and nitrogen trifluoride (NF_3) representing 4.5 percent, 0.55 percent, 0.56 percent and 0.2 percent respectively. Methane (CH_4) emissions accounted for 4.9 percent while nitrous oxide (N_2O) represented 1.5 percent. Emissions of all gases have been increasing except CH_4 which have consistently been decreasing since 1990 due to reduced coal production in the Energy sector and reduced rice cultivation area in the Agriculture sector. Fluorinated gases increased significantly in 2022 compared to 1990 largely due to an increase in the use of HFCs which are commonly used as refrigerants in air conditioning and refrigeration systems, and also PFCs, SF_6 as well as NF_3 which are used in semiconductor and display industries.



| Figure 2-4 | Trends in Total Greenhouse Gas Emissions by Gas (1990-2022)

| Table 2-4 | Recent Trends in Emissions by Gas

(Unit: Mt CO_2-eq)

Gas		1990	2000	2010	2018	2021	2022	Emissions Change (%) From 1990	Emissions Change (%) From 2021
CO_2	Emissions	256.2	462.6	618.0	701.1	652.5	635.8	148.2	-2.6
	Percentage (%)	82.5	86.7	89.6	89.4	88.1	87.8		
CH_4	Emissions	46.8	44.6	40.6	37.2	35.3	35.2	-24.9	-0.5
	Percentage (%)	15.1	8.4	5.9	4.7	4.8	4.9		
N_2O	Emissions	6.3	14.9	10.6	10.9	10.8	10.7	68.9	-0.9
	Percentage (%)	2.0	2.8	1.5	1.4	1.5	1.5		
HFCs	Emissions	1.0	6.0	7.6	23.6	30.3	32.9	3,062.5	8.8
	Percentage (%)	0.3	1.1	1.1	3.0	4.1	4.5		
PFCs[1)]	Emissions	IE,NE,NO	2.5	2.5	3.9	4.7	4.1	116.6	-14.4
	Percentage (%)	-	0.5	0.4	0.5	0.6	0.6		
SF_6	Emissions	0.2	2.8	10.0	6.3	5.5	4.0	2,243.3	-28.4
	Percentage (%)	0.1	0.5	1.4	0.8	0.7	0.5		
NF_3[2)]	Emissions	IE,NO	IE,NO	0.4	1.0	1.8	1.7	359.7	-7.7
	Percentage (%)	-	-	0.1	0.1	0.2	0.2		
Total Emissions (excl. LULUCF)		310.6	533.5	689.8	783.9	741.0	724.3	133.2	-2.3
Percentage (%)		100	100	100	100	100	100		

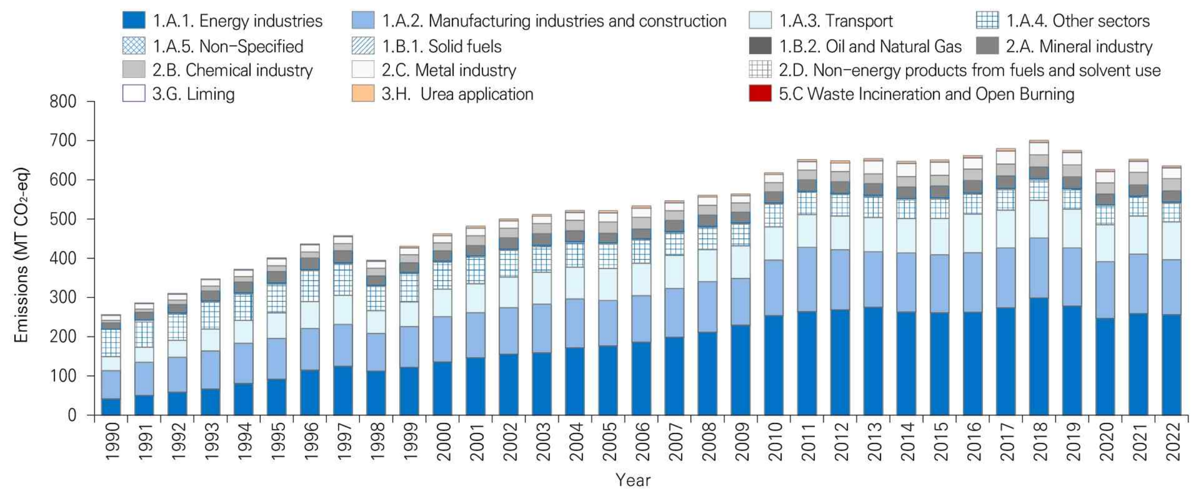
Note: 1) The percentage change of PFCs was calculated based on data for 1997 from which data were available.
2) The percentage change of NF_3 was calculated based on data for 2008 from which data were available.

2.2.1 Carbon Dioxide (CO_2)

In 2022, total CO_2 emissions excluding LULUCF were 635.8 Mt CO_2-eq, accounting for 87.8 percent of total national greenhouse gas emissions. An increase of 148.2 percent from 256.2 Mt CO_2-eq in 1990, and a 2.6 percent decrease from 652.5 Mt CO_2-eq in 2021 were observed. CO_2 emissions continued to increase from industries and transportation led by economic growth until reaching its peak in 2018 and have since been declining except for 2021.

Most CO_2 emissions excluding LULUCF in 2022 were from the Energy sector, representing 85.5 percent, followed by the IPPU sector of 13.9 percent, the Waste and Agriculture sectors of 0.7 percent and 0.01 percent respectively. The increase in CO_2 emissions was largely due to the increased sectoral emissions from the Energy and

IPPU sectors led by the rising demand for electricity, the scale-up of manufacturing industries, and increased logistics and traffics.



| Figure 2-5 | Trends in CO_2 Emissions and Removals by Subcategory (1990-2022)

| Table 2-5 | CO_2 Emissions and Removals by Sector

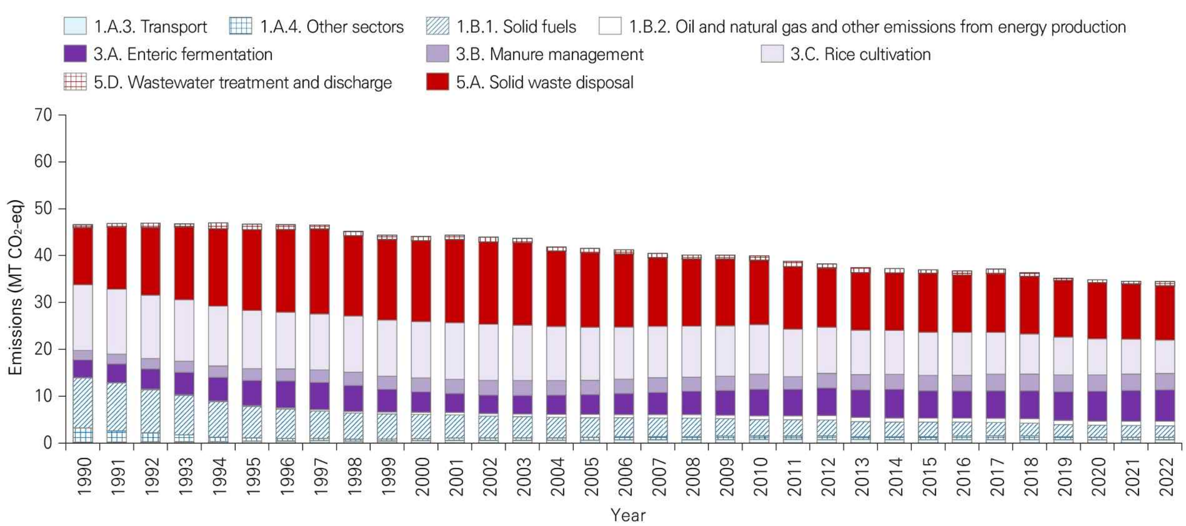
(Unit: Mt CO_2-eq)

Sector/Category		1990	2000	2010	2018	2021	2022
1. Energy	1.A.1. Energy Industries	41.9	135.8	253.7	298.5	258.7	256.2
	1.A.2. Manufacturing Industries and Construction	71.9	115	142.2	152.8	152.2	140.3
	1.A.3. Transport	35.6	70.1	84.5	96.4	97.1	96.1
	1.A.4. Other Sectors	69.3	69.7	57.9	52.0	47.2	47.7
	1.A.5. Other	0.2	2.4	3.0	3.1	2.9	3.0
	1.B.1. Fugitive Emissions : Solid Fuels	0.2	0.05	0.02	0.01	0.01	0.01
	1.B.2. Fugitive Emissions : Oil and Natural Gas	<0.001	<0.001	0.027	0.016	0.004	0.002
2. IPPU	2.A. Mineral Industry	16.4	26.1	28.3	30.5	29.0	28.4
	2.B. Chemical Industry	6.3	20.1	23.6	30.6	32.1	31.3
	2.C. Metal Industry	13.1	18.5	20.3	31.6	28.0	27.8
	2.D. Non-energy Products and Solvent Use	0.36	0.51	0.55	0.60	0.57	0.61
3. Agriculture	3.G. Liming	0.003	0.003	0.003	0.003	0.002	0.002
	3.H. Urea Application	0.43	0.28	0.12	0.12	0.11	0.09
5. Waste	5.C Incineration and Open Burning of Waste	0.5	4.2	3.8	4.8	4.5	4.3
Total CO_2 Emissions (excl. LULUCF)		256.2	462.6	618	701.1	652.5	635.8

2.2.2 Methane (CH_4)

In 2022, total CH_4 emissions excluding LULUCF were 35.2 Mt CO2-eq, accounting for 4.9 percent of total national greenhouse gas emissions. Decreases of 24.9 percent from 46.8 Mt CO_2-eq in 1990, and of 0.5 percent from 35.3 Mt CO_2-eq in 2021 were observed. Methane emissions have consistently been decreasing which was contributed by the reduced rice cultivation area, changes in water regime practices and less volume of landfills.

Most CH_4 emissions excluding LULUCF in 2022 were from the Agriculture sector, representing 49.4 percent, followed by the Waste sector of 35.7 percent, the Energy and IPPU sectors of 14.1 percent and 0.7 percent respectively.



| Figure 2-6 | Trends in CH_4 Emissions by Subcategory (1990-2022)

| Table 2-6 | CH_4 Emissions by Sector

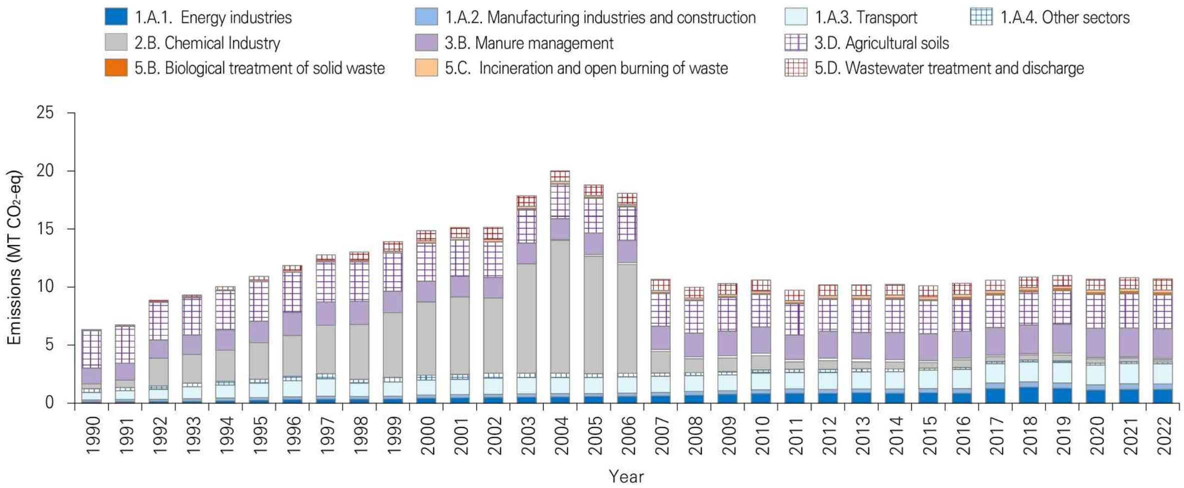
(Unit: Mt CO_2-eq)

Sector/Category		1990	2000	2010	2018	2021	2022
1. Energy	1.A.1. Energy industries	0.03	0.06	0.10	0.07	0.07	0.09
	1.A.2. Manufacturing industries and construction	0.08	0.15	0.20	0.23	0.24	0.23
	1.A.3. Transport	0.20	0.51	0.76	0.72	0.68	0.68
	1.A.4. Other sectors	2.98	0.43	0.73	0.84	0.59	0.57
	1.A.5. Other	0.001	0.009	0.011	0.012	0.011	0.011
	1.B.1. Fugitive emissions : Solid fuels	10.7	5.2	3.5	2.7	2.5	2.4
	1.B.2. Fugitive emissions : Oil and natural gas	0.1	0.5	0.8	1.0	0.9	1.0
2. IPPU	2.B. Chemical industry	0.05	0.28	0.31	0.35	0.32	0.25
3. Agriculture	3.A. Enteric fermentation	3.8	4.3	5.6	6.0	6.6	6.7
	3.B. Manure management	2.0	2.9	3.2	3.5	3.5	3.5
	3.C. Rice cultivation	14.1	12.0	10.6	8.5	7.4	7.1
	3.F. Field burning of agricultural residues	0.04	0.05	0.04	0.03	0.03	0.02
5. Waste	5.A. Solid waste disposal	12.1	17.3	13.8	12.3	11.8	11.6
	5.B. Biological treatment of solid waste	NE	0.005	0.02	0.11	0.13	0.11
	5.C. Incineration and open burning of waste	<0.001	0.002	0.002	0.002	0.002	0.002
	5.D. Wastewater treatment and discharge	0.7	0.9	0.9	0.8	0.6	0.9
Total CH_4 Emissions (excl. LULUCF)		**46.8**	**44.6**	**40.6**	**37.2**	**35.3**	**35.2**

2.2.3 Nitrous Oxide (N_2O)

In 2022, total N_2O emissions excluding LULUCF were 10.7 Mt CO_2-eq, accounting for 1.5 percent of total national greenhouse gas emissions. An increase of 68.9 percent from 6.3 Mt CO_2-eq in 1990, and a 0.9 percent decrease from 10.8 Mt CO_2-eq in 2021 were observed. N_2O emissions from the Chemical industry (2.B.) of the IPPU sector increased in the 1990s until N_2O abatement systems have been employed since 2006 which led to a significant drop in N_2O emissions.

Most N_2O emissions excluding LULUCF in 2022 were from the Agriculture sector, representing 51.3 percent, followed by the Energy sector of 33.1 percent, the Waste and IPPU sectors of 12.7 percent and 2.8 percent respectively.



| Figure 2-7 | Trends in N_2O Emissions by Subcategory (1990-2022)

| Table 2-7 | N_2O Emissions by Sector

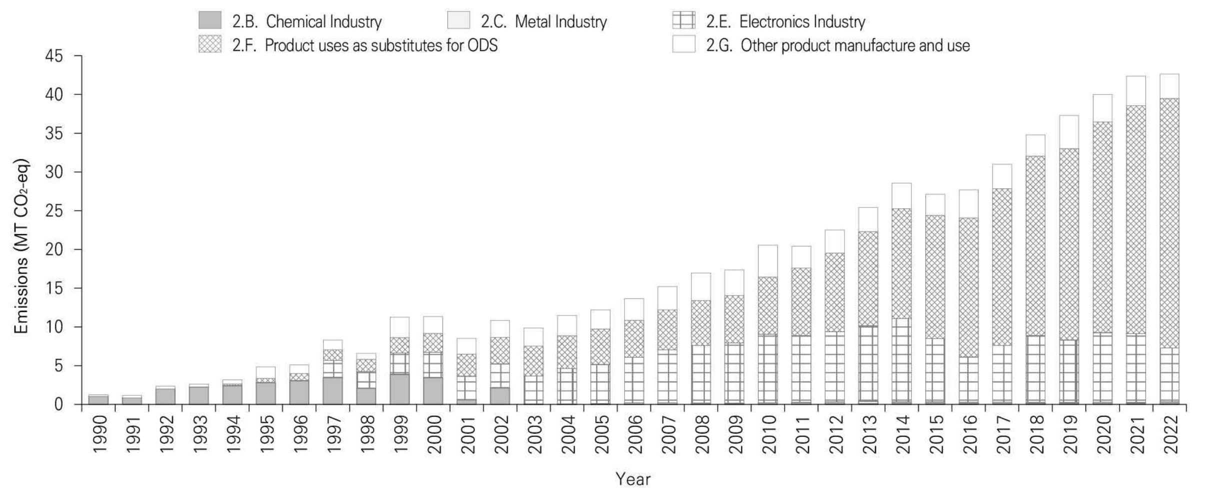
(Unit: Mt CO_2-eq)

Sector/Category		1990	2000	2010	2018	2021	2022
1. Energy	1.A.1. Energy Industries	0.1	0.4	0.8	1.4	1.2	1.2
	1.A.2. Manufacturing Industries and Construction	0.2	0.3	0.3	0.5	0.5	0.5
	1.A.3. Transport	0.6	1.3	1.4	1.7	1.7	1.7
	1.A.4. Other Sectors	0.32	0.42	0.29	0.18	0.16	0.15
	1.A.5. Other	<0.001	0.005	0.006	0.007	0.006	0.006
	1.B.2. Fugitive Emissions : Oil and Natural Gas	NA,NO	NA,NO	<0.001	<0.001	<0.001	<0.001
2. IPPU	2.B. Chemical Industry	0.4	6.3	1.2	0.4	0.3	0.2
	2.G. Other Product Manufacture and Use	NE,NO	NE,NO	0.20	0.13	0.10	0.10
3. Agriculture	3.B. Manure Management	1.3	1.8	2.3	2.4	2.5	2.6
	3.D. Agricultural Soils	3.2	3.3	2.8	2.8	3.0	2.9
	3.F. Field Burning of Agricultural Residues	0.011	0.012	0.010	0.008	0.007	0.005
5. Waste	5.B. Biological Treatment of Solid Waste	NE	0.03	0.07	0.17	0.17	0.17
	5.C. Incineration and Open Burning of Waste	0.03	0.16	0.19	0.22	0.22	0.22
	5.D. Wastewater Treatment and Discharge	0.05	0.88	0.96	0.91	0.97	0.97
Total N_2O Emissions (excl. LULUCF)		6.3	14.9	10.6	10.9	10.8	10.7

2.2.4 Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), Sulfur Hexafluoride (SF_6) and Nitrogen Trifluoride (NF_3)

Fluorinated gases of HFCs, PFCs, SF_6, and NF_3 are emitted only from the IPPU sector. In 2022, total fluorinated greenhouse gas emissions excluding LULUCF were 42.6 Mt CO_2-eq, accounting for 5.9 percent of total national greenhouse gas emissions. Increases of 3,420.7 percent from 1.2 Mt CO_2-eq in 1990, and of 0.6 percent from 42.4 Mt CO_2-eq in 2021 were observed. Fluorinated gas emissions increased largely due to increases in the use of air conditioning systems and in semiconductor production. Contributed by mitigation measures of semiconductor and display manufacturers such as the increased use and improved efficiency of emissions control devices, the growth of fluorinated gas emissions in 2022 was not as high as that from 2021. Measures on the control of fluorinated gases including the law designating HFCs as specific substances in 2022 and institutional arrangements to restrict the production and import of HFCs have been put in place for product uses as substitutes for ODS including refrigeration and air conditioning.

The percentage of fluorinated gases in the IPPU sector continued to increase from 3.2 percent in 1990 to 32.5 percent in 2022. In contrast, CO_2 emissions in the respective sector decreased from 95.6 percent in 1990 to 67.1 percent in 2022.



| Figure 2-8 | Trends in Fluorinated Greenhouse Gas Emissions by Category (1990-2022)

| Table 2-8 | Fluorinated Greenhouse Gas Emissions by Sector

(Unit: Mt CO_2-eq)

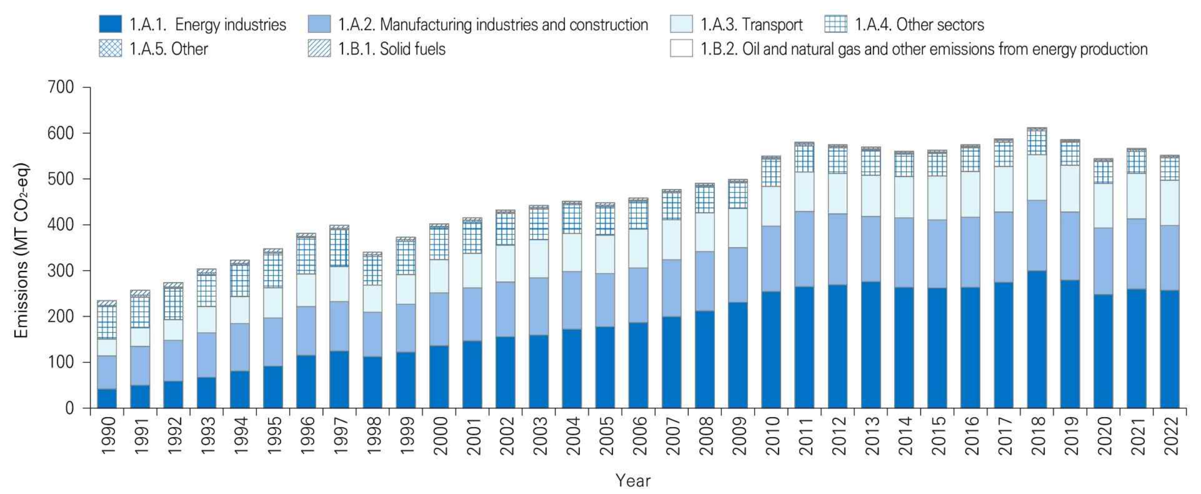
Sector/Category		1990	2000	2010	2018	2021	2022
2. IPPU	2.B. Chemical Industry	1.0	3.4	0.03	0.09	0.10	0.09
	2.C. Metal Industry	<0.001	0.02	0.15	0.15	0.15	0.20
	2.E. Electronics Industry	IE,NO	3.3	8.9	8.7	8.9	7.0
	2.F. Product Uses as Substitutes for ODS	IE,NO	2.5	7.4	23.1	29.4	32.2
	2.G. Other Product Manufacture and Use	0.2	2.2	4.1	2.7	3.8	3.2
Total Emissions of Fluorinated GHGs		**1.2**	**11.3**	**20.5**	**34.8**	**42.4**	**42.6**

2.3 Trends in Emissions and Sinks by Sector

2.3.1 Energy

In 2022, emissions from the Energy sector were 551.9 Mt CO_2−eq, accounting for 76.2 percent of total national emissions. From 1990, sectoral emissions increased by 135.4 percent from 234.5 Mt CO_2−eq, and decreased by 2.6 percent from 566.8 Mt CO_2−eq in 2021.

Emissions from the Energy sector continued to increase in the 1990 to 2011 period except in 1998 in which a sharp decrease was temporarily observed due to the economic crisis. It was followed by some fluctuation between -1.5 percent and 5.4 percent in emissions until it peaked in 2018.



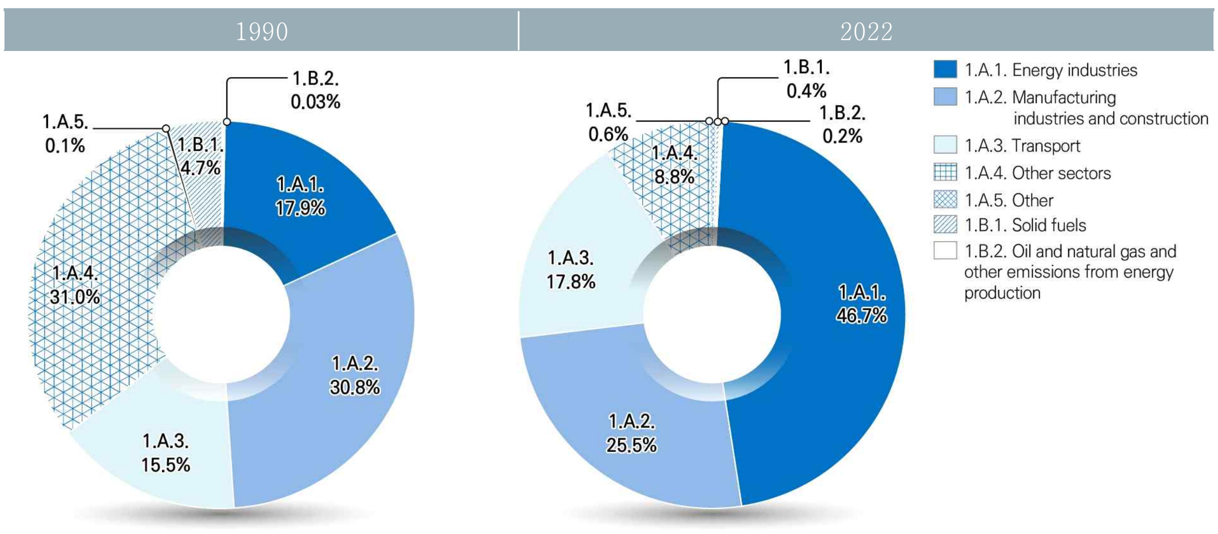
| Figure 2-9 | Trends in Energy Sector Greenhouse Gas Emissions (1990-2022)

| Table 2-9 | Emissions from Energy Sector

(Unit: Mt CO_2-eq)

(Sub)Category	1990	2000	2010	2018	2021	2022	Emissions Change (%)	
							From 1990	From 2021
1.A. Fuel Combustion	**223.5**	**396.5**	**545.9**	**608.4**	**563.4**	**548.5**	**145.4**	**-2.6**
1.A.1. Energy Industries	42.0	136.3	254.6	300.0	260.0	257.5	512.7	-1.0
1.A.2. Manufacturing Industries and Construction	72.2	115.4	142.8	153.5	152.9	141.0	95.4	-7.8
1.A.3. Transport	36.5	71.9	86.7	98.8	99.5	98.5	170.2	-1.0
1.A.4. Other Sectors	72.6	70.5	58.9	53.0	48.0	48.4	-33.3	0.9
1.A.5. Other	0.2	2.4	3.0	3.1	2.9	3.0	1,561.0	3.3
1.B. Fugitive Emissions from Fuels	**11.0**	**5.7**	**4.4**	**3.7**	**3.4**	**3.4**	**-69.1**	**-0.5**
1.B.1. Solid Fuels	10.9	5.2	3.6	2.7	2.5	2.4	-77.8	-2.3
1.B.2. Oil and Natural Gas	0.1	0.5	0.9	1.0	0.9	1.0	1,456.3	4.1
Total	**234.5**	**402.2**	**550.3**	**612.1**	**566.8**	**551.9**	**135.4**	**-2.6**

Emissions from the Energy sector are largely divided into Fuel combustion (1.A.) and Fugitive emissions (1.B.). In 2022, emissions from fuel combustion were 548.5 Mt CO_2-eq, representing 99.4 percent of sectoral emissions while fugitive emissions accounted for 0.6 percent with 3.4 Mt CO_2-eq. From fuel combustion, Energy industries (1.A.1.) was the largest contributor accounting for 46.7 percent, followed by Manufacturing industries and construction (1.A.2.) (25.5 percent), Transport (1.A.3.) (17.8 percent), Other sectors (1.A.4.) (8.8 percent), Other (1.A.5.) (0.6 percent), Solid fuels of fugitive emissions (1.B.1.) (0.4 percent) and Oil and natural gas of fugitive emissions (1.B.2.) (0.2 percent).



| Figure 2-10 | Subcategory as a Portion of Total Energy Emissions (1990 and 2022)

In 2022, emissions from fuel combustion increased by 145.4 percent from 1990 and decreased by 2.6 percent from 2021. All subcategories including energy industries, manufacturing industries and construction, transport, solid fuels and oil and natural gas of fugitive emissions produced less emissions from 2021 except for Other sectors (1.A.4.) and Other (1.A.5.).

Emissions from subcategories of energy industries, and manufacturing industries and construction decreased by 1.0 percent (2.5 Mt CO_2−eq) and 7.8 percent (11.9 Mt CO_2−eq) from 2021 due to reduced fuel consumption in iron and steel industries as well as petrochemical industries. As oil prices rose by 22.6 percent[8] and travel distance of vehicles decreased by 5.8 percent[9] due to the COVID−19 pandemic, the subcategory of transport produced 1.0 Mt CO_2−eq (1.0 percent) less emissions.

In 2022, fugitive emissions from fuels decreased by 69.1 percent and 0.5 percent from 1990 and 2021 respectively. The subcategory of fugitive emissions from solid fuels decreased by 2.3 percent from 2021 due to a reduction in domestic coal production while that from oil and natural gas increased by 4.1 percent largely driven by an increase in the use of natural gas and city gas.

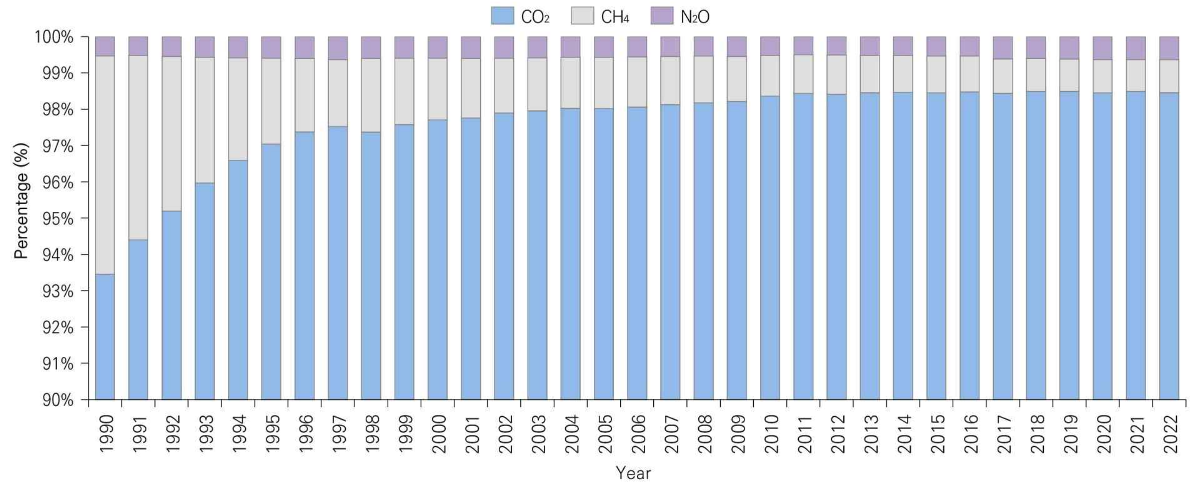
In the Energy sector, three types of greenhouse gases, namely carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are emitted. Between 1990 and 2022, the percentages of CO_2 and N_2O in total emissions from this sector increased[10] while CH_4 decreased.[11] This was due to a decrease in CH_4 from fugitive emissions led by the increasing number of abandoned coal mines and less coal production.

8) The average oil price in 2021 was 1,491 KRW which increased to 1,828 KRW in 2022. (Road Travel Distance Statistics, Korea Transportation Safety Authority (TS))

9) Travel distance in 2021 was 356,372 Million km which decreased to 335,630 Million km in 2022. (*Road Travel Distance Statistics*, Korea Transportation Safety Authority (TS))

10) CO_2: 93.5% (1990) → 98.5% (2022); N_2O: 0.5% (1990) → 0.6% (2022)

11) CH_4: 6.0% (1990) → 0.9% (2022)



| Figure 2-11 | Percentage of Gas in Energy Sector Emissions (1990-2022)

| Table 2-10 | Emissions from Energy Sector by Gas

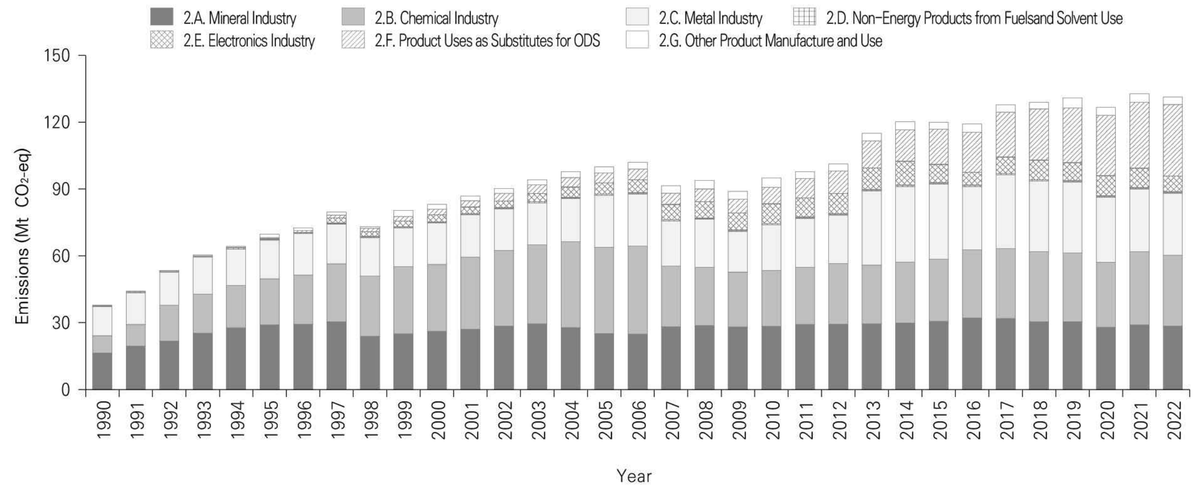
(Unit: Mt CO_2-eq)

Gas	1990	2000	2010	2018	2021	2022	Emissions Change (%)	
							From 1990	From 2021
CO_2	219.1	393.0	541.3	602.9	558.2	543.4	148.0	-2.7
CH_4	14.1	6.8	6.2	5.5	5.0	5.0	-64.8	-0.5
N_2O	1.2	2.4	2.9	3.7	3.6	3.5	184.6	-1.1
Total	234.5	402.2	550.3	612.1	566.8	551.9	135.4	-2.6

2.3.2 Industrial Processes and Product Use (IPPU)

In 2022, emissions from the IPPU sector were 131.3 Mt CO_2-eq, accounting for 18.1 percent of national totals which increased by 247.3 percent from 37.8 Mt CO_2-eq in 1990 and decreased by 1.1 percent from 132.8 Mt CO_2-eq in 2021.

Emissions from all categories except for Product uses as substitutes for ODS (2.F.) and Non-energy products from fuels and solvent use (2.D.) decreased from 2021. In 2022, categories of Electronics industry (2.E.) and Chemical industry (2.B.) produced less emissions from 2021 by 21.6 percent (1.9 Mt CO_2-eq) and 3.0 percent (1.0 Mt CO_2-eq) respectively which were contributed by the reduced input in the naphtha cracking process in the chemistry industry and the enhanced efficacy of emission control equipment in industries across the IPPU sector.



| Figure 2-12 | Trends in IPPU Sector Greenhouse Gas Emissions (1990-2022)

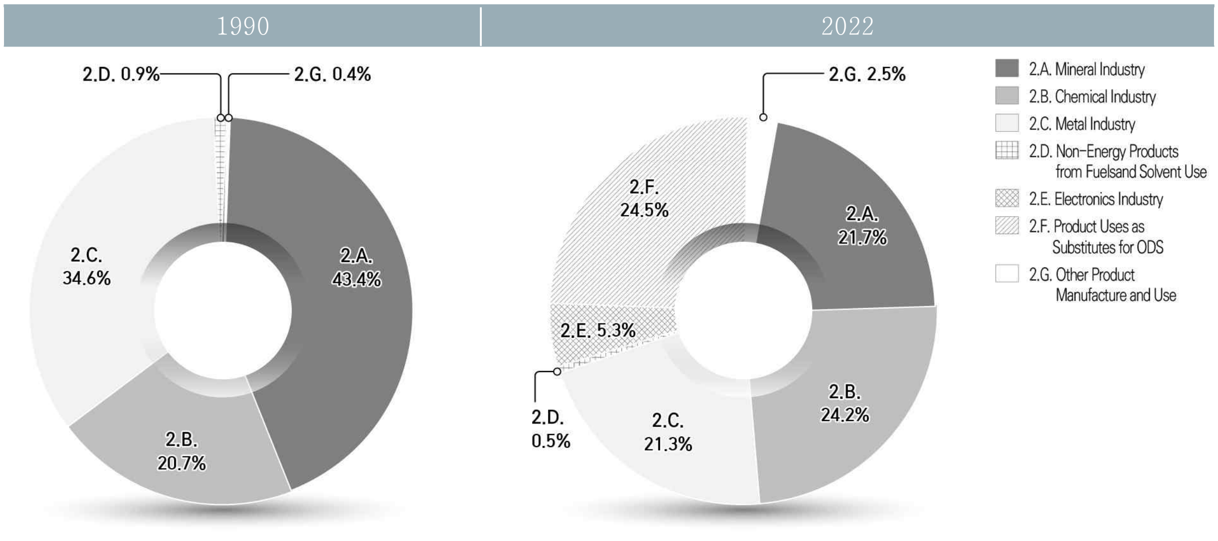
| Table 2-11 | Emissions from IPPU Sector

(Unit: Mt CO_2-eq)

Category	1990	2000	2010	2018	2021	2022	Emissions Change (%)	
							From 1990	From 2021
2.A. Mineral Industry	16.4	26.1	28.3	30.5	29.0	28.4	73.4	−2.0
2.B. Chemical Industry	7.8	30.1	25.1	31.4	32.8	31.8	306.9	−3.0
2.C. Metal Industry	13.1	18.5	20.5	31.7	28.2	28.0	114.1	−0.8
2.D. Non-Energy Products from Fuels and Solvent Use	0.4	0.5	0.5	0.6	0.6	0.6	72.0	7.0
2.E. Electronics Industry[1)]	IE,NA,NO	3.3	8.9	8.7	8.9	7.0	212.5	−21.6
2.F. Product Uses as Substitutes for ODS	IE,NO	2.5	7.4	23.1	29.4	32.2	2,053,154.8	9.5
2.G. Other Product Manufacture and Use[2)]	0.2	2.2	4.3	2.9	3.9	3.3	1,835.1	−16.9
Total	37.8	83.1	95.0	128.9	132.8	131.3	247.3	−1.1

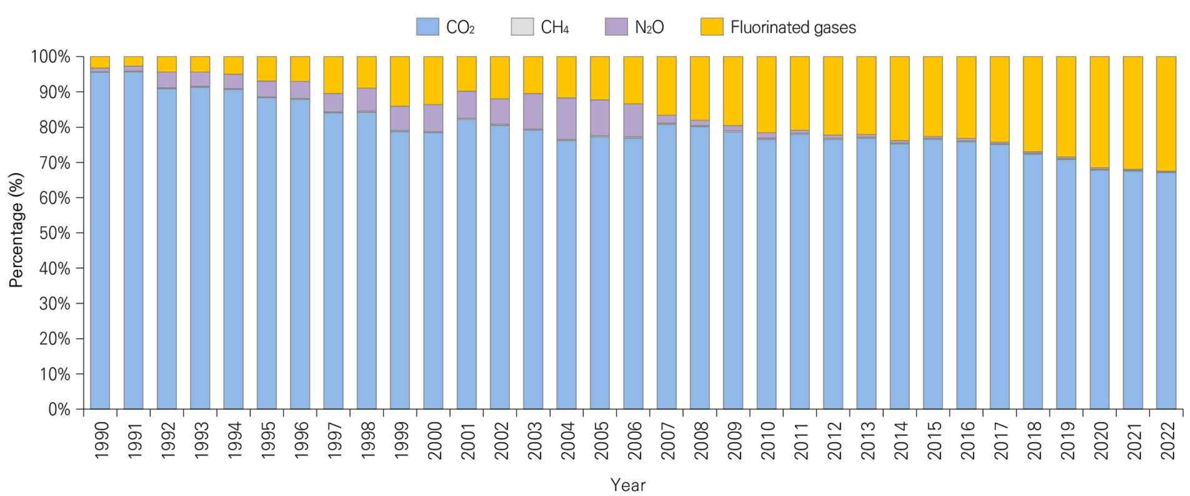
Note: 1) The percentage change of the electronics industry was calculated based on data for 1997 from which data were available.
2) The percentage change of product uses as substitutes for ODS was calculated based on data for 1992 from which data were available.

In 2022, the subcategory of product uses as substitutes from ODS was the largest source, representing 24.5 percent followed by the chemical industry of 24.2 percent, the mineral industry of 21.7 percent, the metal industry of 21.3 percent, the electronics industry of 5.3 percent, other product manufacture and use of 2.5 percent and non-energy products and solvent use of 0.5 percent.



| Figure 2-13 | Category as a Portion of Total IPPU Emissions (1990 and 2022)

Emissions of all seven greenhouse gases subject to reporting, namely CO_2, CH_4, N_2O, HFCs, PFCs, SF_6 and NF_3 occur in the IPPU sector. Between 1990 and 2022, the percentages of CO_2 and N_2O in total emissions from this sector decreased[12] while that of HFCs, SF_6 and CH_4 increased.[13] Some fluorinated gases of PFCs and NF_3 which did not occur in 1990 were emitted in 2022.[14] Increases in emissions from fluorinated gases were driven by the increasing use of HFCs and PFCs as substitutes for ODS in compliance with the Kigali Amendment to the Montreal Protocol.



| Figure 2-14 | Percentage of Gas in IPPU Sector Emissions (1990-2022)

12) CO_2: 95.6% (1990) → 67.1% (2022); N_2O: 1.1% (1990) → 0.2% (2022)
13) HFCs: 2.8% (1990) → 25.1% (2022); SF_6: 0.4% (1990) → 3.0% (2022); CH_4: 0.1% (1990) → 0.2% (2022)
14) PFCs: 0% (1990) → 3.1% (2022); NF_3: 0% (1990) → 1.3% (2022)

| Table 2-12 | Emissions from IPPU Sector by Gas

(Unit: Mt CO_2-eq)

Gas	1990	2000	2010	2018	2021	2022	Emissions Change (%)	
							From 1990	From 2021
CO_2	36.1	65.2	72.8	93.2	89.7	88.1	143.9	-1.8
CH_4	0.1	0.3	0.3	0.4	0.3	0.3	405.0	-21.8
N_2O	0.4	6.3	1.4	0.5	0.4	0.3	-27.3	-25.7
HFCs	1.0	6.0	7.6	23.6	30.3	32.9	3,062.5	8.8
PFCs[1)]	NO	2.5	2.5	3.9	4.7	4.1	116.6	-14.4
SF_6	0.2	2.8	10.0	6.3	5.5	4.0	2,243.3	-28.4
NF_3[2)]	NO	NO	0.4	1.0	1.8	1.7	359.7	-7.7
Total	**37.8**	**83.1**	**95.0**	**128.9**	**132.8**	**131.3**	**247.3**	**-1.1**

Note: 1) The percentage change of PFCs was calculated based on data for 1997 from which data were available.
2) The percentage change of NF_3 was calculated based on data for 2008 from which data were available.

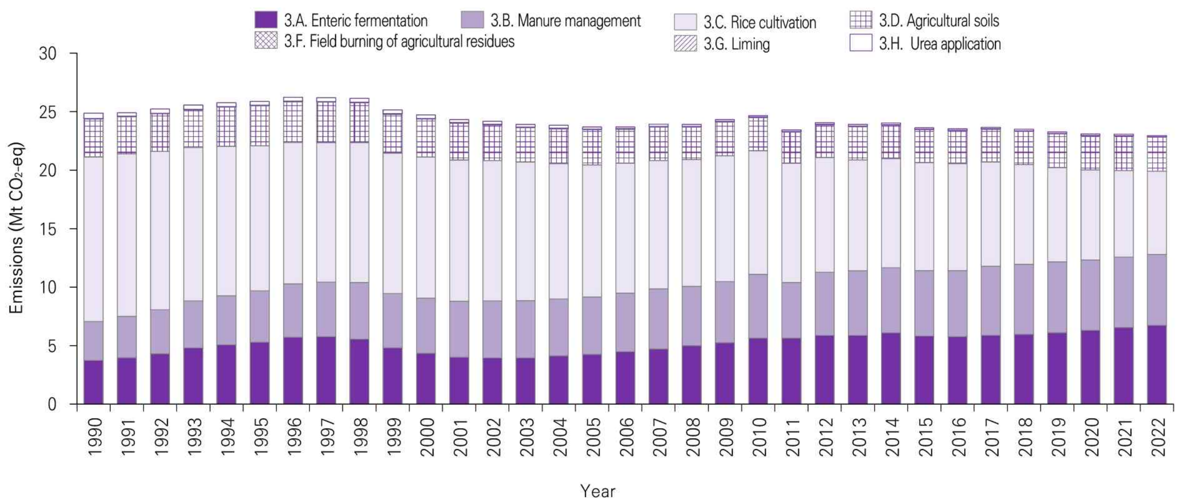
Emissions from the IPPU sector were estimated using activity data from a range of sources. The primary source is data from the Target Management System (TMS) and Emissions Trading Scheme (K-ETS) which are verified by the third party to ensure the completeness and time-series consistency of data, and adequacy of methodologies and emission factors. Categories that use TMS and K-ETS data include : Mineral industry (2.A.), Chemical industry (2.B.), Metal industry (2.C.), Electronics industry (2.E.) and Other product manufacture and use (2.G.). Since TMS and K-ETS data were available from 2007, activity data for emissions in years prior to 2007 were derived from other sources such as national statistics and field survey.

2.3.3 Agriculture

In 2022, total greenhouse gas emissions from the Agriculture sector were 23.0 Mt CO_2-eq, accounting for 3.2 percent of national total emissions which represented decreases of 7.7 percent from 1990 and 0.5 percent from 2021.

Emissions from rice cultivation in 2022 decreased by 4.1 percent (0.3 Mt CO_2-eq) from 2021 which was contributed by changes in water regime practices as well as reduced areas of rice cultivation and of organic amendments applied. The area of rice cultivation as well as the area to which organic amendments were applied decreased by 0.1 percent and 16.3 percent respectively. In contrast, emissions from enteric fermentation increased by 2.8 percent (0.2 Mt CO_2-eq) from 2021 due to the increased livestock population of cattle, chicken and horse. The population of *Hanwoo* (Korean native cattle) and beef cattle increased by 4.4 percent[15)] while chicken and horse populations increased by 1.9 percent and 0.5 percent respectively.[16)]

In 2022, Rice cultivation (3.C.) was the largest source in the Agriculture sector, accounting for 31.0 percent of total sectoral emissions followed by Enteric fermentation (3.A.) (29.4 percent), Manure management (3.B.) (26.4 percent), Agricultural soils (3.D.) (12.7 percent), Urea application (3.H.) (0.4 percent), Field burning of agricultural residues (3.F.) (0.1 percent), and Liming (3.G.) (0.01 percent).



| Figure 2-15 | Trends in Agriculture Sector Greenhouse Gas Emissions (1990-2022)

| Table 2-13 | Emissions from Agriculture Sector

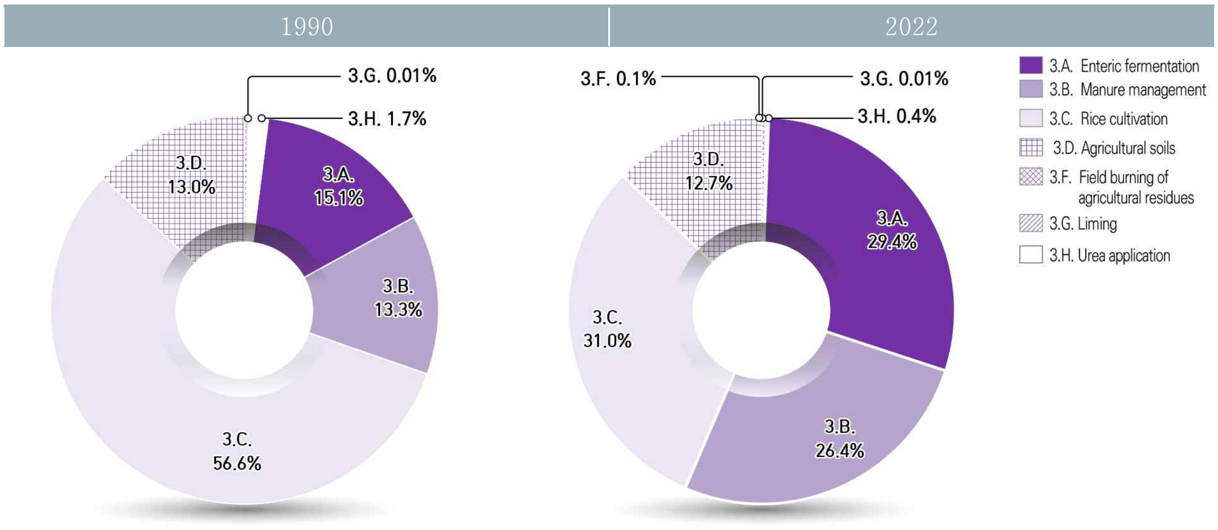
(Unit: Mt CO_2-eq)

Category	1990	2000	2010	2018	2021	2022	Emissions Change (%)	
							From 1990	From 2021
3.A. Enteric Fermentation	3.8	4.3	5.6	6.0	6.6	6.7	79.7	2.8
3.B. Manure Management	3.3	4.7	5.5	6.0	6.0	6.1	82.9	0.8
3.C. Rice cultivation	14.1	12.0	10.6	8.5	7.4	7.1	-49.5	-4.1
3.D. Agricultural soils	3.2	3.3	2.8	2.8	3.0	2.9	-9.7	-1.0
3.F. Field Burning of Agricultural Residues	0.06	0.06	0.05	0.04	0.03	0.03	-53.2	-22.4
3.G. Liming	0.003	0.003	0.003	0.003	0.002	0.002	-2.4	0.7
3.H. Urea Application	0.43	0.28	0.12	0.12	0.11	0.09	-78.8	-16.7
Total	**24.9**	**24.7**	**24.7**	**23.5**	**23.1**	**23.0**	**-7.7**	**-0.5**

15) The population of Hanwoo (Korean native cattle) and beef cattle in 2021 was 3,538,000 which increased to 3,693,000 in 2022. (*Livestock Statistics*, KOSTAT)

16) The population of chicken in 2021 was 174,498,000 which increased to 177,733,000 in 2022 (*Livestock Statistics*, KOSTAT)

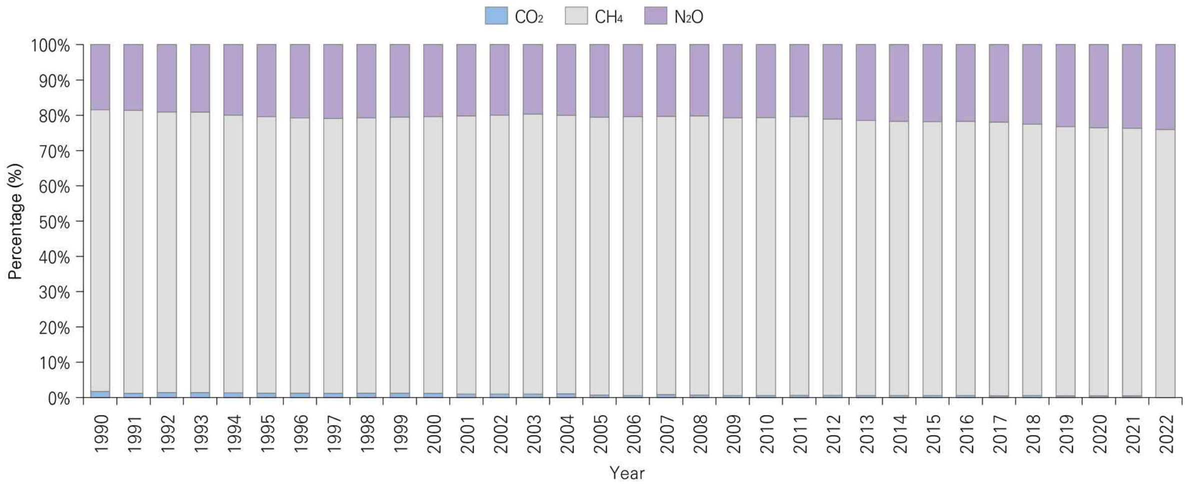
Emissions of three types of greenhouse gases, namely CO_2, CH_4, and N_2O occur in the Agriculture sector. Between 1990 and 2022, the percentages of CO_2 and CH_4 in total emissions from this sector decreased[17)] while that of N_2O increased[18)] which was largely driven by the decrease in the area of rice cultivation leading to less CH_4 emissions.



| Figure 2-16 | Category as a Portion of Total Agriculture Emissions (1990 and 2022)

CH_4 emissions, the primary greenhouse gas emitted from the Agriculture sector, has been consistently decreasing since 1990 which was largely contributed by the reduced area of rice cultivation. In 1990, CH_4 emissions from rice cultivation accounted for 70.9 percent which decreased to 41.0 percent in 2022 resulting from the decreasing area of rice cultivation and also from switching to water regime practices that produce less emissions. In 1990, most N_2O emissions from the Agriculture sector occurred from agricultural soils which accounted for 70.5 percent followed by manure management of 29.2 percent of total N_2O emissions in the sector which, in 2022, decreased to 53.2 percent in agricultural soils and increased to 46.7 percent in manure management.

17) CO_2: 1.7% (1990) → 0.4% (2022); CH_4: 79.8% (1990) → 75.7% (2022)
18) N_2O: 18.5% (1990) → 23.9% (2022)



| Figure 2-17 | Percentage of Gas in Agriculture Sector Emissions (1990-2022)

| Table 2-14 | Emissions from Agriculture Sector by Gas

(Unit: Mt CO_2-eq)

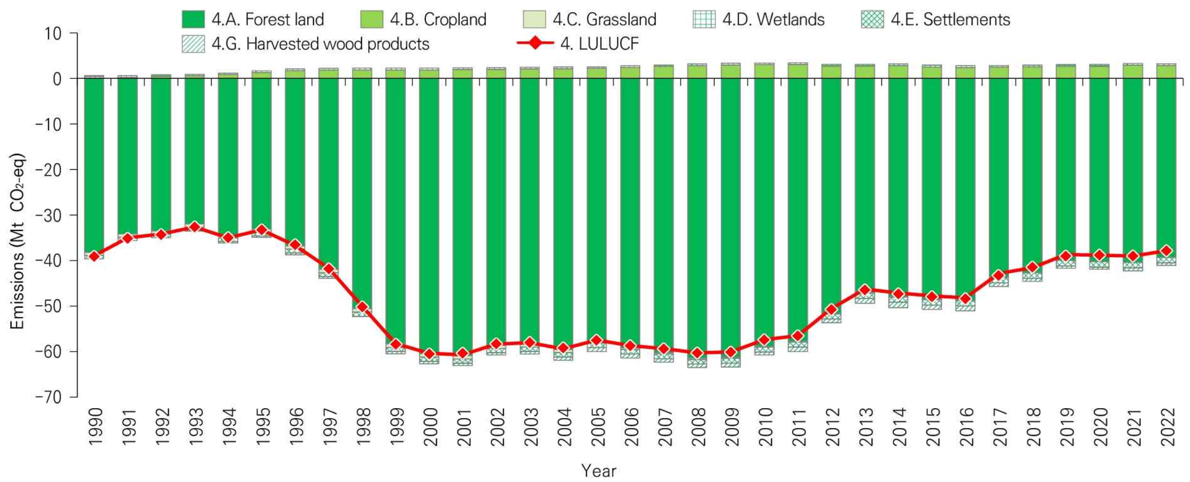
Gas	1990	2000	2010	2018	2021	2022	Emissions Change (%)	
							From 1990	From 2021
CO_2	0.4	0.3	0.1	0.1	0.1	0.1	-78.4	-16.3
CH_4	19.8	19.4	19.5	18.1	17.5	17.4	-12.5	-0.8
N_2O	4.6	5.1	5.1	5.3	5.5	5.5	19.6	0.7
Total	**24.9**	**24.7**	**24.7**	**23.5**	**23.1**	**23.0**	**-7.7**	**-0.5**

2.3.4 Land Use, Land Use Change and Forestry (LULUCF)

In 2022, net removals from the LULUCF sector were 37.8 Mt CO_2-eq, representing decreases of 2.9 percent from 1990 and 3.0 percent from 2021.

Forest land (4.A.) was the largest sink in the LULUCF sector with net removals of 39.3 Mt CO_2-eq, followed by Settlements (4.E.) with 1.2 Mt CO_2-eq and the Harvested Wood Products (HWP) (4.G.) with 0.5 Mt CO_2-eq. Emission sources including Cropland (4.B.), Wetlands (4.D.) and Grassland (4.C.) emitted 2.9 Mt CO_2-eq, 0.38 Mt CO_2-eq and 0.001 Mt CO_2-eq respectively.

Net removals of forest land which accounted for the largest share of the LULUCF sector increased since 1995 as a result of continued reforestation and forest management until it peaked in 2008 removing 61.6 Mt CO_2-eq of carbon. However due to the declining annual net growth of trees caused by aging forests and the reduced area of forest land, net removals have been declining since 2010. Although removals by living biomass have been stable in recent three years from 2020 to 2022, emissions from wildfire increased. In 2022, the burned area was 24,797 ha which was considerably larger than the average burned area of 1,087 ha of the last decade from 2012 to 2021. As a result, net removals from forest land in 2022 was 1.1 Mt CO_2-eq less than that in 2021.



| Figure 2-18 | Trends in LULUCF Sector Greenhouse Gas Emissions and Removals (1990-2022)

| Table 2-15 | Emissions and Removals from LULUCF Sector

(Unit: Mt CO_2-eq)

Category	1990	2000	2010	2018	2021	2022	Emissions Change (Mt CO_2-eq)	
							From 1990	From 2021
4.A. Forest land	-38.2	-60.5	-58.8	-42.6	-40.4	-39.3	-1.1	1.1
4.B. Cropland	0.1	1.9	3.0	2.6	2.9	2.9	2.8	-0.02
4.C. Grassland	-0.67	-0.74	-0.21	-0.04	-0.01	0.001	0.7	0.008
4.D. Wetlands	0.34	0.39	0.37	0.39	0.40	0.38	0.03	-0.03
4.E. Settlements	-0.7	-0.9	-1.1	-1.2	-1.2	-1.2	-0.5	0.005
4.G. Harvested Wood Products	0.2	-0.5	-0.6	-0.7	-0.7	-0.5	-0.7	0.1
Total Net Emissions	-39.0	-60.4	-57.4	-41.6	-39.0	-37.8	1.1	1.2

In the LULUCF sector, three types of greenhouse gases, namely CO_2, CH_4 and N_2O were estimated. The percentage of CO_2 removals was the largest while only a small amount of CH_4 and N_2O emissions was emitted from flooded land, land converted to cropland and biomass burning. Changes in emissions and removals by gas in this sector between 1990 and 2022 were attributed to wildfire in 2022 and the reduced area of land converted to cropland.

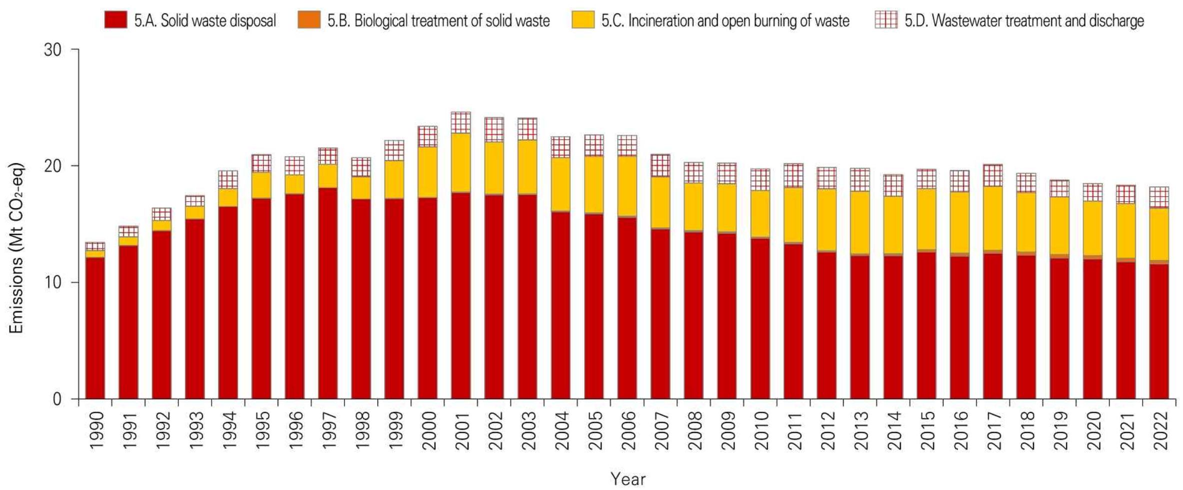
| Table 2-16 | Emissions and Removals from LULUCF Sector by Gas

(Unit: Mt CO_2-eq)

Gas	1990	2000	2010	2018	2021	2022	Emissions Change (Mt CO_2-eq)	
							From 1990	From 2021
CO_2	-39.4	-60.9	-57.7	-42.0	-39.4	-38.4	0.95	0.98
CH_4	0.28	0.39	0.34	0.38	0.40	0.52	0.24	0.12
N_2O	0.14	0.08	0.05	0.02	0.02	0.09	-0.05	0.07
Total (Net Removals)	-39.0	-60.4	-57.4	-41.6	-39.0	-37.8	1.1	1.2

2.3.5 Waste

In 2022, greenhouse gas emissions from the Waste sector were 18.2 Mt CO_2-eq and accounted for 2.5 percent of total national emissions, representing an increase of 35.3 percent from 1990, and a 0.8 percent decrease from 2021. Since 1990, emissions from the Waste sector increased until it peaked in 2001 which was then followed by a declining trend. Such decrease was contributed by less emissions from solid waste disposal which was the largest source in the sector. Emissions from the remaining subcategories continued to increase in the 1990s and remained steady since the mid-2000s.



| Figure 2-19 | Trends in Waste Sector Greenhouse Gas Emissions (1990-2022)

| Table 2-17 | Emissions from Waste Sector

(Unit: Mt CO_2-eq)

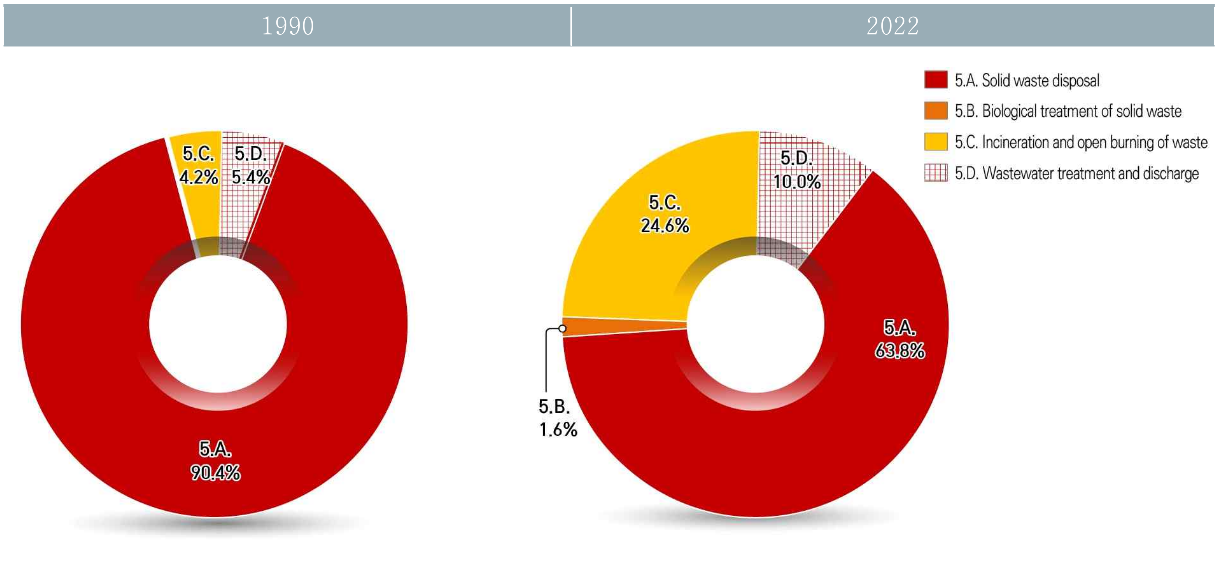
Category	1990	2000	2010	2018	2020	2021	Emissions Change (%)	
							From 1990	From 2021
5.A. Solid Waste Disposal	12.1	17.3	13.8	12.3	11.8	11.6	-4.5	-1.4
5.B. Biological Treatment of Solid Waste[1)]	NE	0.03	0.09	0.28	0.30	0.29	6,593.4[1)]	-3.8
5.C. Waste Incineration	0.6	4.3	4	5.1	4.7	4.5	699.4	-4.5
5.D. Wastewater Treatment and Discharge	0.7	1.8	1.9	1.7	1.6	1.8	149.9	15.2
Total	13.4	23.4	19.7	19.4	18.3	18.2	35.3	-0.8

Note: 1) The percentage change of biological treatment of solid waste was calculated based on data for 1994 from which data were available.

Solid waste disposal (5.A.) in 2022 was the largest source in the Waste sector, representing 63.8 percent of total sectoral emissions, followed by Waste incineration (5.C.) (24.6 percent), Wastewater treatment and discharge (5.D.) (10.0 percent) and Biological treatment of solid waste (5.B.) (1.6 percent).

Emissions from solid waste disposal which was the biggest contributor in this sector peaked in 1997 with 18.1 Mt CO_2-eq and have been consistently decreasing which was contributed by the law prohibiting the direct landfilling of food wastes enacted in 2005. The law led to a shift from landfill to food waste treatment such as composting and waste-to-energy solutions which resulted in a continued decrease in emissions.

The largest increase in emissions was observed from waste incineration as emissions increased by 699.4 percent (3.9 Mt CO_2-eq) from 1990. This was largely due to the growing population and economic growth resulting in the increased volume of wastes incinerated. After establishing the *National Plan for Circular Economy* in 2018, the volume of waste recycled as well as energy recovery from municipal solid waste incineration have consistently been increasing which contributed to the decrease in emissions.



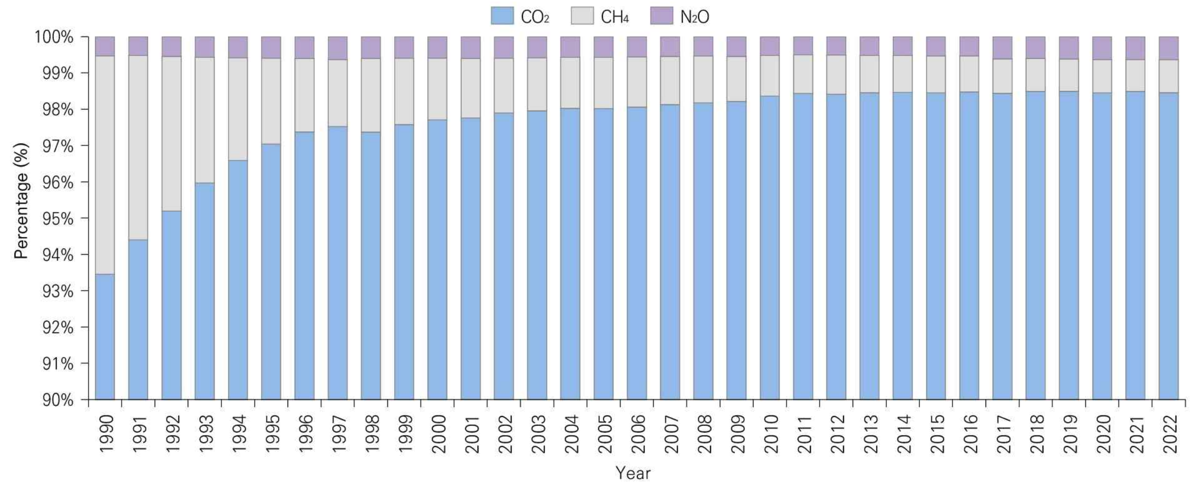
| Figure 2-20 | Category as a Portion of Total Waste Emissions (1990 and 2022)

The percentage of emissions from solid waste disposal decreased from 90.4 percent in 1990 to 63.8 percent in 2022 whereas emissions from incineration increased from 4.2 percent to 24.6 percent during the same period. Although waste incineration increased in both emissions and its portion of total emissions from this sector, energy has been recovered from over 80 percent of municipal wastes incinerated since 2006 which contributed to slowing down the growth of emissions.

Three types of greenhouse gases, namely CO_2, CH_4 and N_2O occur in the Waste sector. Between 1990 and 2022, the percentage of CH_4 in total emissions from this sector decreased[19)] while that of CO_2 and N_2O increased[20)]. Changes in emissions by gas from this sector between 1990 and 2022 were attributed to the Wastes Control Act and the *National Plan for Circular Economy.* As respective law and national plan prohibited direct landfilling of food wastes, it led to the increase in incineration as well as energy recovery, resulting in the decrease in CH_4 and increase in CO_2 emissions.

19) CH_4: 95.5% (1990) → 69.1% (2022)

20) CO_2: 3.9% (1990) → 23.4% (2022); N_2O: 0.6% (1990) → 7.5% (2022)



| Figure 2-21 | Percentage of Gas in Waste Sector Emissions (1990-2022)

| Table 2-18 | Emissions from Waste Sector by Gas

(Unit: Mt CO_2-eq)

Gas	1990	2000	2010	2018	2021	2022	Emissions Change (%)	
							From 1990	From 2021
CO_2	0.5	4.2	3.8	4.8	4.5	4.3	704.4	-4.7
CH_4	12.8	18.2	14.7	13.2	12.5	12.6	-2.1	0.4
N_2O	0.1	1.1	1.2	1.3	1.4	1.4	1,611.3	0.5
Total	13.4	23.4	19.7	19.4	18.3	18.2	35.3	-0.8

SECTION 03

Energy

3 Energy

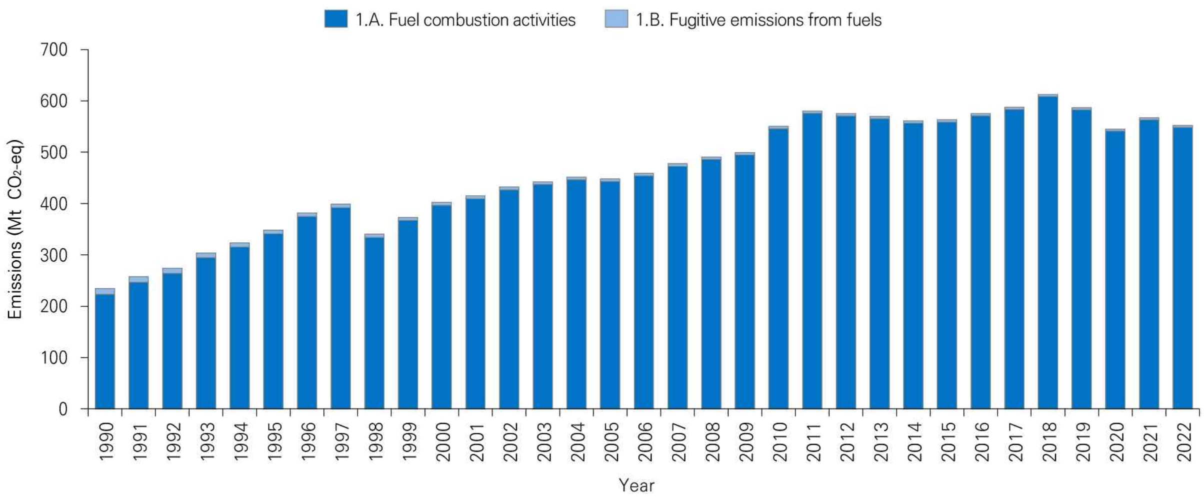
3.1 Overview

The Energy sector is categorized into Fuel Combustion (1.A.), Fugitive Emissions from Fuels (1.B.), CO_2 Transport and Storage (1.C.)[1], and International Bunkers and Multilateral Operations (1.D.) in accordance with the *2006 IPCC Guidelines*.

Emission sources in the Energy sector are largely divided into fuel combustion and fugitive emissions. From fuel combustion, greenhouse gases are emitted during the oxidation of fossil fuels for production of energy while fugitive emissions refer to greenhouse gases during the extraction, processing, storage and transport of fossil fuels. Emissions from international bunkers for international transport[2] and multilateral operations are not included in the national emission totals but reported separately as a memo item.[3]

In 2022, total emissions from the Energy sector were 551.9 Mt CO_2-eq, representing 76.2 percent of the national totals. Emissions from fuel combustion were 548.5 Mt CO_2-eq while fugitive emissions were 3.4 Mt CO_2-eq, accounting for 99.4 percent and 0.6 percent of the sectoral emissions respectively.

1) Emissions from CO_2 Transport and storage (1.C.) do not occur in ROK.
2) Include emissions from fuel supplied for flights and vessels that depart in one country and arrive in a different country.
3) Decision 18/CMA.1 Modalities, procedures and guidelines for the transparency framework for action and support referred to in Article 13 of the Paris Agreement, paragraph 53 of the Annex.



| Figure 3-1 | Trends in Energy Sector Greenhouse Gas Emission Sources (1990-2022)

Emissions from the Energy sector increased by 135.4 percent since 1990, contributed by a 512.7 percent increase in emissions from energy industries primarily due to continued growth in electricity demand. The scale-up of the production in the manufacturing industries driven by exports as well as increased logistics and traffic volume were also major contributors of increased emissions from this sector.

In 2022, key categories in the Energy sector include CO_2 emissions from : solid fuels of Energy industries (1.A.1.) and of Manufacturing industries and construction (1.A.2.); Road transportation (1.A.3.b.); gaseous fuels of Energy industries (1.A.1.) and Other sectors (1.A.4.); liquid fuels of Energy industries (1.A.1.), Other sectors (1.A.4.), and Manufacturing industries and construction (1.A.2.); other fossil fuels of Manufacturing industries and construction (1.A.2.) (see Section 1.4 Key Category Analysis).

| Table 3-1 | Emissions from Energy Sector (1990-2022)

(Unit: Mt CO_2-eq)

Sector		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1.A. Fuel Combustion Activities	1.A.1. Energy Industries	42.0	49.9	59.0	67.0	81.3	92.0	115.6	125.0	112.4	122.4	136.3
	1.A.2. Manufacturing and construction	72.2	85.3	88.9	97.5	102.9	104.6	106.2	107.3	97.1	104.5	115.4
	1.A.3. Transport	36.5	39.7	45.2	57.1	59.2	66.6	70.8	76.4	59.2	64.4	71.9
	1.A.4. Other Sectors	72.6	67.2	68.2	70.0	69.1	75.0	79.2	80.9	62.9	73.0	70.5
	1.A.5. Other	0.2	4.7	3.0	3.2	2.9	2.8	3.1	3.0	2.7	2.8	2.4
	Subtotal	**223.5**	**246.9**	**264.2**	**294.7**	**315.4**	**341.0**	**375.0**	**392.5**	**334.2**	**367.1**	**396.5**
1.B. Fugitive Emissions from Fuels	1.B.1. Solid Fuels	10.9	10.4	9.4	8.6	7.6	6.8	6.3	5.9	5.6	5.4	5.2
	1.B.2. Oil and Natural Gas	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
	Subtotal	**11.0**	**10.5**	**9.5**	**8.7**	**7.8**	**7.0**	**6.6**	**6.2**	**6.0**	**5.8**	**5.7**
Total		**234.5**	**257.3**	**273.8**	**303.5**	**323.2**	**348.0**	**381.5**	**398.7**	**340.2**	**372.9**	**402.2**

Sector		2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
1.A. Fuel Combustion Activities	1.A.1. Energy Industries	147.1	155.9	159.9	172.5	177.4	187.1	199.5	212.4	230.7	254.6	265.0
	1.A.2. Manufacturing and Construction	115.6	119.5	124.4	125.2	116.1	118.8	124.5	129.0	119.9	142.8	164.1
	1.A.3. Transport	75.1	80.1	83.0	83.1	84.0	84.7	86.9	84.5	85.2	86.7	86.4
	1.A.4. Other Sectors	68.6	68.9	66.5	62.6	62.5	60.4	58.7	57.4	56.0	58.9	57.5
	1.A.5. Other	3.1	2.9	3.3	3.2	3.3	2.9	2.9	2.6	2.9	3.0	2.9
	Subtotal	**409.5**	**427.2**	**437.1**	**446.6**	**443.3**	**453.9**	**472.6**	**486.0**	**494.6**	**545.9**	**575.8**
1.B. Fugitive Emissions from Fuels	1.B.1. Solid Fuels	5.0	4.7	4.6	4.4	4.2	4.1	4.1	4.0	3.8	3.6	3.5
	1.B.2. Oil and Natural Gas	0.5	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.8	0.9	0.9
	Subtotal	**5.6**	**5.2**	**5.1**	**5.0**	**4.9**	**4.8**	**4.8**	**4.7**	**4.6**	**4.4**	**4.4**
Total		**415.1**	**432.5**	**442.3**	**451.6**	**448.2**	**458.7**	**477.3**	**490.7**	**499.2**	**550.3**	**580.2**

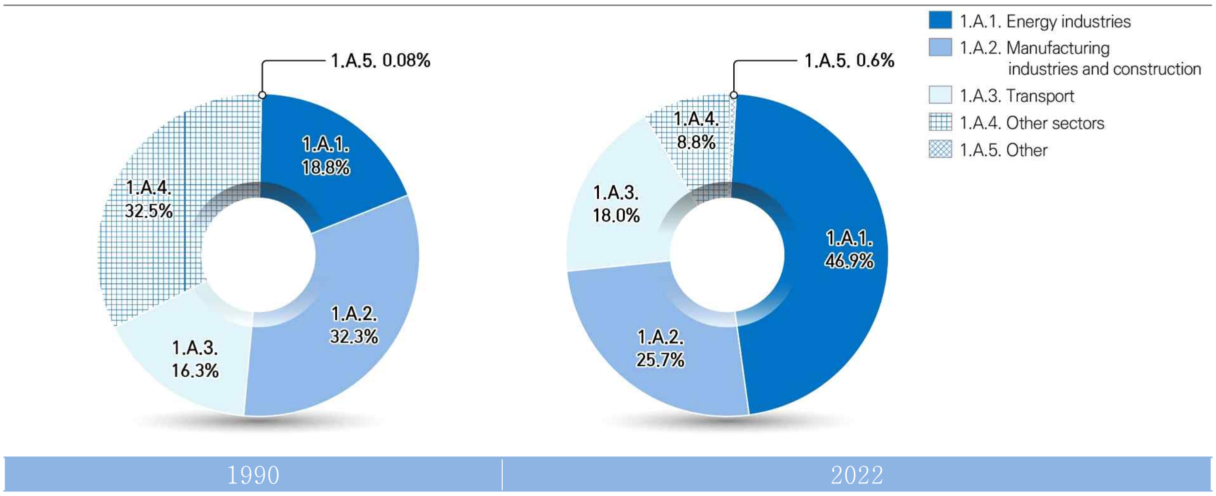
Sector		2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
1.A. Fuel Combustion Activities	1.A.1. Energy Industries	269.4	276.2	263.9	262.3	263.8	275.1	300.0	279.4	248.2	260.0	257.5
	1.A.2. Manufacturing and Construction	154.6	142.1	151.3	148.4	152.6	153.1	153.5	148.8	144.9	152.9	141.0
	1.A.3. Transport	87.7	89.7	89.9	95.4	99.9	99.3	98.8	101.7	96.8	99.5	98.5
	1.A.4. Other Sectors	55.9	54.6	48.8	49.8	51.7	53.0	53.0	49.9	48.3	48.0	48.4
	1.A.5. Other	3.0	3.0	2.9	3.1	3.1	3.2	3.1	3.0	2.9	2.9	3.0
	Subtotal	**570.6**	**565.5**	**556.8**	**558.9**	**571.1**	**583.7**	**608.4**	**582.9**	**541.1**	**563.4**	**548.5**
1.B. Fugitive Emissions from Fuels	1.B.1. Solid Fuels	3.4	3.3	3.2	3.2	3.1	2.8	2.7	2.6	2.6	2.5	2.4
	1.B.2. Oil and Natural Gas	1.0	0.9	0.9	0.8	0.9	0.9	1.0	0.9	0.9	0.9	1.0
	Subtotal	**4.4**	**4.2**	**4.1**	**4.0**	**3.9**	**3.8**	**3.7**	**3.6**	**3.5**	**3.4**	**3.4**
Total		**575.0**	**569.7**	**560.9**	**562.9**	**575.0**	**587.5**	**612.1**	**586.4**	**544.6**	**566.8**	**551.9**

3.2 Fuel Combustion (1.A.)

Fuel combustion activities are divided into stationary and mobile combustion. Stationary combustion occurs in Energy Industries (1.A.1.), Manufacturing Industries and Construction (1.A.2.), Other Sectors (1.A.4.), and Other (1.A.5.) while mobile combustion source refers to Transport (1.A.3.).

In 2022, emissions from fuel combustion were 548,487 kt CO_2-eq, or 2.6 percent below emissions in 2021, contributing 75.7 percent of the national totals and 99.4 percent of the Energy sector. Energy industries was the largest source of emissions representing 46.9 percent of the sectoral totals, followed by manufacturing industries and construction of 25.7 percent, transport of 18.0 percent, other sectors of 8.8 percent, and the last subcategory of Other (1.A.5.) of 0.6 percent.

| Figure 3-2 | Trends in Fuel Combustion Emissions (1990-2022)



| Figure 3-3 | Subcategory as a Portion of Total Emissions from Fuel Combustion Activities (1990 and 2022)

| Table 3-2 | Emissions from Fuel Combustion

(Unit: kt CO_2-eq)

Sub-category	1990	2000	2010	2018	2021	2022
1.A.1. Energy industries	42,027	136,316	254,619	299,964	260,020	257,502
1.A.2. Manufacturing industries and construction	72,169	115,401	142,754	153,545	152,932	140,999
1.A.3. Transport	36,461	71,850	86,660	98,764	99,474	98,502
1.A.4. Other sectors	72,641	70,540	58,921	53,012	47,986	48,438
1.A.5. Other	183	2,427	2,970	3,148	2,950	3,046
Total	223,482	396,534	545,925	608,432	563,362	548,487

3.2.1 Comparison of the Sectoral Approach with the Reference Approach

Further expert elicitation is in process to provide the detailed calculations for estimating CO_2 emissions from fuel combustion using the reference approach to ensure the comparability with estimates calculated using the sectoral approach. The results will be included in future documents.

3.2.2 International Bunkers

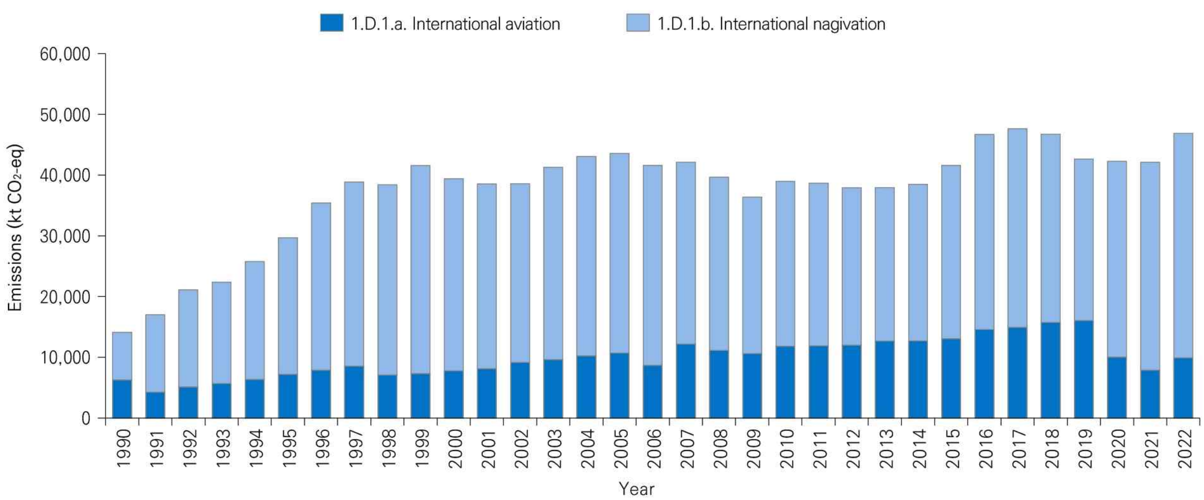
3.2.2.1 Category Overview

	Gas	Methodology	Emission Factor	Activity Data
2022	CO_2	Tier 1, 2	D, CS	Fuel consumption
	CH_4, N_2O	Tier 1	D	

International bunkers refer to greenhouse gases resulting from fuel supplied for international transport including Aviation (1.D.1.a.) and Navigation (1.D.1.b.) regardless of the nationality of the aircraft or vessel, that departs in one country and arrives in a different country. In accordance with the Paris Agreement, emissions from international aviation and navigation are excluded from national totals but reported as a memo item.[4)]

In 2022, emissions from international bunkers were 46,887 kt CO_2−eq, an 11.3 percent increase since 2021. International aviation accounted for 21.2 percent while international navigation contributed 78.8 percent. International aviation produced 9,930 kt CO_2−eq emissions which was 26 percent more emissions relative to 2021 driven by the recovery from the COVID−19. Emissions from international navigation were 36,956 kt CO_2−eq showing a 8.0 percent increase primarily due to increased shipments for imports and exports.

Under the reporting category of Multilateral operations (1.D.2.), emissions of CO_2, CH_4 and N_2O from fuel combustion of aviation and navigation for multilateral operations pursuant to the Charter of the United Nations are separately reported and not included in national totals.



| Figure 3−4 | Trends in Emissions from International Bunkers (1990−2022)

4) Decision 18/CMA.1 Modalities, procedures and guidelines for the transparency framework for action and support referred to in Article 13 of the Paris Agreement, *paragraph 53 of the Annex.*

| Table 3-3 | Emissions from International Bunkers

(Unit: kt CO_2-eq)

Source	1990	2000	2010	2018	2021	2022
International aviation	6,296	7,753	11,822	15,767	7,880	9,930
International navigation	7,828	31,671	27,148	30,975	34,233	36,956
Total	14,123	39,424	38,970	46,742	42,113	46,887

3.2.2.2 Methodology

3.2.2.2.1 Method

Methodologies used for international aviation and navigation were the same as those for Transportation (1.A.3.) as presented in Sections 3.2.6.2.2 (Domestic aviation) and 3.2.6.5.2 (Domestic water-borne navigation) respectively.

3.2.2.2.2 Emission Factor

Emission factors used for international aviation and navigation were the same as for Transportation (1.A.3.) as presented in Sections 3.2.6.2.2 (Domestic aviation) and 3.2.6.5.2 (Domestic water-borne navigation) respectively.

3.2.2.2.3 Activity Data

Fuel consumption data for international bunkers were obtained from the *Annual Oil Statistics*. To estimate emissions from international aviation, data on aviation fuel consumed by aircraft irrespective of the nationality that were engaged in international flights were used. For international navigation, data on fuel including diesel, bunker A (B-A) oil, bunker C (B-C) oil consumed by national vessels engaged in international water-borne navigation were used to estimate respective emissions. In 2022, fuel consumption in international aviation was 3,454 ktoe, an increase of 25.5 percent relative to 2021 while international navigation consumed 12,072 ktoe, showing an increase of 10.9 percent from 2021.

| Table 3-4 | Activity Data Source for International Bunkers

Period	Activity Data	Name of Statistics	Published by	Gas
1990-2022	Fuel consumption	*Annual Oil Statistics*	Korea National Oil Corporation (KNOC)	CO_2, CH_4, N_2O

| Table 3-5 | Activity Data for International Bunkers

(Unit: ktoe)

Fuel Consumption		1990	2000	2010	2018	2021	2022
International aviation	Aviation fuel	2,227.2	2,742.8	4,161.0	5,507.2	2,752.4	3,454.1
International navigation	Diesel	440.1	1,196.6	708.8	1,029.2	1,831.7	2,202.6
	B-C oil	2,037.3	8,927.8	8,110.7	8,702.9	9,043.0	9,854.4
	Other petroleum products[1)]	82.1	197.4	136.4	65.8	13.0	15.4
	Subtotal	2,559.5	10,321.8	8,955.9	9,797.9	10,887.7	12,072.3
Total		**4,786.7**	**13,064.5**	**13,116.9**	**15,305.1**	**13,640.1**	**15,526.4**

Note: 1) Include gasoline, kerosene, B-A oil, B-B oil and Liquefied Petroleum Gas (LPG)
Source: *2022 Annual Oil Statistics*, KNOC (2023)

3.2.2.3 Time-series Consistency

Emissions from international bunkers were estimated using the same methodology and emission factors as for Transport (1.A.3.), and activity data from 1990 through 2022 were sourced from *Annual Oil Statistics* to ensure time series consistency.

3.2.3 Feedstocks and Non-energy Use of Fuels

3.2.3.1 Overview

In accordance with the Paris Agreement, Parties should indicate whether emissions from feedstocks and non-energy use of fuels are reported under the Energy or Industrial Processes and Product Use (IPPU) sector.[5)]

Fuels are consumed as either feedstock, reductant or non-energy products where feedstock refers to fuels such as naphtha and Liquefied Petroleum Gas (LPG) including propane and butane used as raw materials in chemical and petrochemical industries whereas coke is used in the iron and steel industry as a reductant. Non-energy products include asphalt, lubricants, paraffin wax and solvents.

Fuels consumed as feedstock or for non-energy purposes are reported under either the IPPU or Energy sector. Such fuels reported under the IPPU sector include coke,

5) Decision 18/CMA.1 Modalities, procedures and guidelines for the transparency framework for action and support referred to in Article 13 of the Paris Agreement, paragraph 54 of the Annex.

coking coal, and other bituminous coal used in Iron and steel production (2.C.1.), and naphtha, propane, and butane used in Petrochemical products and carbon black production (2.B.8.) whereas those reported under the Energy sector include coke and coking coal used in the Iron and steel (1.A.2.a.), and catalytic converters using urea from Road transportation (1.A.3.b.).

| Table 3-6 | Emissions from Feedstock and Non-energy Use of Fuels

Sector	CRT Category	Fuel and Feedstock
Energy	1.A.2.a. Iron and steel	Coke, coking coal
	1.A.3.b. Road transportation	Urea
IPPU	2.C.1. Iron and steel production	Coke, coking coal, other bituminous coal, coke oven gas
	2.B.8. Petrochemical and carbon black production	Naphtha, propane, butane

3.2.4 Energy Industries (1.A.1.)

3.2.4.1 Category Description

	Category	Gas	Methodology	Emission Factor	Activity Data
2022	Public Electricity and Heat Production	CO_2	Tier 1, 2	D, CS	Fuel consumption
		CH_4, N_2O	Tier 1, 2	D, CS	
	Petroleum Refining	CO_2	Tier 1, 2, OTH	D, CS, PS	
		CH_4, N_2O	Tier 1	D	
	Manufacture of Solid Fuels and Other Energy Industries	CO_2	Tier 1, 2	D, CS	
		CH_4, N_2O	Tier 1	D	

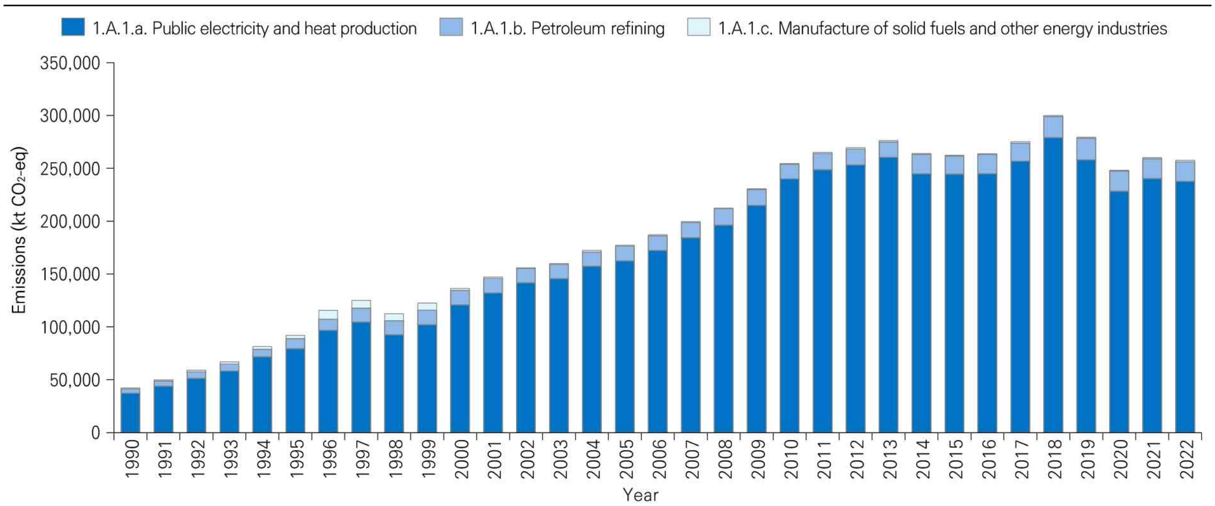
Emissions from the Energy industries (1.A.1.) are reported under three subcategories: Public electricity and heat production (1.A.1.a.), Petroleum refining (1.A.1.b.), and Manufacture of solid fuels and other energy industries (1.A.1.c.).

In accordance with the *2006 IPCC Guidelines*, the public electricity and heat production includes emissions from fuel combustion in power plants whose primary purpose is to supply electricity to the public. On the other hand, emissions from autoproducers of which activities generate electricity or heat for their own use or for sale, but not as its main business, with the purpose to support their primary business are assigned to corresponding subcategories where they were generated.

The petroleum refining is where emissions from the combustion associated with the production of petroleum products that involves crude oil refining and also emissions from catalyst regeneration are reported.

The manufacture of solid fuels and other energy industries includes combustion emissions from fuel use for the production of solid fuels such as coke and patent fuels[6], and for coal mining as well as the extraction of crude oil and natural gas. Emissions from the coke oven process under the subcategory of Manufacture of solid fuels (1.A.1.c.i.) were included in Iron and steel (1.A.2.a.).

In 2022, total emissions from the energy industries were 257,502 kt CO_2−eq, showing a 1.0 percent decrease from 2021. The public electricity and heat production produced 237,677 kt CO_2−eq, representing 92.3 percent of the total emissions from the energy industries. Emissions from the petroleum refining and manufacture of solid fuels and other energy industries were 18,426 kt CO_2−eq and 1,399 kt CO_2−eq respectively, contributing 7.2 percent and 0.5 percent.



| Figure 3−5 | Trends in Energy Industries Emissions (1990−2022)

6) According to the *Energy Supply and Demand Statistics* which is the primary source of activity data for the energy sector, patent fuels refer to manufactured fuels using coking coal such as briquettes whereas the International Energy Agency (IEA) defines them as composition fuels made by moulding hard coal fines into briquette shapes with the addition of a binding agent.

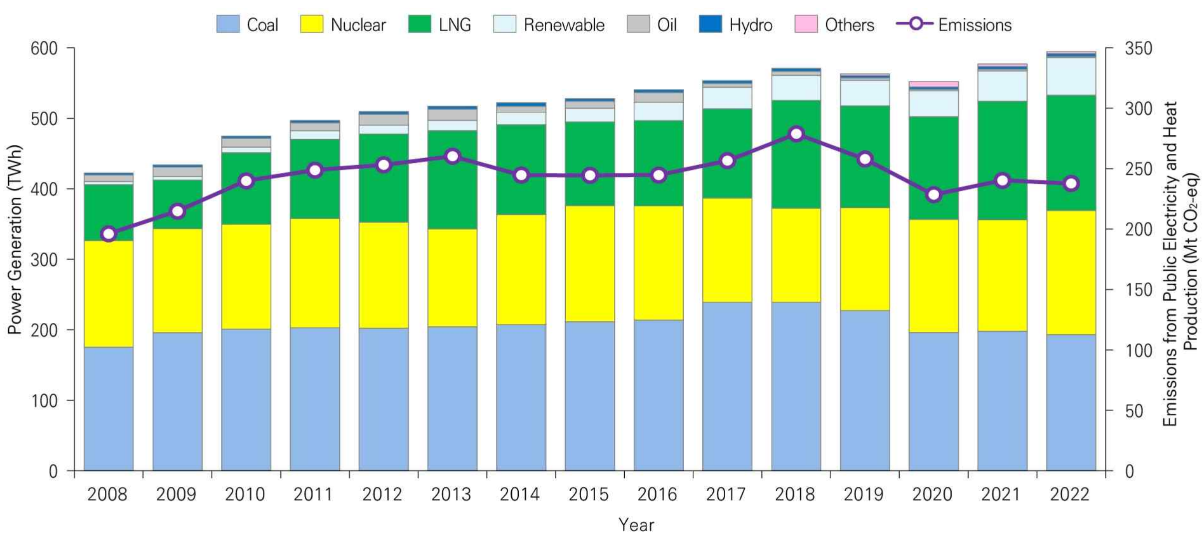
| Table 3-7 | Emissions from Energy Industries

(Unit: kt CO_2-eq)

Category	1990	2000	2010	2018	2021	2022
1.A.1.a. Public Electricity and Heat Production	37,175	120,792	239,940	278,849	240,292	237,677
1.A.1.b. Petroleum Refining	4,194	13,704	14,001	20,290	18,753	18,426
1.A.1.c. Manufacture of Solid Fuels and Other Energy Industries	659	1,821	678	825	974	1,399
Total	42,027	136,316	254,619	299,964	260,020	257,502

Emissions in 2022 increased by 512.7 percent from 1990 which was largely driven by increased consumption of electricity following economic growth and industrial development. The total electricity production rose from 107.7 TWh in 1990 to 594.4 TWh in 2022, increasing by 452 percent.[7]

Despite the continued growth in electricity production, emissions from the energy industries have been decreasing since 2018 which was led by a phase-out of old coal-fired power plants, a replacement of coal-based power plants with Liquefied Natural Gas (LNG) plants which produce less emissions, and an increased share of carbon-free energy sources such as nuclear and renewable energy.[8]



| Figure 3-6 | Trends in Power Generation by Energy source and Emissions in the Public Electricity and Heat Production (2008-2021)

7) *1990-2023 Electric Power Statistics of Korea*, Korea Electric Power Corporation (KEPCO)

8) Section 3.2.2 (Power generation) in the *First Biennial Transparency Report (BTR) of Republic of Korea*

3.2.4.2 Methodology

3.2.4.2.1 CO_2

1) Method

○ CO_2 Emissions

Emissions of CO_2 from the energy industries were estimated using the Tier 2 methodology of the *2006 IPCC Guidelines*.9) Emissions were calculated by multiplying the amount of fuel consumed for energy purposes by the joule-to-toe conversion factor, energy conversion factor and emission factor. For coke production under Manufacture of solid fuels (1.A.1.c.i.) and catalyst regeneration at Petroleum refining facilities (1.A.1.b.), different equations were used as described below.

CO_2 emissions from energy industries
※ Excluding coke production and catalyst regeneration
$E = \sum_{ij}\left[FC_{ij} \times 41.868 \times CF_i \times EF_i \times 44/12 \times 10^{-3}\right]$
E : CO_2 emissions(kt CO_2)
FC : fuel consumption (ktoe)
41.868 : joule-toe conversion factor (TJ/ktoe)
CF : conversion factor (Net calorific value/Gross calorific value)
EF : emission factor (t C/TJ)
44/12 : conversion of carbon-based emissions to CO_2-based emissions (kg CO_2/kg C)
i : fuel type
j : subcategory or subsector under 1.A.1.

Source: *2006 IPCC Guidelines, Vol.2, Ch.2, Equation 2.1*

○ CO_2 Emissions from Coke Production

Coke is used as a fuel and feedstock (reducing agent) in the iron and steel industry from which emissions from coke consumed are estimated under Iron and steel (1.A.2.a.) in the Energy sector, and under Iron and steel production (2.C.1.) in the IPPU sector respectively. CO_2 emissions from coke production for Energy industries (1.A.1.) were included in Iron and steel (1.A.2.a.).

In the coke oven process, coking coal is used to produce coke and coke oven gas (COG) producing coal tar as a process byproduct. COG and blast furnace gas (BFG) are

9) The Tier 1 methodology was applied for the 1990 to 2006 time period until the Tier 2 methodology has been applied since 2007.

consumed to operate coke ovens. Emission sources of the iron and steel industry are described in Table 3-8.

Coke is produced either on site at the iron and steel facility or off site at separate facilities. The Tier 2 methodology of the *2006 IPCC Guidelines* distinguishes between onsite and offsite production. As every process including coke production, iron making, steel making and rolling takes place at the integrated facility in ROK, the onsite methodology was applied.

CO_2 emissions from onsite coke production

$$E=[CC\times C_{CC}+\Sigma_a(PM_a\times C_a)+BG\times C_{BG}-CO\times C_{CO}-COG\times C_{COG}-\Sigma_b(COB_b\times C_b)]\times 41.868\times 44/12\times 10^{-3}$$

E	:	CO_2 emissions (kt CO_2)
CC	:	input of coking coal (ktoe)
PM	:	input of process material (ktoe)
BG	:	input of blast furnace gas (BFG) (ktoe)
CO	:	coke production (ktoe)
COG	:	coke oven gas (COG) production (ktoe)
COB	:	by-product production from coke ovens (ktoe)
C_X	:	carbon content of inputs and outputs (t C/TJ)
a	:	input of process material
b	:	by-product
41.868	:	conversion factor from toe to joule (TJ/ktoe)
44/12	:	conversion factor from carbon-based to CO_2-based emissions (kg CO_2/kg C)

Source: *2006 IPCC Guidelines, Vol.3, Ch.4, Equation 4.2*

| Table 3-8 | Emission Sources and Reporting Category of Iron and Steel Industry

Source	Fuel	Reporting Category
Coke Oven Process[1]	Coking coal, coke, coal tar, COG, BFG	Manufacturing Industries and Construction (1.A.2.) > Iron and Steel (1.A.2.a.)
Casting and Rolling Process	Coke, COG, other recovered gases	
Blast Furnace Process	Coke, coking coal, other bituminous coal, COG, BFG, other recovered gases	Metal Industry (2.C.) > Iron and Steel Production (2.C.1.)
Electric Arc Furnace Process	Electrodes	
Carbonate Consumption	Limestone, dolomite, magnesite	

Note: 1) Emissions from the coke oven process under Manufacture of solid fuel and other energy industries (1.A.1.c.i.) were included in Iron and Steel (1.A.2.a.).

CO_2 Emissions from Catalyst Regeneration

Petroleum refineries equipped with catalyst regenerator are subject to the Korea Emissions Trading System (K-ETS) and required to report emissions in the K-ETS information system. CO_2 emissions from catalyst regeneration, as reported in the system, were incorporated into the Inventory. Such emissions were calculated using the equation for the catalytic regeneration process outlined in the *Guidelines for Reporting and Certification of Emissions under the Greenhouse Gas Emissions Trading System*.[10] For the 1990 through 2006 time period during which K-ETS data were not available, emissions were estimated using a linear regression model with variables such as facility capacity.

<table>
<tr><th colspan="2">CO₂ emissions from catalyst regeneration</th></tr>
<tr><th>K-ETS Tier 1</th><th>K-ETS Tier 3b</th></tr>
<tr><td>$E_{CO_2} = AR \times CF \times 1.963$</td><td>$E_{CO_2} = AR \times CF \times 1.963$</td></tr>
<tr><td colspan="2">E_{CO_2} : CO_2 emissions (kt CO_2)
AR : air input (1000 m^3)
1.963 : molecular weight of CO_2 (44.010) / Molar volume of CO_2 at standard conditions (22.414)</td></tr>
<tr><td>CF : oxygen content in input air (= 0.21)</td><td>CF : sum of CO and CO_2 concentration ratios in exhaust gas</td></tr>
</table>

Source: Annex 6, Item 14: Petroleum Refining Activities in *Guidelines for Reporting and Certification of Emissions under the GHG Emissions Trading System,* Ministry of Environment (MOE)

2) Emission Factor

Carbon Emission Factor

ROK has been reporting energy calorific values using energy conversion factors since 1992. Gross and net calorific values have been available and updated every five years from 2006 forward in accordance with Article 5 of the *Enforcement Rule of the Energy Act.* Based on such values, ROK has developed country-specific carbon emission factors which have been applied from 2007 inventory onward and updated every five years reflecting updated energy calorific values.

Country-specific emission factors for the energy industries excluding for coke production and catalyst regeneration have been applied since 2007. For the 1990 to 2006 time period, IPCC default values were applied based on expert judgment (Table 3-10).

10) Annex 6, Item 14: Petroleum Refining Activities in *Guidelines for Reporting and Certification of Emissions under the GHG Emissions Trading System,* Ministry of Environment (MOE)

Carbon Emission Factor for Coke Production

Emissions from coke production were calculated using country-specific emission factors as presented in Table 3-9 throughout the time series. The unit of the emission factor was expressed in the amount of CO_2 per tonne of input and output (t CO_2/t) whereas activity data were based on gross calorific value indicated in ktoe. Therefore the emission factor was converted by applying the energy conversion factor based on gross calorific value, and expressed in the amount of CO_2 per unit of energy (t CO_2/TJ) of input and output.

| Table 3-9 | Carbon Emission Factors for Coke Production

Fuel Type	Coke	Other Bituminous Coal	Coking Coal	BFG	COG	Other Recovered Gases
Emission Factor	0.8651 t C/t	0.7929 t C/t	0.7707 t C/t	0.1873 t C/t	0.4169 t C/t	0.2735 t C/t

Note: Carbon emission factors were developed in 2021 based on K-ETS data for the 2017 to 2019 period reported by three domestic integrated iron and steel facilities.

Carbon Emission Factor for Catalyst Regeneration

CO_2 emissions from catalyst regeneration were estimated using plant-specific emission factors presented in the *Guidelines for Reporting and Certification of Emissions under the Greenhouse Gas Emissions Trading System.*[11]

| Table 3-10 | Carbon Emission Factor

(Unit: t C/TJ)

Fuel Type		1990–2006	2007–2011	2012–2016	2017–2021	2022	Fuel Type		1990–2006	2007–2011	2012–2016	2017–2021	2022
Petroleum	Crude Oil	20.0					Coal	Sub-bituminous Coal	26.2	29.3	26.2	26.468	26.868
	Orimulsion	21.0						Lignite/Brown coal	27.6				
	Natural Gas Liquids (NGL)	17.5						Oil Shale	29.1				
	Gasoline[1]	18.9	19.7	20.0	19.548	19.731		BKB & Patent Fuel	26.6				
	Jet Fuel[2]	19.5	19.6	19.8	19.931	19.956		Coke	29.2				
	Boiler Kerosene[3]	19.6	19.5	19.6	19.969	19.926		Coke Oven Gas	12.1				

11) Annex 6, Item 14: Petroleum Refining Activities in *Guidelines for Reporting and Certification of Emissions under the GHG Emissions Trading System*, Ministry of Environment (MOE)

Fuel Type		1990–2006	2007–2011	2012–2016	2017–2021	2022
	Indoor Kerosene[3]	19.6	19.5	19.6	19.969	19.926
	Shale Oil	20.0				
	Diesel	20.2	20.0	20.2	20.111	20.090
	B-A Oil	20.5[4]	20.2	20.4	20.657	20.440
	B-B Oil	20.8[4]	20.6	20.5	21.384	20.900
	B-C Oil	21.1	20.8	20.6	21.929	21.249
	By-product Fuel No, 1[5]	20.0	20.0	19.7	20.067	20.165
	By-product Fuel No. 2[5]	20.0	20.0	21.0	21.729	21.877
	Propane	17.2	17.6	17.6	17.641	17.630
	Butane	17.2	18.1	18.1	18.107	18.094
	Ethanol	16.8				
	Naphtha	20.0	18.6	19.2	19.157	19.083
	White spirit & SBP	20.0	19.4	19.3	19.172	19.128
	Bitumen	22.0	21.5	21.6	21.544	21.473
	Lubricants	20.0	19.7	19.9	19.979	19.897
	Petroleum Coke	26.6	27.2	27.2[6]	26.086	26.192
	Refinery Gas	15.7				
	Other Oil Products[7]	20.0	20.0	19.7	20.067	20.165
Coal	Domestic Anthracite	26.8	29.7	30.5	30.185	29.705
	Imported Anthracite (Fuel)[8]	26.8	26.8	28.6	27.404	27.320
	Imported Anthracite (Feedstock)[8]	26.8	26.8	29.2	29.909	28.990
	Coking Coal[8]	25.8	25.8	26.2	25.963	25.349
	Other Bituminous	25.8	25.9	26.0	25.951	26.105

Fuel Type		1990–2006	2007–2011	2012–2016	2017–2021	2022
	Blast Furnace Gas	70.8				
	Oxygen Steel Furnace Gas[9]	49.6				
	Peat	28.9				
	Coal Tar	22.0				
Gas	Natural Gas	15.3	15.4	15.3	15.312	15.281
	City Gas (LNG)[10]	15.3	15.4	15.3	15.272	15.236
	City Gas (LPG)	17.2	17.6	17.6	17.454	17.453
Other Fossil Fuels	Municipal Waste (Non-renewable)	25.0				
	Industrial Waste	39.0				
Other Non-Fossil Fuels	Municipal Waste (Renewable)	27.3				
Biomass	Wood/Wood Waste	30.5				
	Sulfite Lye	26.0				
	Other Primary Solid Biomass	27.3				
	Charcoal	30.5				
	Biogasoline	19.3				
	Biodiesel	19.3				
	Other Liquid Biofuels	21.7				
	Landfill Gas	14.9				
	Sludge Gas	14.9				
	Other Biogas	14.9				

(shaded) : Country-specific emission factors

(unshaded) : Default emission factors from the *2006 IPCC Guidelines*

Note: Country-specific emission factors have been applied from 2007 onward. For the time period prior to 2007, default emission factors from the *2006 IPCC Guidelines* were applied based on expert judgment. For fuels without country-specific emission factors, default values were applied across the entire time series.

1) The values for gasoline were also used for aviation gasoline (AVI-G).
2) Jet fuel includes kerosene jet fuels (Jet A-1, JP-8) and gasoline jet fuels (JP-4).
3) As the relevant policy on the supply of boiler kerosene was abolished in 2011, the country-specific emission factor for indoor kerosene was used instead from 2012 onward.
4) B-A oil is a blended fuel consisting of 70 percent of diesel and 30 percent of B-C oil while B-B oil is blended with 30 percent of diesel and 70 percent of B-C oil. As neither country-specific factor nor default values from the *2006 IPCC Guidelines* for respective oils were available from 1990 to 2006, default emission factors for diesel (20.2 t C/TJ) and residual fuel oil (21.1 t C/TJ) were applied based on the respective ratio of blended oils.
5) For by-product fuel No. 1 and No. 2, default emission factor for "Other petroleum products" from the *2006 IPCC Guidelines* were applied for the 1990 to 2011 time period.
6) As country-specific emission factors for petroleum coke were not available for the 2012 to 2016 time series, the country-specific emission factors for the 2007 to 2011 were applied
7) For other oil products, default emission factor for Other petroleum products from the *2006 IPCC Guidelines* was used from the 1990 to 2011 time period, and the country-specific emission factor for by-product fuel No. 1 was used from 2012 onward. For other types of petroleum with no country-specific or IPCC default emission factor available, the respective value for other oil products was used instead.
8) For imported anthracite and coking coal, default emission factors from the *2006 IPCC Guidelines* were used for the 2007 and 2011 time period.
9) For other recovered gases, default value for oxygen steel furnace gas from the *2006 IPCC Guidelines* was used.
10) Natural gas is the primary gas of city gas (LNG) with propane added as a supplementary fuel to adjust calorific value. Emission factors were developed based on the ratio of feedstocks used in the production of city gas per year. Since 2007, a country-specific emission factor reflecting the share of each feedstock used has been applied.

Carbon Emission Factor for City Gas (LNG)

(Unit: t C/TJ)

1990	1991	1992	1993	1994	1995	1996	1997	1998
15.300	15.300	15.300	15.300	15.300	15.300	15.300	15.300	15.300

1999	2000	2001	2002	2003	2004	2005	2006
15.300	15.300	15.323	15.319	15.310	15.309	15.308	15.305

Source: *2006 IPCC Guidelines*; Country-specific emission factors published by Greenhouse Gas Inventory and Research Center of Korea *(GIR) (Updated in 2012, 2013, 2018 and 2021)*

3) Activity Data

Data on fuel consumption from the *Energy Supply and Demand Statistics* were used. For catalyst regeneration, a separate set of activity data was used. As values in the *Energy Supply and Demand Statistics* were based on gross calorific value whereas the carbon emission factor was derived from net calorific value, fuel-specific conversion factors were applied to convert the values to that based on net calorific value.

In 2022, total fuel consumption in the energy industries was 86,308.3 ktoe, a 0.6 percent decrease from 2021. Solid fuels and gaseous fuels were primary fuels used with consumption of 47,160.5 ktoe and 32,531.2 ktoe respectively, followed by liquid fuels, biomass and other fossil fuels. Between 1990 and 2022, consumption of gaseous fuels and solid fuels increased by 1,337.1 percent and 669.1 percent respectively while liquid fuels were 28.1 percent less consumed.

| Table 3-11 | Activity Data Source for Energy Industries

Period	Activity Data	Name of Statistics	Published by	Gas
1990-2022	Fuel consumption	*Energy Supply and Demand Statistics*	Korea Energy Economics Institute (KEEI)	CO_2, CH_4, N_2O

| Table 3-12 | Fuel Consumption in Energy Industries

(Unit: ktoe)

Fuel Type	1990	2000	2010	2018	2021	2022
Solid fuels	6,131.6	24,819.1	50,293.3	58,641.8	47,588.0	47,160.5
Liquid fuels	6,420.6	10,840.6	7,334.7	5,526.2	4,302.9	4,615.8
Gaseous fuels	2,263.6	6,605.0	20,058.2	29,761.7	33,194.6	32,531.2
Biomass	NO	NO	126.2	1,452.8	1,687.5	1,953.9
Other fossil fuels[1)]	NO	NO	NO	79.8	40.2	46.9
Total	**14,815.8**	**42,264.7**	**77,812.4**	**95,462.2**	**86,813.3**	**86,308.3**

Note: 1) Other fossil fuels include non-renewable municipal waste.
Source: *Energy Supply and Demand Statistics*, KEEI (2024); K-ETS data, MOE (2023)

Detailed information on the use of activity data per subcategory under the Energy industries are described below.

○ Public Electricity and Heat Production

Fuel consumption at power plants that is dedicated solely to either electricity generation or heat production with no other purpose, and also in combined heat and power (CHP) plants as reported in the *Energy Supply and Demand Statistics* were used as activity data for public electricity and heat production.

○ Petroleum Refining

Activity data of fuel consumption for petroleum refining were from the *Energy Supply and Demand Statistics*.[12)] As the respective statistics do not provide data on refinery gas consumption from 1990 to 1996, a surrogate data method as suggested by the *2006 IPCC Guidelines* was applied to estimate the consumption of refinery gas from the 1990 to 1996 period. Similarly, the consumption of B-C oil in the 1990 to 1996 period which showed more than a ninefold difference in the post-1997 years was calculated using the surrogate

12) Fuel consumption for pipeline transport was considered for emissions reported under Other transportation (1.A.3.e.), not for petroleum refining.

data method.

For catalytic regeneration in petroleum refining, either the amount of air injected for coke removal or that of coke deposit combusted from K-ETS data were used as activity data.

| Table 3-13 | Estimated Consumption of Refinery Gas and B-C Oil in Petroleum Refining[1)2)]

(Unit: ktoe)

Category		1990	1991	1992	1993	1994	1995	1996
Refining Input	Crude Oil	42,571	54,302	69,389	76,199	76,919	86,121	98,244
	Refinery Feedstock	1,257	2,049	2,892	3,429	4,448	5,749	5,262
	Total	**43,828**	**56,350**	**72,281**	**79,628**	**81,367**	**91,870**	**103,506**
Fuel Consumption	Total Energy	1,173	1,508	1,934	2,130	2,177	2,458	2,769
	Refinery Gas	387	497	637	702	718	810	913
	B-C Oil	786	1,011	1,296	1,428	1,459	1,648	1,857
Category		**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	
Refining Input	Crude Oil	118,961	112,673	119,140	121,722	117,349	107,406	
	Refinery Feedstock	9,506	8,383	6,997	6,286	8,021	11,048	
	Total	**128,467**	**121,056**	**126,138**	**128,008**	**125,370**	**118,454**	
Fuel Consumption	Total Energy	3,647	3,731	3,962	4,012	4,136	3,938	
	Refinery Gas	1,009	1,009	1,086	1,209	1,240	1,042	
	B-C Oil	2,104	2,214	2,333	2,243	2,258	2,231	

Note: 1) Values that were calculated using the surrogate data method in grey shaded cells (▭).

2) Since the amount of B-C oil consumption did not fluctuate much in the 1997 to 2002 period until it considerably decreased relative to total energy starting from 2003, the average amount of B-C oil consumption in the 1997 to 2002 period was used to determine the total energy and B-C oil consumption in the 1990 to 1996 period.

○ Coke Production

Input feedstock for the coking process, production volumes and fuel consumption for coke oven from the *Energy Supply and Demand Statistics* were used as activity data.

○ Other (Waste Incineration with Energy Recovery)

In accordance with the *2006 IPCC Guidelines,* emissions from energy recovery in waste incineration shall be reported under the Energy sector. Accordingly, emissions from the combustion of municipal waste and industrial waste (alternative fuel for cement kiln) for energy recovery at waste-to-energy facilities were reported under the Energy sector. Emissions from incineration of all other wastes with and without energy recovery were reported under the Waste sector to avoid double-counting. Research is underway to collect data on energy recovery from the combustion of industrial waste other than alternative fuel for cement kiln. Once national statistics on energy recovery at waste-to-energy facilities are complete and available, associated emissions will be reported under the Energy sector after the verification process by experts on the time-series consistency.

4) Calorific Value

Fuel consumption data from the *Energy Supply and Demand Statistics* which were based on gross calorific value were converted to net calorific value. Conversion factors were calculated using the ratio of net calorific value (NCV) to gross value per fuel type of which country-specific net and gross calorific values (GCV) were available in the *Enforcement Rule*[13] (see Table 3-14).

For fuels of which country-specific gross and net calorific values were not available, conversion factors suggested by International Energy Agency (IEA) were used, or calculated using calorific conversion factors. Conversion factors of some fuels were obtained by using calorific conversion factors of gross and net calorific values reported in the K-ETS information system. The remaining fuels of which conversion factors cannot be obtained using the aforementioned methods were derived by applying country-specific calorific values of domestic fuels that were similar in properties (see Table 3-15).

| Table 3-14 | Country-Specific Calorific Values

(Unit: MJ)

Fuel Type[1]			Unit	1990-2006	2007-2011		2012-2016		2017-2021		2022	
				GCV	GCV	NCV	GCV	NCV	GCV	NCV	GCV	NCV
Petroleum	Crude oil		kg	41.9	45.0	42.3	44.9	42.2	45	42.2	45.7	42.8
	Gasoline[2]		L	34.8	33.5	31.0	32.6	30.3	32.7	30.4	32.4	30.1
	Boiler kerosene[3]		L	36.4	37.5	35.0	36.8	34.3	36.7	34.2	36.6	34.1
	Indoor kerosene		L	36.4	36.8	34.3						
	Diesel		L	38.5	37.9	35.4	37.7	35.3	37.8	35.2	37.8	35.3
	Biodiesel[4]		L	38.5	37.9	35.4	37.7	35.3	37.8	35.2	34.7	32.3
	B-A		L	39.4	38.9	36.6	38.9	36.4	39.0	36.4	39.0	36.5
	B-B		L	40.6	40.4	38.1	40.5	38.0	40.5	38.0	40.6	38.1
	B-C		L	41.4	41.4	39.1	41.6	39.2	41.7	39.2	41.8	39.3
	Propane		kg	50.2	50.4	46.3	50.4	46.3	50.4	46.3	50.2	46.2
	Butane		kg	49.4	49.6	45.7	49.6	45.6	49.5	45.7	49.3	45.5
	Naphtha		L	33.5	33.7	31.2	32.3	30.0	32.3	29.9	32.2	29.9
	White spirit & SBP		L	34.3	33.3	30.8	33.3	31.0	32.8	30.3	32.8	30.4
	Jet Fuel	JET A-1[5]	L	36.4	36.6	34.3	36.5	34.1	36.5	33.9	36.5	34.0
		JP-4	L	35.6								
	Bitumen		kg	41.9	41.4	39.1	41.5	39.2	41.4	39.2	41.4	39.0

13) Annex of the *Enforcement Rule of the Energy Act* (Ordinance of the Ministry of Trade, Industry and Energy (MOTIE))

Fuel Type[1]		Unit	1990-2006	2007-2011		2012-2016		2017-2021		2022	
			GCV	GCV	NCV	GCV	NCV	GCV	NCV	GCV	NCV
	Lubricants	L	39.4	38.7	36.2	39.8	37.0	40.0	37.3	39.6	37.0
	Petroleum coke	kg	45.2	33.9	32.9	33.5	31.6	35.0	34.2	34.9	34.2
	By-product fuel oil No. 1	L	37.0	37.0	35.0	36.9	34.3	37.1	34.6	37.3	34.8
	By-product fuel oil No. 2	L	40.6	40.6	38.5	40.0	37.9	39.9	37.7	39.9	37.7
Gas	Natural gas(LNG)	kg	54.4	54.5	49.2	54.6	49.3	54.7	49.4	54.7	49.4
	City gas (LNG)	Nm³	44.0	44.2	40.0	43.6	39.4	43.1	38.9	42.7	38.5
	City gas (LPG)	Nm³	62.8	62.8	57.8	62.8	57.7	63.6	58.4	63.4	58.3
Coal	Domestic anthracite	kg	18.8	19.5	19.3	18.9	18.6	19.8	19.4	19.7	19.4
	Imported Anthracite (Fuel)	kg	25.1	27.4	26.8	21.0	20.6	21.2	20.5	23.0	22.3
	Imported Anthracite (Feedstock)					24.7	24.4	25.2	24.7	25.8	25.3
	Coking Coal	kg	27.6	26.0	24.9	25.8	24.7	24.8	23.7	24.6	23.3
	Other Bituminous			29.3	28.3	29.3	28.2	29.2	28.0	29.4	28.3
	Sub-bituminous Coal	kg	22.4	22.4	20.9	22.7	21.4	21.4	19.9	20.6	19.1
	Coke	kg	27.2	29.5	29.3	29.1	28.9	29.0	28.9	28.6	28.5
Other	Firewood and charcoal[6]	kg	18.8	18.8	18.8	18.8	18.8	18.8	18.8	18.8	18.8

Source: *Annex of the Enforcement Rule* of the *Energy Act*

Note: 1) For fuels of which country-specific calorific values were not available, default values suggested by IEA were applied (e.g. coal tar, peat, refinery gas, paraffin wax), or values from similar fuels were used (e.g. lignite, patent fuels, refinery feedstock, aviation gasoline, JP-8, other oil products).

2) The values of gasoline were used for aviation gasoline (AVI-G).

3) As the relevant policy on the supply of boiler kerosene was abolished in 2011, the values of indoor kerosene were used instead from 2012 onward.

4) The values of diesel were used for biodiesel until 2021 as no calorific value was available.

5) The values of JET A-1 were used for JP-8.

6) A conversion factor of 1 was used for firewood and charcoal which also applies to industrial waste. municipal waste, solid biomass, biogas, landfill gas and charcoal.

| Table 3-15 | Calorific Values and Conversion Factors

Fuel Type		Gross Calorific Value (MJ/kg)	Net Calorific Value (MJ/kg)	Conversion Factor (MJ/MJ)[1)]
Petroleum Fuels	Paraffin wax	42.0	39.9	0.950
	Refinery gas	52.0	47.6	0.915
Coal Fuels	COG	38.1	33.9	0.889
	BFG	2.7	2.7	0.982
	Other recovered gases[2)]	4.3	4.0	0.942
	Peat, Coal tar	-	-	0.95

Note: 1) Conversion factors in full decimal number were used.
2) The values of other recovered gases were used for FINEX gas. When using Tier 2 methodology (e.g. coke ovens, blast furnaces), gross calorific value was used.
Source: (For Petroleum Fuels) *Oil Information*, IEA (2019); (For Coke oven gas, Blast furnace gas, Other recovered gases) K-ETS data, MOE; (For Peat, Coal tar) *Energy Supply and Demand Statistics*, KEEI

3.2.4.2.2 Non-CO_2 Gases (CH_4 and N_2O)

1) Method

Non-CO_2 emissions from the energy industries were estimated using either the Tier 1 or Tier 2 methodology in accordance with the *2006 IPCC Guidelines*. For public electricity and heat production, the Tier 2 was applied.[14)] Both Tier 1 and Tier 2 methodologies estimate emissions by multiplying the consumption of fuel used for energy by the joule-to-toe conversion factor, calorific value conversion factor and emission factor. Under Tier 2, the Tier 1 default emission factors were replaced by country-specific emission factors.

CH_4 and N_2O emissions from energy industries

※ Excluding coke production

$$E_k = \sum_{ijk}\left[FC_{ijk} \times 41.868 \times CF_i \times EF_{i,k} \times 10^{-6}\right]$$

E : emissions (kt CH_4, kt N_2O)
FC : total fuel consumption (ktoe)
41.868 : Joule-toe conversion factor (TJ/ktoe)
CF : conversion factor (Net calorific value/Gross calorific value)
EF : emission factors (kg CH_4/TJ, kg N_2O/TJ)
i : fuel type
j : subcategory or subsector under 1.A.1
k : Type of gas (CH_4, N_2O)

Source: *2006 IPCC Guidelines, Vol.2, Ch.2, Equation 2.1*

14) Based on expert review, the Tier 1 methodology was applied for the 1990 to 2016 time series until non-CO_2 country-specific emission factors were developed and have been applied using the Tier 2 methodology since 2017.

CH_4 emissions from coke production were estimated by using coke production and the default emission factor in accordance with the Tier 1 methodology of the *2006 IPCC Guidelines.*

CH_4 emissions from coke production

$$E = Coke \times 41.868 \times 10^{-6} \times EF$$

E : emissions (kt CH_4)

Coke : domestic coke production (ktoe)

41.868 : Joule−toe conversion factor (TJ/ktoe)

EF : emission factor (kg CH_4/TJ)

Source: *2006 IPCC Guidelines, Vol.3, Ch.4, Equation 4.1*

2) Emission Factor

Default emission factors from the *2006 IPCC Guidelines* were applied to petroleum refining and manufacture of solid fuels and other energy industries.[15] For public electricity and heat production, both default emission factors from the *2006 IPCC Guidelines* and country−specific emission factors were applied.

| Table 3−16 | CH_4 and N_2O Emission Factors for Energy Industries

(Unit: kg/TJ)

Fuel Type		CH_4	N_2O
Coal		1	1.5
Petroleum		3	0.6
Gas[1)]		1	0.1
Waste	Municipal waste (non−renewable)	30	4
	Industrial waste	30	4
Biomass	Other solid biomass	30	4
	Liquid biomass	3	0.6
	Gaseous biomass	1	0.1

Note: 1) Emission factors of gas were applied for petroleum−based gases including refinery gas, propane and butane, and coal−based gases including coke oven gas and blast furnace gas.

Source: *2006 IPCC Guidelines, Vol.2, Ch.2, Table 2.2*

15) The unit of default emission factor from the *2006 IPCC Guidelines* (CH_4/t) was converted to kg CH_4/TJ by applying the country−specific gross calorific value for coke (toe/t) and the joule conversion factor (TJ/toe).

| Table 3-17 | CH_4 and N_2O Emission Factors for Public Electricity and Heat Production[1)]

(Unit: kg/TJ)

Fuel Type	CH_4	N_2O
Coal[2)]	0.25	1.66
Petroleum	0.15	1.75
Gas[3)]	0.41	1.06

Note: 1) Default emission factors from the *2006 IPCC Guidelines* were used from the 1990 to 2016 time period.
2) For solid waste and biomass such as municipal waste and solid biomass, emission factors of coal were applied based on expert judgment.
3) Emission factors of gas were applied for petroleum-based gases including refinery gas, propane and butane, coal-based gases including coke oven gas and blast furnace gas. and gaseous biomass including biogas and landfill gas.

Source: *2017 Country-specific Emission Factors*, Greenhouse Gas Inventory and Research Center of Korea (GIR)

3) Activity Data

Fuel consumption data from the *Energy Supply and Demand Statistics* were used.

3.2.4.3 Uncertainty Assessment and Time-series Consistency

3.2.4.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

3.2.4.3.2 Time-series Consistency

Fuel consumption data from the *Energy Supply and Demand Statistics* were used for the energy industries from 1990 through 2022 to ensure time-series consistency.

For the 1990 through 1996 time period where there were data gaps on fuel consumption of some fuels including refinery gas and B-C oil reported under the subcategory of petroleum refining, the surrogate method was applied.

To ensure time-series consistency, emissions from catalyst regeneration reported under the petroleum refining were estimated using a linear regression model for the years prior to 2007 until K-ETS data have become available. From 2007 onward, respective emissions were calculated using K-ETS data.

For carbon emission factors for coke production in the energy industries, country-specific factors were used throughout the entire time series.

For other sources of CO_2 emissions, default emission factors from the *2006 IPCC*

Guidelines were applied based on expert judgment for the years prior to 2007. From 2007 onward, country-specific emission factors have been applied.

For city gas, B-A oil and B-B oil, weighted averages of default emission factors based on the ratio of feedstock inputs in the 1990 through 2006 time period were used until country-specific factors have been applied from 2007.

For CH_4 and N_2O, default emission factors from the *2006 IPCC Guidelines* were applied throughout the entire time series. Country-specific emission factors for public electricity and heat production have been applied since 2017.

3.2.4.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

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

3.2.5.1 Category Description

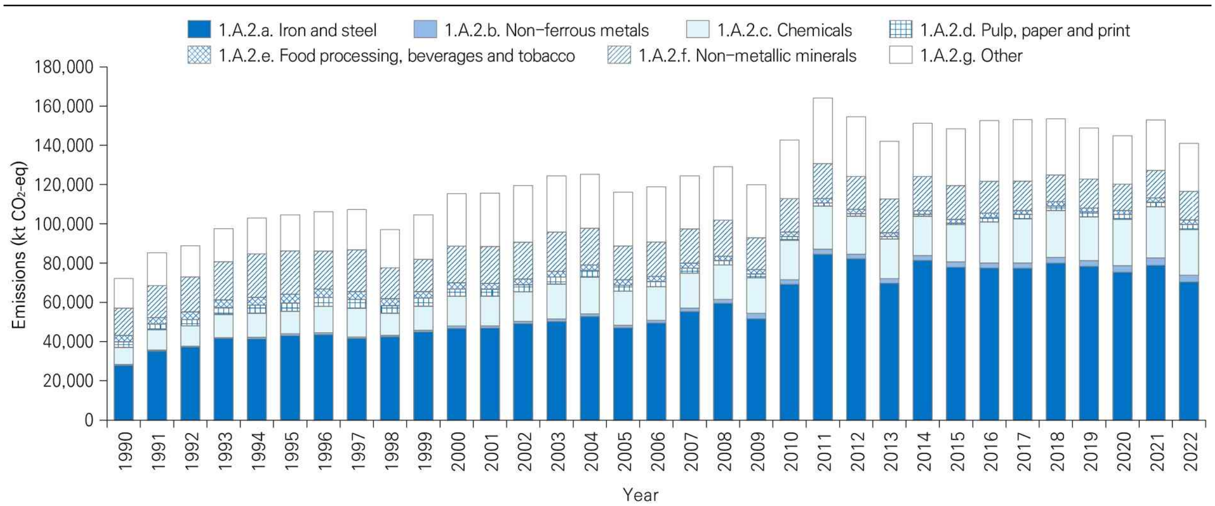
2022	Gas	Methodology	Emission Factor	Activity Data
	CO_2	Tier 1, 2	D, CS	Fuel consumption
	CH_4, N_2O	Tier 1	D, OTH	

Emissions from the Manufacturing industries and construction (1.A.2.)[16] are reported under the following subcategories: Iron and steel (1.A.2.a.), Non-ferrous metals (1.A.2.b.), Chemicals (1.A.2.c.), Pulp, paper and print (1.A.2.d.), Food processing, beverages and tobacco (1.A.2.e.), Non-metallic minerals (1.A.2.f.), and Other (1.A.2.g.). The subcategory of Other (1.A.2.g.) includes emissions from Manufacturing of machinery (1.A.2.g.i.), Manufacturing of transport equipment (1.A.2.g.ii.), Mining (excluding fuels) and quarrying (1.A.2.g.iii.), Wood and wood products (1.A.2.g.iv.), Construction (1.A.2.g.v.), Textiles and leather (1.A.2.g.vi.), and Other manufacturing activities (1.A.2.g.viii.). Fuel consumption of Off-road vehicles and other machinery (1.A.2.g.vii.) which was not disaggregated in national statistics were included in subcategories of the Manufacturing industries and construction (1.A.2.).

16) Includes emissions from fuel combustion for electricity and heat production for their own use as well as from non-stationary fuel combustion sources such as mobile machinery, transport equipment and vehicles.

In 2022, emissions from manufacturing industries and construction were 140,999 kt CO_2−eq, a 7.8 percent decrease from 2021. Iron and steel contributed 49.9 percent emitting 70,329 kt CO_2−eq, followed by Other (1.A.2.g.) accounting for 17.3 percent with 24,448 kt CO_2−eq, chemicals contributing 16.5 percent with 23,239 kt CO_2−eq and 10.4 percent from non−metallic minerals with emissions of 14,601 kt CO_2−eq. The remaining subcategories of non−ferrous metals, pulp, paper and print, and food processing, beverages and tobacco accounted for 2.5 percent (3,490 kt CO_2−eq), 1.9 percent (2,673 kt CO_2−eq), and 1.6 percent (2,219 kt CO_2−eq) respectively.

Emissions from the manufacturing industries and construction in 2022 increased by 95.4 percent from 1990, primarily due to the increased energy−intensive industries and overall industrial growth. During the same period, gross domestic product (GDP) from the mining, quarrying and manufacturing industries increased by 507.2 percent[17] with exports accounting for 32.7 percent[18] of GDP. As a significant portion of fuel was used by energy−intensive industries such as iron and steel, petrochemicals, and cement, the manufacturing industries and construction significantly contributed to the increase in greenhouse gas emissions.



| Figure 3−7 | Trends in Emissions from Manufacturing Industries and Construction (1990−2022)

17) From 86,832 billion KRW in 1990 to 532,671 billion KRW in 2022 (Source: *Real GDP and real GNI in chained 2015 KRW, National Accounts,* Bank of Korea (Accessed on April 15, 2024)

18) *Analysis of the National Economic Contribution of Exports*, Korea International Trade Association (KITA) (2024)

| Table 3-18 | Emissions from Manufacturing Industries and Construction

(Unit: kt CO_2-eq)

Sub-category	1990	2000	2010	2018	2021	2022
1.A.2.a. Iron and Steel	27,836	46,669	69,271	79,998	78,916	70,329
1.A.2.b. Non-Ferrous Metals	550	1,174	2,218	2,927	3,766	3,490
1.A.2.c. Chemicals	8,583	15,119	20,119	23,795	25,985	23,239
1.A.2.d. Pulp, Paper and Print	2,884	3,861	1,879	2,292	2,372	2,673
1.A.2.e. Food, Beverages and Tobacco	3,314	3,150	2,320	2,170	2,112	2,219
1.A.2.f. Non-Metallic Minerals	13,956	18,587	17,059	13,685	14,101	14,601
1.A.2.g. Other	15,047	26,841	29,888	28,677	25,681	24,448
1.A.2.g.i. Manufacturing of Machinery	2,009	3,229	2,461	3,491	4,093	4,236
1.A.2.g.ii. Manufacturing of Transport Equipment	757	2,936	2,076	2,447	2,254	2,239
1.A.2.g.iii. Mining (excl. fuels) and quarrying	439	152	195	122	132	124
1.A.2.g.iv. Wood and Wood Products	221	262	221	164	132	140
1.A.2.g.v. Construction	1,657	1,415	2,537	2,218	2,035	1,966
1.A.2.g.vi. Textiles and Leather	6,204	10,564	6,858	4,961	4,368	4,233
1.A.2.g.vii. Off-road vehicles and other machinery	IE	IE	IE	IE	IE	IE
1.A.2.g.viii. Other	3,759	8,285	15,540	15,274	12,666	11,509
Total	72,169	115,401	142,754	153,545	152,932	140,999

3.2.5.2 Methodology

3.2.5.2.1 CO_2

1) Method

CO_2 emissions from the manufacturing industries and construction were estimated following the same method used for Energy industries (1.A.1.).

2) Emission Factor

Carbon emission factors used for Energy industries (1.A.1.) were used for calculating emissions from the manufacturing industries and construction.

3) Activity Data

Fuel consumption in the *Energy Supply and Demand Statistics* were used.

| Table 3-19 | Activity Data Source for Manufacturing Industries and Construction

Period	Activity Data	Name of Statistics	Published by	Gas
1990-2022	Fuel consumption	*Energy Supply and Demand Statistics*	Korea Energy Economics Institute (KEEI)	CO_2, CH_4, N_2O

| Table 3-20 | Fuel Consumption in Manufacturing Industries and Construction

(Unit: ktoe)

Fuel Type	1990	2000	2010	2018	2021	2022
Solid fuels	6,089.3	12,159.0	17,642.7	19,103.4	18,163.1	16,150.5
Liquid fuels	11,214.8	12,395.2	7,574.5	4,509.2	4,511.5	4,748.4
Gaseous fuels	239.4	3,502.8	8,284.9	9,624.3	9,896.3	9,805.6
Biomass	NO	186.1	455.4	1,781.9	2,091.6	1,919.1
Other fossil fuels[1)]	NO	269.7	507.4	1,049.3	1,165.2	1,313.8
Total	**17,543.5**	**28,512.8**	**34,464.9**	**36,068.0**	**35,827.7**	**33,937.5**

Note: 1) Other fossil fuels include non-renewable municipal waste.
Source: *2024 Energy Supply and Demand Statistics*, KEEI

○ Activity Data for Autoproducers of Electricity and Heat

Emissions from autoproducers that generate electricity or heat for their own use to support their primary activity and not for public supply were assigned to the sector where they were generated. Fuel consumption by autoproducers in the manufacturing industries and construction were included in this subcategory.

○ Other (Waste Incineration with Energy Recovery)

In accordance with the *2006 IPCC Guidelines,* emissions from energy recovery in waste incineration shall be reported under the Energy sector. Accordingly, emissions from the combustion of municipal waste and industrial waste (alternative fuel for cement kiln) for energy recovery at waste-to-energy facilities were reported under the Energy sector. Emissions from incineration of all other wastes with and without energy recovery were reported under the Waste sector to avoid double-counting. Research is underway to collect data on energy recovery from the combustion of industrial waste other than alternative fuel for cement kiln. Once national statistics on energy recovery at waste-to-energy facilities are complete and available, associated emissions will be reported under the Energy sector after the verification process by experts on the time-series consistency.

3.2.5.2.2 Non-CO_2 Gases (CH_4 and N_2O)

1) Method

Non-CO_2 emissions from the manufacturing industries and construction were estimated following the same method used for Energy industries (1.A.1.).

2) Emission Factor

CH_4 and N_2O default emission factors from the *2006 IPCC Guidelines* were used for the manufacturing industries and construction as shown in Table 3-21. According to the *Energy Consumption Survey*[19], gasoline, diesel, propane and butane were also used for mobile purposes. To reflect such use of fuels, default emission factors were calculated as described below.

| Table 3-21 | CH_4 and N_2O Emission Factor for Manufacturing Industries and Construction

(Unit: kg/TJ)

Fuel Type		CH_4 Emission Factor	N_2O Emission Factor
Coal		10	1.5
Petroleum		3	0.6
Gas[1]		1	0.1
Waste	Municipal waste	30	4
	Industrial waste	30	4
Biomass	Other solid biomass	30	4
	Liquid biomass	3	0.6
	Gaseous biomass	1	0.1

Note: 1) For petroleum-based gases and coal-based gases, emission factors of gas were applied.
Source: *2006 IPCC Guidelines, Vol.2, Ch.2, Table 2.3*

○ Emission Factors for Gasoline, Diesel, Propane and Butane

Using data from the *Energy Consumption Survey,* the share of stationary combustion and transport use of fuel consumption of gasoline, diesel, propane and butane was calculated per subcategory.[20] As the survey is conducted every three years, interpolation was used to calculate the values for years in which data were not collected.

19) The *Energy Consumption Survey* is conducted every three years to identify energy consumption patterns across sectors including agriculture, forestry and fisheries, construction, transportation, commercial and public services, and buildings. It provides more detailed data by industry and purpose (e.g. transport, feedstock, equipment) than the *Energy Supply and Demand Statistics* (KEEI) and thus is used as supplementary data for estimating the national greenhouse gas emissions.

20) Includes fuel consumed by transport equipment, vehicles for transporting goods and shipping.

Default emission factors for stationary combustion and road transportation[21] from the *2006 IPCC Guidelines* were adjusted to obtain the weighted average using the share of fuel consumption by stationary and transport use which were used as emission factors for each subcategory and fuel type.

3) Activity Data

Fuel consumption data from the *Energy Supply and Demand Statistics* were used.

3.2.5.3 Uncertainty Assessment and Time-series Consistency

3.2.5.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

3.2.5.3.2 Time-series Consistency

Activity data from the *Energy Supply and Demand Statistics* were used across the entire time series to ensure time-series consistency. Emissions were estimated using the same emission factors and methodology as Energy industries (1.A.1.).

3.2.5.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

3.2.5.5 Planned Improvements

ROK is exploring the potential to develop country-specific emission factors for non-fossil fuels of which most are non-renewable municipal wastes.

3.2.6 Transport (1.A.3.)

3.2.6.1 Category overview

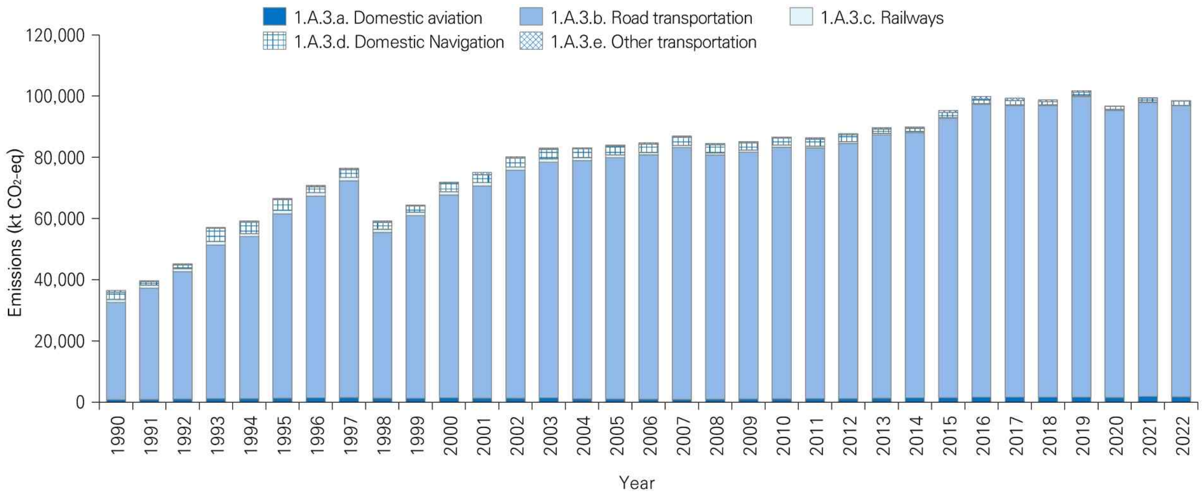
Emissions from transport are reported under subcategories including Domestic aviation

21) Fuel consumption for transportation includes all fuels used for transport activities including transport equipment, vehicles for transporting goods and shipping. As details on the modes of transport cannot be identified, default emission factor for road transportation as suggested in the *2006 IPCC Guidelines, Vol.2, Ch.3, Table 3.2.2* was applied.

(1.A.3.a), Road transportation (1.A.3.b), Railways (1.A.3.c), Domestic navigation (1.A.3.d), and Other transportation (1.A.3.e). In accordance with the Paris Agreement, emissions from international aviation and navigation are excluded from national totals but reported as a memo item (see Section 3.2.2 International Bunkers).

In 2022, total emissions from this reporting category were 98,502 kt CO_2−eq, a 1.0 percent decrease from 2021. Road transportation was the largest source with 95,093 kt CO_2−eq, contributing 96.5 percent to total emissions from this subcategory, followed by domestic aviation with 1,744 kt CO_2−eq accounting for 1.8 percent and domestic navigation emitting 1,395 kt CO_2−eq accounting for 1.4 percent. The remaining sources of railways and other transportation produced emissions of 200 kt CO_2−eq and 70 kt CO_2−eq, contributing 0.2 percent and 0.1 percent respectively.

Total emissions from this subcategory in 2022 increased by 170.2 percent from 1990 which was largely contributed by increased emissions from road transportation and domestic aviation driven by increased vehicle ownership, higher freight transport volumes as well as rising air travel demand associated with economic growth.



| Figure 3−8 | Trends in Emissions from Transport (1990−2022)

| Table 3−22 | Emissions from Transport

(Unit: kt CO_2−eq)

Source	1990	2000	2010	2018	2021	2022
1.A.3.a. Domestic Aviation	824	1,408	1,137	1,594	1,833	1,744
1.A.3.b. Road Transportation	31,718	66,270	82,207	95,307	96,011	95,093
1.A.3.c. Railways	974	1,077	618	320	238	200
1.A.3.d. Domestic Navigation	2,481	2,795	2,305	1,038	1,299	1,395
1.A.3.e. Other Transportation	464	300	393	505	93	70
Total	36,461	71,850	86,660	98,764	99,474	98,502

3.2.6.2 Domestic Aviation (1.A.3.a.)

3.2.6.2.1 Category Description

	Gas	Methodology	Emission Factor	Activity Data
2022	CO_2	Tier 1 (General Aviation)	CS	Fuel consumption
		Tier 2 (Civil Aviation)		Fuel consumption, number of landings and takeoffs
	CH_4, N_2O	Tier 1 (General Aviation)	D	Number of landings and takeoffs
		Tier 2 (Civil Aviation)		Fuel consumption, number of landings and takeoffs

Under domestic aviation, emissions from flights that depart and arrive in the same country are reported whereas international aviation includes emissions from aircrafts that depart in one country and arrive in a different country as described in Section 3.2.2. Domestic Aviation distinguishes between general aviation and civil aviation. General aviation refers to small corporate aircraft that is not included in civil aviation, non-passenger purpose aircraft, and aircraft and helicopters operated by the government. Civil aviation comprises domestic aircraft for the commercial transport of passenger and freight.

In 2022, emissions from domestic aviation were 1,744 kt CO_2-eq, a 4.8 percent decrease from 2021, accounting for 1.8 percent of total emissions from transport. Civil aviation contributed 96.6 percent emitting 1,685 kt CO_2-eq while general aviation accounted for 3.4 percent with 59 kt CO_2-eq. From 1990, emissions from domestic aviation increased by 111.7 percent, driven by economic growth and an increase in domestic travel and air freight.

| Table 3-23 | Emissions from Domestic Aviation

(Unit: kt CO_2-eq)

Source	1990	2000	2010	2018	2021	2022
General Aviation	13	16	32	38	43	59
Civil Aviation	811	1,393	1,105	1,556	1,790	1,685
Total	824	1,408	1,137	1,594	1,833	1,744

3.2.6.2.2 Methodology

1) Method

For general aviation, emissions were estimated using a Tier 1 methodology in accordance with available data on total fuel consumption. For civil aviation, a Tier 2 methodology was used to distinguish between emissions from the landing and take−off (LTO) cycle[22] and from cruise.[23] The *2006 IPCC Guidelines* note that CH_4 emissions in the cruise mode are negligible and are assumed to be zero.[24]

CO_2 emissions from general aviation	
$$E = \Sigma_i \left[FC_i \times 41.868 \times CF_i \times EF_i \times OF_i \times 44/12 \times 10^{-3} \right]$$	
E	CO_2 emissions (kt CO_2)
FC	fuel consumption (ktoe) = fuel consumption of general aviation(L) × 1bbl/158.984L × unit conversion factor (toe/bbl) × 10^{-3}
41.868	joule−toe conversion factor (TJ/ktoe)
CF	conversion factor (net calorific value/gross calorific value)
EF	emission factor (t C/TJ)
OF	oxidation factor
44/12	conversion of carbon emissions to CO_2 emissions (kg CO_2/kg C)
i	fuel type

Source: *2006 IPCC Guidelines, Vol.2, Ch.3, Equation 3.6.1*

CH_4 and N_2O emissions from general aviation	
$$E = \Sigma_{ij} \left[FC_i \times 41.868 \times CF_i \times EF_{ij} \times 10^{-6} \right]$$	
E	emission (kt CH_4, kt N_2O)
FC	fuel consumption (ktoe) = Fuel consumption of general aviation (L) × 1 bbl / 158.984 L × unit conversion factor (toe/bbl) × 10^{-3}
41.868	joule−toe conversion factor (TJ/ktoe)
CF	conversion factor (net calorific value/gross calorific value)
EF	emission factor (kg CH_4/TJ, kg N_2O/TJ)
i	fuel type
j	gas type (CH_4, N_2O)

Source: *2006 IPCC Guidelines, Vol.2, Ch.3, Equation 3.6.1*

22) Flight activity of reaching cruising altitude above 3,000 feet (914 metres) after take−off
23) Aircraft operation at altitudes above 3,000 feet (914 metres)
24) *2006 IPCC Guidelines, Vol.2, Ch.3, p.3.64*

Emissions from civil aviation

$$E_i = \Sigma_j\left[\left(LTO_j \times EF_{LTO_{ij}}\right) + \left(A_{cruise} \times \frac{LTO_j}{LTO_{Total}} \times EF_{cruise_i}\right)\right],$$

$$A_{cruise} = \Sigma_j\left(A_{Total_j} \times 0.7950 \times CF\right) - \Sigma_j\left(LTO_j \times A_{LTO_j}\right)$$

E	emission (kg CO_2, kg CH_4, kg N_2O)
LTO	landing & take-off
EF_{LTO}	LTO Emission Factor (kg/LTO)
A_{cruise}	fuel consumption during cruise (t)
EF_{cruise}	emission factor for cruise (kg/t)
A_{total}	total fuel consumption for LTO and cruise (kl)
0.7950[1)]	density of jet kerosene (t/kl) 1) Source: *Korea Automobile Testing and Research Institute (2012)*
CF	conversion factor (net/gross calorific value)
A_{LTO}	fuel consumed during LTO (t/LTO)
i	gas type (CO_2, CH_4, N_2O)
j	aircraft type

Source: *2006 IPCC Guidelines, Vol.2, Ch.3, Equation 3.6.2-3.6.5*

2) Emission Factor

General aviation used the same carbon emission factors as for Energy industries (1.A.1.). For CH_4 and N_2O, default emission factors from the *2006 IPCC Guidelines* were applied throughout the entire time series.

For civil aviation, emission factors were distinguished between the landing and take-off (LTO) cycle and cruise. For LTO cycle, default emission factors by aircraft type from the *2006 IPCC Guidelines* were applied as described in Table 3-26. For aircraft types not available in the *2006 IPCC Guidelines,* emission factors of similar aircraft with comparable engine types and thrust levels were applied based on expert judgement.

For the cruise phase, CO_2 emissions were estimated by converting country-specific emission factors to the corresponding unit. For the period from 1990 to 2006, when country-specific emission factors were not available, default emission factors from the *2006 IPCC Guidelines* were used. A default emission factor from the *2006 IPCC Guidelines* was applied across the entire time series for N_2O emissions.

| Table 3-24 | Emission Factors for General Aviation

Fuel	CO_2(t C/TJ)					CH_4 (kg/TJ)	N_2O (kg/TJ)
	1990-2006	2007-2011	2012-2016	2017-2021	2022-present		
Aviation Gasoline	18.9	19.7	20.0	19.548	19.731	0.5	2.0
Jet-type Aviation Fuel	19.5	19.6	19.8	19.931	19.956		

Note: Country-specific emission factors in grey shaded cells (▭)
Source: *2006 IPCC Guidelines, Vol.2, Ch.1, Table 1.4 and Ch.3, Table 3.6.5*

| Table 3-25 | Emission Factors for Civil Aviation (Cruise Phase)[1)]

Source	CO_2(kg/t)				CH_4 (kg/t)	N_2O (kg/t)
	1990-2006	2007-2011	2012-2016	2017-2022		
Cruise	3,150	3,101	3,114	3,116	0[2)]	0.1

Note: 1) Unit of country-specific emission factors (tC/ TJ) that was converted into kg/ t in grey shaded cells. (▭)
2) In the cruise mode, CH_4 emissions are assumed to be negligible.
Source: *2006 IPCC Guidelines, Vol.2, Ch.1, Table 1.4 and Ch.3, Table 3.6.5*

| Table 3-26 | Emission Factors and Fuel Consumption of Civil Aviation (LTO Cycle)

Aircraft Type	Emission Factor (kg/LTO)			Fuel Consumption (kg/LTO)
	CO_2	CH_4	N_2O	
A300	5,450	0.12	0.20	1,720
A320	2,440	0.06	0.10	770
A321	3,020	0.14	0.10	960
A330-200/300	7,050	0.13	0.20	2,230
A340-500/600	10,600	0.01	0.30	3,370
727-200	4,610	0.81	0.10	1,460
737-300/400/500	2,480	0.08	0.10	780
737-600	2,280	0.10	0.10	720
737-700	2,460	0.09	0.10	780
737-800/900	2,780	0.07	0.10	880
747-200	11,370	1.82	0.40	3,600
747-300	11,080	0.27	0.40	3,510
747-400	10,240	0.22	0.30	3,240
747-100	10,140	4.84	0.30	3,210
767-300	5,610	0.12	0.20	1,780
777-200/300	8,100	0.07	0.30	2,560
DC-10	7,290	0.24	0.20	2,310
DHC8-100	640	0.00	0.02	200
Fokker100/70/28	2,390	0.14	0.10	760
Gulfstream Ⅳ	2,160	0.14	0.10	680
MD-11	7,290	0.24	0.20	2,310

Source: *2006 IPCC Guidelines, Vol.2, Ch.3, Table 3.6.9*

3) Activity Data

Fuel consumption was used as activity data for both general and civil aviation. Data on the number of LTO by aircraft type were additionally used for civil aviation. Data are compiled annually by Korea Transportation Safety Authority based on aircraft registration information managed by Ministry of Land, Infrastructure and Transport (MOLIT). As fuel consumption for general aviation have been collected since 2009, activity data for the 1990 to 2008 time period were calculated based on expert judgement as described in Table 3-27.

In 2022, domestic aviation consumed 741.9 Ml of fuel, decreasing by 5.5 percent from 2021. The number of LTO of civil aviation was 219,000, increasing by 3.8 percent from 2021.

| Table 3-27 | Fuel Consumption of General Aviation (1990-2008)

No. of registered general aviation fleet
= total no. of registered aviation fleet[1] − no. of registered civil fleet (flag carrier)[2]

Fuel consumption of general aviation
= annual fuel consumption (kL/fleet)[3] × no. of registered general aviation fleet per year

Fuel consumption of general aviation fleet by fuel type
= fuel consumption of general aviation fleet (1990-2008) × the share of consumed fuel per fuel type[4]

Note: 1) Data from Ministry of Land, Infrastructure and Transport (MOLIT)
2) Data from Korea Civil Aviation Promotion Association (KCA) and Korea Transportation Safety Authority (TS)
3) Fuel consumption per fleet was calculated for the years 1990-2008 by applying the average annual rate of change (−2.5%) observed from 2009 to 2013.
4) The share of consumed fuel per fuel type (JET A-1, JP-8, aviation gasoline) for general aviation aircraft in 2009

| Table 3-28 | Activity Data Source for Domestic Aviation

Period	Activity Data	Name of Statistics	Published by	Gas
1990-2022	General aviation fuel consumption	*Fuel consumption*	Korea Transportation Safety Authority (TS)	CO_2 CH_4 N_2O
	Civil aviation fuel consumption	*Fuel consumption*		
	Number of LTO for civil aviation	*Number of LTO*		

| Table 3-29 | Fuel Consumption and LTO in Domestic Aviation

(Unit: million L (fuel consumption); Thousand LTO)

Fuel Type		1990	2000	2010	2018	2021	2022
Jet kerosene	Civil	341.6	586.8	470.1	666.7	767.4	718.2
	General	5.1	6.0	12.0	13.5	15.8	21.9
Aviation gasoline		0.4	0.5	0.7	1.8	1.6	1.8
Total consumption		347.1	593.2	482.8	682.0	784.8	741.9
No. of LTO		86.1	166.3	148.7	196.3	210.8	218.7

Note: Fuel consumption calculated for the 1990 through 2008 period in grey shaded cells (▭)

Source: Korea Transportation Safety Authority (TS)

3.2.6.2.3 Uncertainty Assessment and Time-series Consistency

3.2.6.2.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

3.2.6.2.3.2 Time-series Consistency

Emissions from domestic aviation were estimated using activity data collected from aircraft operators across the entire time series and used methodologies consistently. For general aviation, fuel consumption from the 1990 to 2008 time period for which data were not available was calculated based on expert judgement. For CO_2, country-specific emission factors were applied from 2007 onward, and default emission factors were used for the 1990 to 2006 time period in which country-specific values were not available based on expert judgment. For CO_2 (LTO), CH_4 and N_2O, default emission factors from the *IPCC Guidelines* were applied across the entire time series.

3.2.6.2.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

3.2.6.3 Road Transportation (1.A.3.b.)

3.2.6.3.1 Category Overview

2022	Gas	Methodology	Emission Factor	Activity Data
	CO_2	Tier 1, 2, OTH	D, CS	Fuel consumption
	CH_4, N_2O	Tier 1	D, OTH	

Under the reporting subcategory of road transportation, emissions from fuel combustion in road vehicles such as passenger cars, light- and heavy-duty trucks, buses and motorcycles are reported. In *Annual Oil Statistics* which was used as activity data for this subcategory, fuel consumption was divided by fuel type, not by vehicle type. Accordingly, emissions from Light duty trucks (1.A.3.b.ii.), Heavy duty trucks and buses (1.A.3.b.iii.) and Motorcycles (1.A.3.b.iv.) were included in the subcategory of Cars (1.A.3.b.i.).

In 2022, emissions from road transportation were 95,093 kt CO_2-eq, representing a 1.0 percent decrease from 2021, and contributed 96.5 percent of total emissions from the Transport sector (1.A.3.). An increase of 199.8 percent from 1990 was observed, primarily due to industrialisation and urbanisation which led to a rise in the number of vehicles, travelling distance and freight traffic volumes.

| Table 3-30 | Emissions from Road Transportation

(Unit: kt CO_2-eq)

Source	1990	2000	2010	2018	2021	2022
Road Transportation	31,718	66,270	82,207	95,307	96,011	95,093

3.2.6.3.2 Methodology

1) Method

Emissions from road transportation used the same method as Energy industries (1.A.1.) as described in Sections 3.2.4.2.1 to 3.2.4.2.2.[25]

CO_2 emissions from road transportation

$$E = \sum_i \left[FC_i \times 41.868 \times CF_i \times EF_i \times OF_i \times 44/12 \times 10^{-3} \right]$$

E : CO_2 emission (kt CO_2)

FC : fuel consumption (ktoe)

41.868 : joule-toe conversion factor (TJ/ktoe)

CF : conversion factor (net/gross calorific value)

EF : emission factor (t C/TJ)

OF : oxidation factor (1)

44/12 : conversion of carbon emissions to CO_2 emissions (kg CO2/kg C)

i : fuel type

Source: *2006 IPCC Guidelines, Vol.2, Ch.3, Equation 3.2.1*

25) CO_2 emissions were estimated using Tier 1 methodology from the 1990 to 2006 time period and Tier 2 methodology from 2007 onward whereas non-CO_2 emissions were estimated using Tier 1 methodology for the entire time series.

CH$_4$ and N$_2$O emissions from road transportation

$$E_k = \sum_{ij}\left[FC_i \times 41.868 \times CF_i \times EF_{ij} \times 10^{-6}\right]$$

E	:	emission (kt CH$_4$, kt N$_2$O)
FC	:	total fuel consumption (ktoe)
41.868	:	joule-toe conversion factor (TJ/ktoe)
CF	:	conversion factor (net/gross calorific value)
EF	:	emission factor (kg CH$_4$/TJ, kg N$_2$O/TJ)
i	:	fuel type
j	:	gas type (CH$_4$, N$_2$O)

Source: *2006 IPCC Guidelines, Vol.2, Ch.3, Equation 3.2.3*

CO$_2$ emissions resulting from the use of urea-based catalysts were estimated using the methodology provided in the *2006 IPCC Guidelines.*

CO$_2$ emissions from urea-based catalytic converters

$$E = AD \times 12/60 \times Purity \times 44/12$$

E	:	CO$_2$ emission (kt CO$_2$)
AD	:	amount of urea-based additive used in catalytic converters (kt)
12/60	:	stoichiometric conversion factor from urea to carbon
Purity	:	mass fraction of urea in the additive (%), 32.5%
44/12	:	conversion from carbon-based emissions to CO$_2$-based emissions (kt CO$_2$/kt C)

Source: *2006 IPCC Guidelines, Vol.2, Ch.3, Equation 3.2.2*

2) Emission Factor

Carbon emission factors used for Energy industries (1.A.1.) were used for road transportation. Default emission factors for road transportation in the *2006 IPCC Guidelines* were applied for non-CO$_2$ emissions. For city gas (LNG), a default emission factor for road transportation in the *2006 IPCC Guidelines* that were adjusted by reflecting a blend ratio of propane (LPG) and natural gas (LNG) was applied.

| Table 3-31 | CH$_4$ and N$_2$O Emission Factors for Road Transportation

(Unit: kg/TJ)

Fuel Type	CH$_4$	N$_2$O
Natural Gas (LNG)	92	3.0
Gasoline[1)]	25	8.0
Diesel[2)]	3.9	3.9
LPG	62	0.2

Note: 1) For residual fuel oil including B-A, B-B, B-C as well as kerosene and other petroleum products (e.g. lubricants, by-product fuels, other oil products), emission factors for gasoline were used.
2) For biodiesel, emission factors for diesel were used based on expert judgment.

Source: *2006 IPCC Guidelines, Vol.2, Ch.3, Table 3.2.2*

3) Activity Data

Activity data for the road transportation include the consumption of petroleum-based fuels, city gas, biodiesel, diesel exhaust fluid (urea solution) and lubricants. Petroleum fuel consumption was sourced from the *Annual Oil Statistics* while city gas and biodiesel consumption data were from the *Energy Supply and Demand Statistics.* For urea solution and lubricants, relevant statistics were used. The *Annual Oil Statistics* provide fuel consumption for road passenger transport, road freight transport and other ground transport for passengers. From the *Energy Supply and Demand Statistics,* energy use in road transport were used. In 2022, total fuel consumption was 33,705.7 ktoe, a 1.4 percent decrease from 2021.[26]

| Table 3-32 | Activity Data Source for Road Transport

Period	Activity Data	Name of Statistics	Published by	Gas
1990-2022	Petroleum consumption	*Annual Oil Statistics*	Korea National Oil Corporation (KNOC)	CO_2, CH_4, N_2O
	City gas and biodiesel consumption	*Energy Supply and Demand Statistics*	Korea Energy Economics Institute (KEEI)	
	Urea solution consumption	*Urea Solution Statistics*	Ministry of Environment (MOE)	CO_2
	Lubricant (2-cycle motor oil) sales volume	*Lubricants Industry Data*	Korea Lubricating Oil Industry Association (KLOIA)	

| Table 3-33 | Fuel Consumption in Road Transportation

(Unit: ktoe (Fuel consumption); kt (Urea solution))

Fuel Type	1990	2000	2010	2018	2021	2022
Gasoline	2,899.1	7,859.6	8,419.0	9,501.3	10,329.4	10,687.9
Diesel	6,958.3	12,122.8	14,133.2	18,908.0	19,030.1	18,320.7
LPG	1,215.9	3,437.0	5,297.3	3,674.6	3,041.6	2,987.8
Other[1)]	33.3	11.9	32.6	5.9	2.6	2.2
City Gas (LNG)	NO	NO	1,111.7	1,238.2	1,059.6	1,025.5
Biodiesel	NO	NO	357.3	685.8	704.0	681.6
Total Consumption	**11,106.7**	**23,431.3**	**29,351.1**	**34,013.8**	**34,167.3**	**33,705.7**
Urea Solution[2)]	NO	NO	NA (9.2)	NA (183.1)	NA (289.6)	NA (273.0)

Note: 1) Other includes kerosene, B-A oil, B-B oil, B-C oil, by-product fuels and lubricants.

2) While the consumption of urea solution in kilotonne (kt) is presented as shown in the Table, it was reported as 'Not Applicable (NA)' in the CRT of which the given unit is terajoule (TJ) due to the absence of a corresponding calorific value which is required for conversion of unit. Accordingly, urea solution was excluded from the total fuel consumption.

Source: *2022 Annual Oil Statistics*, KNOC; *2024 Energy Supply and Demand Statistics*, KEEI; *2023 Lubricant Industry Data,* KLOIA; *2024 Urea Solution Statistics,* MOE

26) Activity data for urea solution were provided in kilotonne. Due to the absence of a calorific value for conversion to toe, it was excluded from the total consumption.

3.2.6.3.3 Uncertainty Assessment and Time-series Consistency

3.2.6.3.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

3.2.6.3.3.2 Time-series Consistency

Emissions from road transportation were estimated using the same methodology and carbon emission factors as Energy industries (1.A.1.). And default emission factors for road transportation in the *2006 IPCC Guidelines* were applied for non-CO_2 emissions.

Activity data for petroleum products, city gas and biodiesel, and for urea solution and lubricants were sourced from the *Annual Oil Statistics, Energy Supply and Demand Statistics* as well as relevant statistics which were used consistently across the entire time series.

3.2.6.3.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

3.2.6.4 Railways (1.A.3.c.)

3.2.6.4.1 Category Overview

2022	Gas	Methodology	Emission Factor	Activity Data
	CO_2	Tier 2	CS	Fuel consumption
	CH_4, N_2O	Tier 1	D	

Emissions from railway include greenhouse gases produced by direct combustion of fossil fuels for three different types of locomotive engines: diesel, electric, and steam. Diesel locomotives and diesel multiple units use diesel engines combined with alternating current or direct current generators to produce electricity for traction motors. Electric locomotives and electric multiple units are supplied with electricity generated at power plants, and associated emissions are reported under the Energy industries. Steam locomotives are currently used only for tourism purposes.

In 2022, emissions from railway were 200 kt CO_2-eq, a 16.1 percent decrease from 2021. Between 1990 and 2022, emissions decreased by 79.5 percent, primarily due to the increased use of electric locomotives and electric multiple units which led to the reduced share of diesel locomotives and diesel multiple units, contributing a continued decline in emissions.

| Table 3-34 | Emissions from Railways

(Unit: kt CO_2-eq)

Sub-category	1990	2000	2010	2018	2021	2022
Railways	974	1,077	618	320	238	200

3.2.6.4.2 Methodology

1) Method

Emissions were estimated using the same methodology used for Energy industries (1.A.1.) as described in Sections 3.2.4.2.1 to 3.2.4.2.2.

2) Emission Factor

Carbon emission factors used for Energy industries (1.A.1.) were used for railways as described in Sections 3.2.4.2.1 to 3.2.4.2.2. For CH_4 and N_2O, default emission factors for railways in the *2006 IPCC Guidelines* were applied.

| Table 3-35 | CH_4 and N_2O Emission Factors for Railways

(Unit: kg/TJ)

Fuel Type	CH_4	N_2O
Diesel[1)]	4.15	28.6

Note: 1) Emission factors for diesel were used for gasoline, residual fuel oils (B-A, B-B, B-C), kerosene, LPG, and other oil products.

Source: *2006 IPCC Guidelines, Vol.2, Ch.3, Table 3.3.1*

3) Activity Data

Fuel consumption by railways as provided in the *Annual Oil Statistics* were used as activity data. In 2022, fuel consumption of railways were 62.8 ktoe, a 16.3 percent decrease compared to 2021.

| Table 3-36 | Activity Data Source for Railways

Period	Activity Data	Name of Statistics	Published by	Gas
1990-2022	Petroleum consumption	*Annual Oil Statistics*	Korea National Oil Corporation (KNOC)	CO_2, CH_4, N_2O

| Table 3-37 | Fuel Consumption by Railways

(Unit: ktoe)

Fuel Type	1990	2000	2010	2018	2021	2022
Diesel	299.4	335.2	194.7	100.7	75.0	62.8
Other[1)]	4.8	1.6	0.4	0.01	0.04	0.01
Total	304.2	336.8	195.1	100.7	75.0	62.8

Note: 1) Other includes gasoline, kerosene, B-B oil, B-C oil, and LPG.
Source: *2022 Annual Oil Statistics*, KNOC (2023)

3.2.6.4.3 Uncertainty Assessment and Time-series Consistency

3.2.6.4.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

3.2.6.4.3.2 Time-series Consistency

Emissions from railways were estimated using the same carbon emission factors and methodology as Energy industries (1.A.1.). Default emission factors for railways in the *2006 IPCC Guidelines* were applied for non-CO_2 emissions. Activity data were consistently sourced from the *Annual Oil Statistics* across the entire time series.

3.2.6.4.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

3.2.6.5 Domestic Navigation (1.A.3.d.)

3.2.6.5.1 Category Description

2022	Gas	Methodology	Emission Factor	Activity Data
	CO_2	Tier 1	CS	Fuel consumption
	CH_4, N_2O	Tier 1	D	

Under domestic navigation, emissions from vessels such as coastal passenger vessels, coastal cargo ships, recreational boats, hovercraft, hydrofoils, and other domestic marine transport excluding fishing vessels that depart and arrive in the same country are reported. International navigation that includes emissions from vessels that depart in one country and arrive in a different country are described in Section 3.2.2 International bunkers.

In 2022, emissions from domestic navigation were 1,395 kt CO_2-eq, representing a 7.4 percent increase from 2021. Between 1990 and 2022, emissions decreased by 43.8 percent which was largely driven by the enhanced fuel efficiency of vessels per unit of cargo and a shift toward low-carbon fuels.

| Table 3-38 | Emissions from Domestic Navigation

(Unit: kt CO_2-eq)

Sub-category	1990	2000	2010	2018	2021	2022
Domestic Navigation	2,481	2,795	2,305	1,038	1,299	1,395

3.2.6.5.2 Methodology

1) Method

Emissions from domestic navigation followed the same methodological approach as Energy industries (1.A.1.) as described in Sections 3.2.4.2.1 to 3.2.4.2.2.

2) Emission Factor

Carbon emission factors for Energy industries (1.A.1.) described in Sections 3.2.4.2.1 to 3.2.4.2.2 were used for domestic navigation. For CH_4 and N_2O emission factors, default emission factors for domestic navigation in the *2006 IPCC Guidelines* were applied. For CH_4 and N_2O emissions from LPG and LNG of which emission factors are not provided in the *2006 IPCC Guidelines,* default emission factors from road transportation were used based on expert judgement taking into account characteristics of the fuels.

| Table 3-39 | CH_4 and N_2O Emission Factors for Domestic Navigation

(Unit: kg/TJ)

Fuel Type	CH_4	N_2O
Residual Fuel Oil[1)]	7	2.0
LPG	62	0.2
LNG	92	3.0

Note: 1) Emission factor for residual fuel oil were used for gasoline, diesel and by-product fuels.
Source: *2006 IPCC Guidelines, Vol.2, Ch.3, Table 3.2.2, Table 3.5.3*

3) Activity Data

For petroleum fuels in domestic navigation, activity data on fuel consumption were sourced from the *Annual Oil Statistics.*

For LNG which was consumed by coastal vessels, data on LNG supply for domestic vessels were used. LNG is also consumed by trail operation but included in the subcategory of Other (1.A.2.g.) under the Manufacturing industries and construction (1.A.2.) as respective operation is part of the shipbuilding process.

In 2022, fuel consumption in domestic navigation was 465.9 ktoe, increasing by 8.5 percent from 2021.

| Table 3-40 | Activity Data Source for Domestic Navigation

Period	Activity Data	Name of Statistics	Published by	Gas
1990-2022	Petroleum consumption	*Annual Oil Statistics*	Korea National Oil Corporation (KNOC)	CO_2, CH_4, N_2O
	LNG supply volume of coastal vessel	*LNG supply (for ships) volume*	LNG suppliers	

| Table 3-41 | Domestic Navigation Fuel Consumption

(Unit: ktoe)

Fuel Type	1990	2000	2010	2018	2021	2022
Diesel	222.1	360.2	209.7	151.1	183.2	195.3
B-A Oil	49.5	98.6	109.1	88.4	77.4	56.7
B-B Oil	27.1	29.9	24.5	27.5	2.3	3.2
B-C Oil	517.8	435.1	427.5	65.9	160.1	204.1
Other[1)]	0.3	3.8	0.4	14.1	6.4	6.6
Total	816.8	927.7	771.2	347.0	429.4	465.9

Note: 1) Other includes gasoline, by-product fuels, LPG, and LNG.
Source: *2022 Annual Oil Statistics*, KNOC (2023); Ship-use LNG Supply Data, Marine LNG Suppliers (2024)

3.2.6.5.3 Uncertainty Assessment and Time-series Consistency

3.2.6.5.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

3.2.6.5.3.2 Time-series Consistency

Emissions from domestic navigation were estimated using the same methodology and carbon emission factors as Energy industries (1.A.1.). Default emission factors for domestic navigation in the *2006 IPCC Guidelines* were applied for non−CO_2 emissions. For CH_4 and N_2O emissions from LPG and LNG, default emission factors from road transportation were applied. Activity data were sourced from the *Annual Oil Statistics* and LNG supply data.

3.2.6.5.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

3.2.6.6 Other Transportation (1.A.3.e.)

3.2.6.6.1 Category Overview

	Gas	Methodology	Emission Factor	Activity Data
2022	CO_2	Tier 2	CS	Fuel consumption
	CH_4, N_2O	Tier 1	D	

Other transportation includes emissions from transport activities such as pipeline transport, ground activities in airports, and off−road transport activities for the operation of terminals, toll roads, and parking facilities not otherwise reported under any other subcategories.

In 2022, emissions from other transportation were 70 kt CO_2−eq, a 24.9 percent decrease from 2021. Emissions have been declining after reaching its peak in 2016 with emissions of 813.0 kt CO_2−eq. Between 1990 and 2022, emissions decreased by 85.0 percent.

| Table 3−42 | Emissions from Other Transportation

(Unit: kt CO_2−eq)

Sub−category	1990	2000	2010	2018	2021	2022
Other Transportation	464	300	393	505	93	70

3.2.6.6.2 Methodology

1) Method

Other transportation followed the same methodological approach as Energy industries (1.A.1.) as described in Sections 3.2.4.2.1 to 3.2.4.2.2.

2) Emission Factor

Carbon emission factors for other transportation were applied using the same values of carbon emission factor as used for Energy industries (1.A.1).[27] For non-CO_2 gases, default emission factors for road transportation from the *2006 IPCC Guidelines* were applied.

| Table 3-43 | CH_4 and N_2O Emission Factors for Other Transportation

(Unit: kg/TJ)

Fuel Type	CH_4	N_2O
Natural Gas (LNG)	92	3.0
Gasoline, Residual Fuel Oil[1], Kerosene	25	8.0
Diesel	3.9	3.9
LPG	62	0.2

Note: 1) Residual fuel oil includes B-A, B-B, and B-C oil.
Source: *2006 IPCC Guidelines, Vol.2, Ch.3, Table 3.2.2*

3) Activity Data

Activity data for other transportation were based on fuel consumption reported in the *Annual Oil Statistics.* Aviation fuels were excluded from other transportation to avoid double counting with Domestic aviation (1.A.3.a.) and International aviation (1.D.1.). In 2022, fuel consumption in other transportation was 23.8 ktoe, decreasing by 25.1 percent from 2021.

| Table 3-44 | Activity Data Source for Other Transportation

Period	Activity Data	Name of Statistics	Published by	Gas
1990-2022	Petroleum consumption	*Annual Oil Statistics*	Korea National Oil Corporation (KNOC)	CO_2, CH_4, N_2O

27) Default emission factors from the *2006 IPCC Guidelines* were used for the 1990 to 2006 time period. From 2007 onward, country-specific emission factors were applied.

| Table 3-45 | Fuel Consumption in Other Transportation

(Unit: ktoe)

Fuel Type	1990	2000	2010	2018	2021	2022
Gasoline	38.2	26.5	66.5	126.5	10.9	7.8
Diesel	66.7	67.6	46.4	44.0	18.8	14.2
Other[1)]	51.1	9.1	21.2	3.0	2.2	1.8
Total	**156.1**	**103.2**	**134.1**	**173.5**	**31.8**	**23.8**

Note: 1) Other includes kerosene, fuel oil, by-product fuels, and LPG.
Source: *2022 Annual Oil Statistics*, KNOC (2023)

3.2.6.6.3 Uncertainty Assessment and Time-series Consistency

3.2.6.6.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

3.2.6.6.3.2 Time-series Consistency

Emissions from other transportation were estimated using the same methodology and carbon emission factors as Energy industries (1.A.1.) as described in Sections 3.2.4.2.1 to 3.2.4.2.2. For non-CO_2 gases, default emission factors for road transportation from the *2006 IPCC Guidelines* were applied. Activity data were sourced from the *Annual Oil Statistics* and applied consistently across the entire time series.

3.2.6.6.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

3.2.7 Other Sectors (1.A.4.)

3.2.7.1 Category Overview

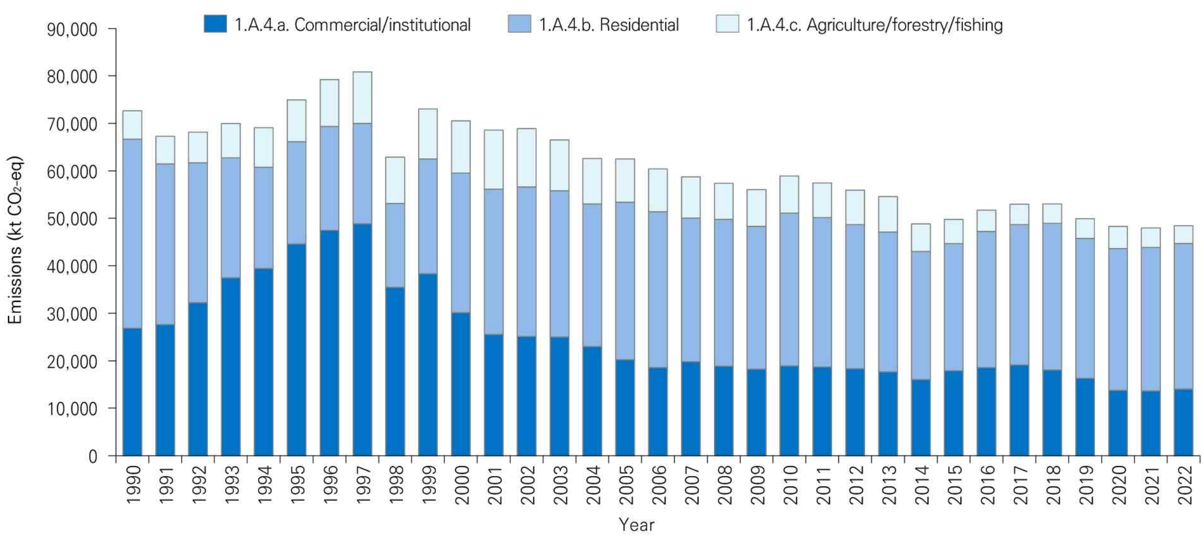
2022	Gas	Methodology	Emission Factor	Activity Data
	CO_2	Tier 1, 2	D, CS	Fuel consumption
	CH_4, N_2O	Tier 1	D, OTH	

Other sectors (1.A.4.) are subdivided into Commercial/institutional (1.A.4.a.), Residential (1.A.4.b.), and Agriculture/forestry/fishing (1.A.4.c.). Emissions from combustion activities in commercial and institutional building are reported under Commercial/institutional sector while that from households are categorized into Residential sector. Emissions by fuel combustion in agriculture, forestry, fishing and fishing industries are included in Agriculture/forest/fishing sector. Each subcategory of commercial/institutional and residential sector distinguish emissions between stationary combustion, off-road vehicles, and other machinery while agriculture/forestry/fishing sector categorizes its emissions into stationary combustion, off-road vehicles and machinery, and fishing. Fuel consumption of off-road vehicles and other machinery which was not disaggregated in national statistics were included in stationary combustion.

In 2022, emissions from other sectors were 48,438 kt CO_2-eq, a 0.9 percent increase from 2021. Residential sector produced more than half of the total emissions from other sectors emitting 30,678 kt CO_2-eq, accounting for 63.3 percent while commercial/institutional sector produced 13,997 kt CO_2-eq, contributing 28.9 percent. The remaining emissions of 3,763 kt CO_2-eq were from agriculture/forestry/fishing sector accounting for 7.8 percent.

Between 1990 and 2022, emissions decreased by 33.3 percent. The downward trend has been observed since reaching a peak in 1997 in which emissions were 80,863 kt CO_2-eq. This was largely contributed by reduced emissions from commercial/institutional sector where kerosene, diesel, B-C oil and propane were replaced by city gas, and also by electricity as well as heat which do not produce direct emissions.

In the residential sector, patent fuel such as coal briquettes in the early 1990s were replaced with city gas, leading to less emissions. Since 2000, consumption of city gas has continued to rise, and associated emissions have remained relatively steady. Emissions from the agriculture/forestry/fishing sector have continued to decrease since a peak in 2001.



| Figure 3-9 | Trends in Emissions from Other Sectors (1990-2022)

3. Energy

| Table 3-46 | Emissions from Other Sectors

(Unit: kt CO_2-eq)

Sub-category	1990	2000	2010	2018	2021	2022
Commercial/ institutional	26,807	30,136	18,899	18,100	13,636	13,997
Residential	39,883	29,358	32,161	30,804	30,243	30,678
Agriculture/forestry /fishing	5,952	11,046	7,861	4,108	4,107	3,763
Total	72,641	70,540	58,921	53,012	47,986	48,438

3.2.7.2 Methodology

3.2.7.2.1 Method

Other sectors followed the same methodological approach as Energy industries (1.A.1.).

3.2.7.2.2 Emission factor

Carbon emission factors used for other sectors were the same as those used for Energy industries (1.A.1.).[28] For CH_4 and N_2O, default emission factors from the *2006 IPCC Guidelines* were applied.

In the agriculture/forestry/fishing sector, fuels including gasoline, diesel, and propane were also used for mobile purposes. Accordingly, default emission factors for stationary combustion, road transportation, and off-road mobile sources and other machinery in the *2006 IPCC Guidelines*[29] were adjusted reflecting the share of consumption of such fuels reported in the *Energy Consumption Survey*.[30]

For propane of which a default emission factor for off-road vehicles and other machinery is not provided in the *2006 IPCC Guidelines,* the default value from the *2019 EMEP/EEA Air Pollutant Emission Inventory Guidebook* was used.[31]

28) Default emission factors from the *2006 IPCC Guidelines* were used from 1990 until default emission factors and country-specific emission factors have been applied since 2007.
29) *2006 IPCC Guidelines, Vol.2, Ch.2, Table 2.5; Ch.3, Table 3.2.2, Table 3.3.1*
30) Ministry of Trade, Industry and Energy (MOTIE)
31) *2019 EMEP/EEA air pollutant emission inventory guidebook*, EMEP/EEA (2019)

| Table 3-47 | CH_4 and N_2O Emission Factors for Other Sectors

(Unit: kg/TJ)

Category	Fuel Type			CH_4	N_2O
Commercial/Institutional	Coal			10	1.5
	Petroleum			10	0.6
	Gas			5	0.1
	Waste	Municipal waste		300	4
		Industrial waste			
	Biomass	Solid biomass		300	4
		Liquid biomass		10	0.6
		Gaseous biomass		5	0.1
Residential/Agriculture/ Forestry/Fishing (Stationary Combustion)	Coal			300	1.5
	Petroleum			10	0.6
	Gas			5	0.1
	Waste	Municipal waste		300	4
		Industrial waste			
	Biomass	Solid biomass		300	4
		Liquid biomass		10	0.6
		Gaseous biomass		5	0.1
Agriculture/Forestry (Off-road Vehicles and Other Machinery)	Petroleum	Gasoline[1)]	4-stroke	80	2
			2-stroke	140	0.4
		Diesel		4.15	28.6
		Propane[2)]		7.6	3.5
Fishing (Mobile Combustion)	Gasoline, Jet A-1, Diesel, B-A oil, B-B oil, B-C oil[3)]			7	2

Source: *2006 IPCC Guidelines, Vol.2, Ch.2, Table 2.5; Ch.3, Table 3.2.2, Table 3.3.1; 2019 EMEP/EEA Air Pollutant Emission Inventory Guidebook,* EMEP/EEA (2019)

Note: 1) As the share of 4-stroke and 2-stroke gasoline-powered engines was unknown, the average emission factor of both engine types was used.

2) Since emission factors in the *EMEP/EEA Guidebook* are expressed in g/tonnes fuel, the unit was converted using the net calorific value conversion factor for propane which is 46.3 MJ/kg.

3) For petroleum products not indicated above such as propane, butane, kerosene, by-product fuel No. 1, and by-product fuel No. 2, emission factors for stationary combustion were applied.

1) CH_4 and N_2O Emission Factors for Gasoline, Diesel, and Propane in Agriculture/ Forestry

Fuel consumption in agriculture/forestry sector are classified into stationary combustion, off-road vehicles and other machinery, and fishing (mobile sources). Activity data for agriculture/forestry sector provided in the *Energy Supply and Demand Statistics* include not only stationary combustion from buildings and facilities, but also mobile consumption from off-road vehicles and other machinery. To distinguish between different purposes of fuel use, the *Energy Consumption Survey*[32)] was used to identify the consumption per fuel type and end-use category.

32) Ministry of Trade, Industry and Energy (MOTIE)

Fuel consumption of gasoline, diesel, and propane which are predominantly used in agricultural machinery was considered for off-road vehicles and other machinery. The share of fuel consumed for transport and agricultural machinery was calculated using total consumption of such fuels in agriculture/forestry based on data provided in *the Energy Consumption Survey.* For years in which the respective *Survey* was not conducted, such share of fuel consumption was interpolated. For the 1990 to 1994 period which is before the first *Survey* was conducted, the average of the share values from the next four years was applied. For following years after the latest *Survey* in 2019, the 2019 values were applied.

3.2.7.2.3 Activity Data

Data for commercial/institutional, residential, and agriculture/forestry/fishing sectors under this reporting subcategory were primarily from the *Energy Supply and Demand Statistics.* The *Annual Oil Statistics* were also used for the institutional sector. For the fishing sector, both the *Annual Oil Statistics* and the *Energy Supply and Demand Statistics* were used to enhance the completeness and accuracy of activity data as described below.

In 2022, total fuel consumption in this reporting subcategory was 21,891.1 ktoe which was an increase of 1.4 percent from 2021.

| Table 3-48 | Activity Data Source for Other Sectors

Period	Activity Data	Name of Statistics	Published by	Gas
1990-2022	Fuel consumption (commercial/institutional, residential, agriculture/forestry/fishing)	*Energy Supply and Demand Statistics*	Korea Energy Economics Institute (KEEI)	CO_2, CH_4, N_2O
	Petroleum consumption (fishing, partially institutional)	*Annual Oil Statistics*	Korea National Oil Corporation (KNOC)	

| Table 3-49 | Fuel Consumption in Other Sectors

(Unit: ktoe)

Category	1990	2000	2010	2018	2021	2022
Commercial/Institutional	9,467.9	11,498.8	8,447.6	8,246.2	6,593.4	6,671.1
Residential	9,686.3	11,954.8	13,664.8	13,598.6	13,514.7	13,800.7
Agriculture/Forestry/Fishing	1,890.9	3,676.3	2,563.9	1,944.2	1,487.1	1,419.3
Total	21,045.2	27,129.9	24,676.3	23,788.9	21,595.3	21,891.1

Source: *Energy Supply and Demand Statistics,* KEEI (2024); *2022 Annual Oil Statistics*, KNOC (2023)

1) Activity Data for the Institutional Sector

The primary activity data for the institutional sector were the public-use fuel consumption provided in the *Energy Supply and Demand Statistics.* As the *Energy Statistics* include petroleum consumption for non-combat purpose by the military, associated emissions were included in Other (Not specified elsewhere) (1.A.5.). The exact fuel consumption for public use was obtained by subtracting the consumption for non-combat purpose by the military from the public-use consumption provided in the *Energy Statistics.*

2) Activity Data for Electricity and Heat Autoproducers

Emissions from autoproducers that generate electricity or heat primarily for their own use rather than for public supply shall be estimated and reported under the sector where they are generated. Under this subcategory, emissions from the use of fuel for their own use were reported.

3) Other (Waste Incineration with Energy Recovery)

In accordance with the *2006 IPCC Guidelines,* emissions from energy recovery in waste incineration shall be reported under the Energy sector. Accordingly, emissions from the combustion of municipal waste and industrial waste (alternative fuel for cement kiln) for energy recovery at waste-to-energy facilities were reported under the Energy sector. Emissions from incineration of all other wastes with and without energy recovery were reported under the Waste sector to avoid double-counting. Research is underway to collect data on energy recovery from the combustion of industrial waste other than alternative fuel for cement kiln. Once national statistics on energy recovery at waste-to-energy facilities are complete and available, associated emissions will be reported under the Energy sector after the verification process by experts on the time-series consistency.

4) Activity Data for Fishing Sector

The primary activity data for the fishing were from the *Annual Oil Statistics,* specifically the fuel consumption in inshore fisheries, distant-water fisheries, and other unspecified fishing operations.

For 1990 to 1993 period, the average of the share in consumption in fishing relative to that in the agriculture/forestry/fishing sector provided in the *Annual Oil Statistics* (KNOC) was calculated per fuel type using data for the 1994 to 1997 period. The total fuel consumption in fishing was estimated such average values and the fuel consumption in the agriculture/forestry/fishing sector for the years 1990, 1991, 1992 and 1993 provided in the *Energy Supply and Demand Statistics,*

3.2.7.3 Uncertainty Assessment and Time-series Consistency

3.2.7.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

3.2.7.3.2 Time-series Consistency

Emissions from this reporting subcategory were estimated using the same methodological approach and carbon emission factors as Energy industries (1.A.1.). For CH_4 and N_2O, default emission factors from the *2006 IPCC Guidelines* were adjusted reflecting the share of fuel consumption for transport use which were applied across the entire time series. The *Energy Supply and Demand Statistics* were used as the primary source of activity data while the *Annual Oil Statistics* were used for fishing and institutional sectors.

3.2.7.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

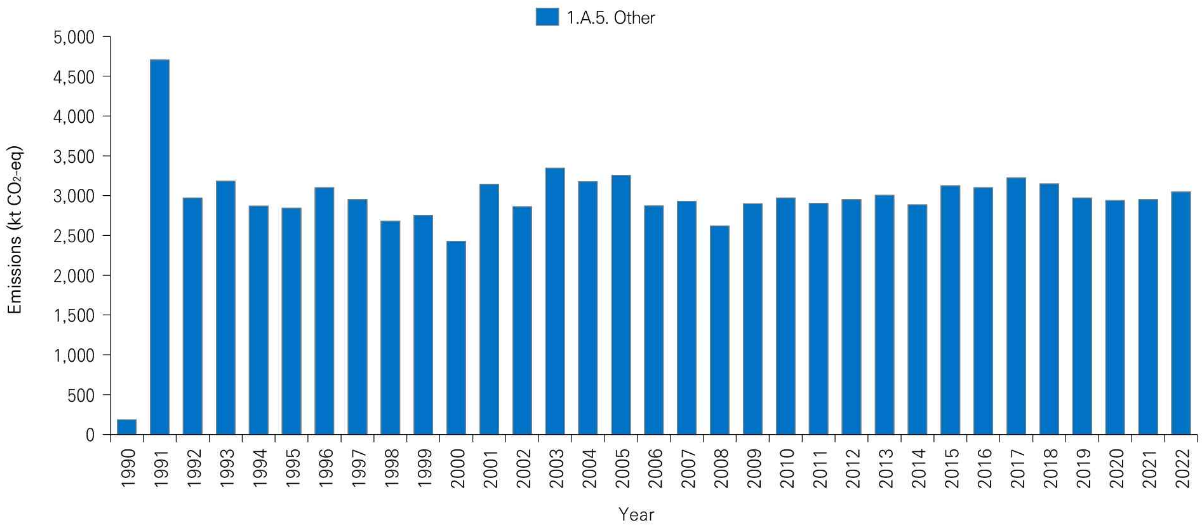
3.2.8 Other (Not specified elsewhere) (1.A.5.)

3.2.8.1 Category Overview

	Gas	Methodology	Emission Factor	Activity Data
2022	CO_2	Tier 1, 2	D, CS	Fuel consumption
	CH_4, N_2O	Tier 1	D	

This reporting subcategory includes emissions from fuel combustion that are not clearly assigned to a specific sector including the fuel use by the military. Emission sources are divided into Stationary (1.A.5.a.) and Mobile (1.A.5.b.) where the former includes emissions from stationary sources not specified elsewhere and the latter includes emissions from mobile sources of road, water-borne, and aviation and other machinery not specified elsewhere. As fuel consumption from mobile sources was not disaggregated from stationary in national statistics, associated emissions were included in stationary sources.

In 2022, emissions from this subcategory were 3,046 kt CO_2−eq, increasing by 3.3 percent from 2021. From 1992 to 2022, emissions fluctuated between 2,427 kt and 3,347 kt CO_2−eq.



| Figure 3−10 | Trends in Emissions from Other (Not specified elsewhere) (1990−2022)

| Table 3−50 | Emissions from Other (Not specified elsewhere)

(Unit: kt CO_2−eq)

Sub−category	1990	2000	2010	2018	2021	2022
Stationary	183	2,427	2,970	3,148	2,950	3,046

3.2.8.2 Methodology

3.2.8.2.1 Method

This reporting subcategory followed the same methodological approach as Energy industries (1.A.1.) as described in Sections 3.2.4.2.1 to 3.2.4.2.2.

3.2.8.2.2 Emission Factor

Carbon emission factors used for this subcategory were same as for Energy industries (1.A.1.) as described in Sections 3.2.4.2.1 to 3.2.4.2.2[33]. For non−CO_2 gases, default emission factors from the Commercial/institutional sector (1.A.4.a.) provided in the *2006 IPCC Guidelines* were applied.

33) Default emission factors from the *2006 IPCC Guidelines* were used from 1990 until default emission factors as well as country−specific emission factors have been applied since 2007 onward.

3.2.8.2.3 Activity Data

Activity data for this subcategory were based on fuel consumption in the *Annual Oil Statistics*. In 2022, fuel consumption in this subcategory were 1,058.6 ktoe, increasing by 3.0 percent from 2021.

| Table 3-51 | Activity Data Source for Other (Not specified elsewhere)

Period	Activity Data	Name of Statistics	Published by	Gas
1990-2022	Petroleum consumption	*Annual Oil Statistics*	Korea National Oil Corporation (KNOC)	CO_2, CH_4, N_2O

| Table 3-52 | Activity Data for Other (Not specified elsewhere)

(Unit: ktoe)

Amount	1990	2000	2010	2018	2021	2022
Liquid Fuel Consumption	62.9	848.4	1,041.2	1,097.0	1,028.0	1,058.6

Source: *2022 Annual Oil Statistics*, KNOC (2023)

3.2.8.3 Uncertainty Assessment and Time-series Consistency

3.2.8.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

3.2.8.3.2 Time-series Consistency

Emissions from other sources not specified elsewhere were estimated using the same methodology and carbon emission factors as Energy industries (1.A.1.). For non-CO_2 gases, emission factors from the Commercial/institutional sector (1.A.4.a.) provided in the *2006 IPCC Guidelines* were applied. Activity data were consistently sourced from the *Annual Oil Statistics* across the entire time series.

3.2.8.4 QA/QC

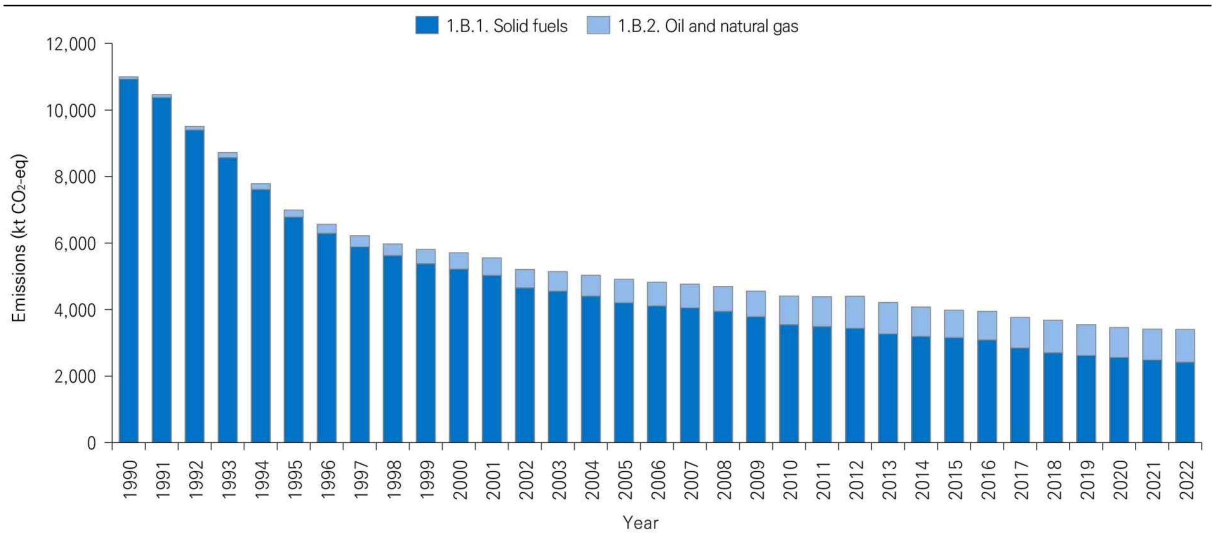
General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

3.3 Fugitive Emissions from Fuels (1.B.)

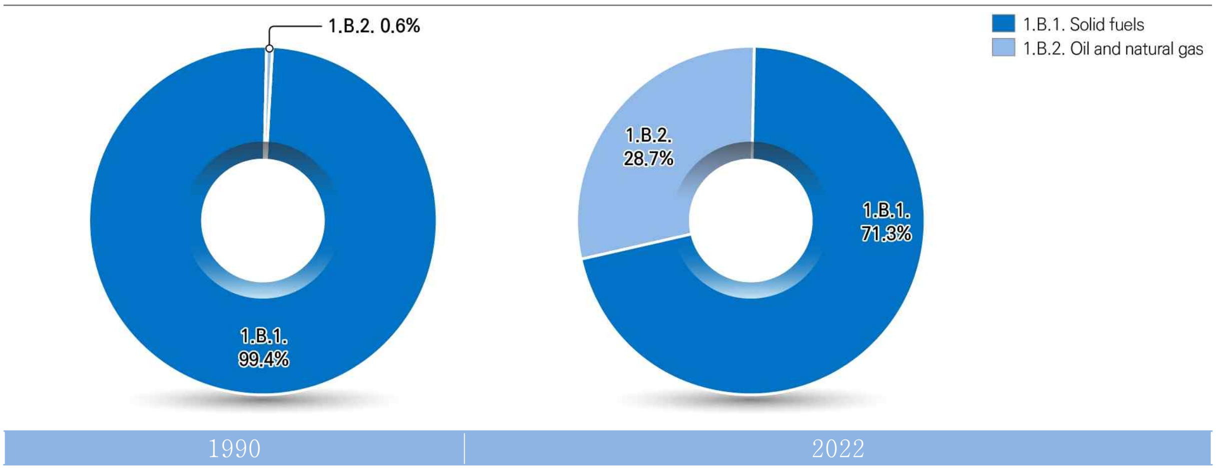
Fugitive emissions refer to greenhouse gases that are intentionally or unintentionally released during the extraction, production, processing, refining, storage, and delivery of fossil fuels such as coal, oil, and natural gas. Such emissions are divided into Solid fuels (1.B.1.) and Oil and natural gas (1.B.2.).

In 2022, fugitive emissions were 3,402 kt CO_2−eq, a 0.5 percent decrease from 2021, and accounted for 0.6 percent of total emissions in the Energy sector. Solid fuels accounted for 71.3 percent and the remaining 28.7 percent was from oil and natural gas.

Between 1990 and 2022, emissions decreased by 69.1 percent, primarily due to reduced coal production and decreased emissions from abandoned underground mines. On the other hand, emissions from oil and natural gas increased steadily until 2013 which was driven by increased consumption of natural gas and city gas, and have since continued to fluctuate.



| Figure 3−11 | Trends in Emissions from Fugitive Emissions (1990−2022)



| Figure 3-12 | Subcategory as a Portion of Total Fugitive Emissions (1990 and 2022)

| Table 3-53 | Emissions from Fugitive Emissions

(Unit: kt CO_2-eq)

Fuel Type	1990	2000	2010	2018	2021	2022
1.B.1. Solid Fuels	10,931	5,215	3,552	2,704	2,484	2,426
1.B.2. Oil and Natural Gas	63	493	857	984	937	976
Total	**10,994**	**5,708**	**4,409**	**3,688**	**3,420**	**3,402**

3.3.1 Solid Fuels (1.B.1.)

3.3.1.1 Category Overview

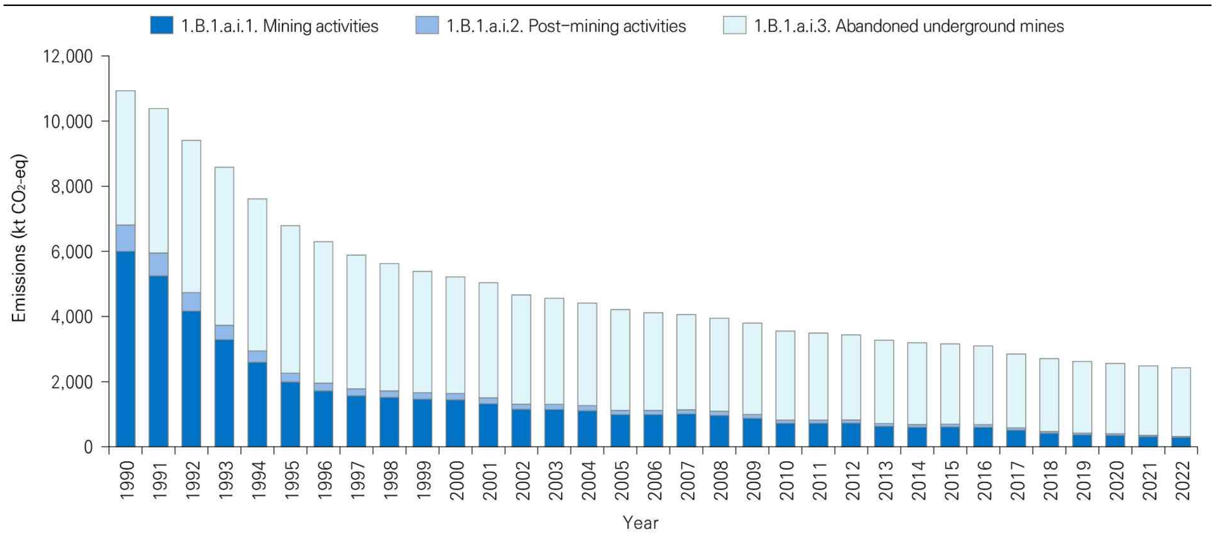
	Source	Gas	Methodology	Emission Factor	Activity Data
2022	Mining activities/ Post-mining activities	CO_2, CH_4	Tier 1	D	Fuel production
	Abandoned underground mines	CH_4	Tier 1	D	Number of abandoned mines

Emissions from solid fuels are divided into Coal mining and handling (1.B.1.a.) and Fuel transformation (1.B.1.b.). In ROK, emissions were estimated only for coal mining and handling as there is no methodology for fuel transformation available in the *2006 IPCC Guidelines.*

Coal mining and handling (1.B.1.a.) includes CO_2 and CH_4 emissions released intentionally or unintentionally during the extraction, processing, storage, and transportation of coal as well as CH_4 emissions from abandoned coal mines. Emissions are again subdivided into Underground mining (1.B.1.a.i.) and Surface mining (1.B.1.a.ii.). Only underground mining was reported as there is no surface mine in ROK.

Coal extraction releases stored gas during the breakage of the coal and surrounding strata which are vented from coal mine ventilation and degasification systems. Coal emits gas during the processing, storage, and transportation. After mining has ceased, abandoned coal mines continue to emit CH_4 until it is fully flooded and the water prevents further release of CH_4 to the atmosphere. CH_4 may still be emitted to the atmosphere through natural or manmade conduits even if the mines have been sealed.

In 2022, fugitive emissions from solid fuels were 2,426 kt CO_2−eq, a 2.3 percent decrease from 2021, and accounted for 71.3 percent of total fugitive emissions. Between 1990 and 2022, emissions decreased by 77.8 percent, primarily due to the continued decline in fugitive emissions from abandoned underground mines, resulting from reduced domestic coal production.



| Figure 3-13 | Trends in Fugitive Emissions from Solid Fuels (1990-2022)

| Table 3-54 | Fugitive Emissions from Solid Fuels

(Unit: kt CO_2−eq)

Source	1990	2000	2010	2018	2021	2022
1.B.1.a.i.1. Mining Activities	6,001	1,446	726	419	313	286
1.B.1.a.i.2. Post-mining Activities	807	195	98	56	42	38
1.B.1.a.i.3. Abandoned Mines	4,123	3,574	2,728	2,229	2,129	2,102
Total	10,931	5,215	3,552	2,704	2,484	2,426

3.3.1.2 Methodology

3.3.1.2.1 Method

CO_2 and CH_4 emissions are produced from coal mining activities, and CH_4 emissions continue to occur from post-mining activities. In accordance with the Tier 1 methodology from the *2006 IPCC Guidelines* for CH_4 and the *2019 Refinement* for CO_2, emissions were calculated by multiplying domestic coal production by the emission factor and density of CH_4 (conversion factor).

CO_2 and CH_4 emissions from mining activities
CH_4 emissions from post-mining activities
$$E_{i,j} = A_{Coal} \times EF_{i,j} \times CF_j$$
$E_{i,j}$: greenhouse gas i emissions from emission source j (kt CO_2, kt CH_4)
A_{Coal} : domestic coal production(Mt)
$EF_{i,j}$: emission factor of GHG i from emission source j (m^3 CO_2/t, m^3 CH_4/t)
CF_j : density of greenhouse gas j (kt $CO_2/10^6m^3$ CO_2, kt $CH_4/10^6m^3$ CH_4)
i : emission source (mining, post-mining)
j : greenhouse gases (mining - CO_2, CH_4; post-mining - CH_4)

Source : *2006 IPCC Guidelines, Vol.2, Ch.4, Equation 4.1.3 and 4.1.4; 2019 Refinement, Vol.2, Ch.4, Equation 4.1.3A*

CH_4 emissions from underground abandoned mines were calculated using the Tier 1 methodology from the *2006 IPCC Guidelines*. As emission factor for each abandoned mine starts to decrease from the point of mine closure, emissions for each time interval to the inventory year of interest were estimated and summed to derive the total abandoned mine emissions for each inventory year.

To estimate activity data for CH_4 emissions from underground abandoned mines, the number of non-flooded abandoned mines was multiplied by the share of gassy mines to derive the number of abandoned mines that produces fugitive emissions. It was assumed that all abandoned mines remained non-flooded and the share of gassy mines as of 2018 which was 80.0 percent[34] was applied across the entire time series.

34) The *2006 IPCC Guidelines* provide only the high and low default values for the percentage of gassy mines, and recommend that each country should consider all available national information (Vol.2, Ch.4, p. 4.23-4.24). Under the *Enforcement Decree of the Mine Safety Act*, coal mines with high methane concentrations in ventilation shafts and work areas were classified as Class A mines. The percentage of Class A mines from mines that were in operation or closed in 2018 was calculated and applied across the entire time series.

CH₄ emissions from abandoned underground coal mines

$$E_t = \sum_{i=1}^{t} Abandoned_i \times Mine_{gassy,_i} \times EF_{i,t} \times CF$$

E_t	:	CH_4 emissions from abandoned underground coal mines in year t (kt CH_4)
$Abandoned_i$	:	number of underground coal mines abandoned during period i
$Mine_{gassy,i}$	:	percentage of gassy coal mines during period i
$EF_{i,t}$	:	CH_4 emission factor t for period i (10^6 m^3 CH_4)
CF	:	CH_4 density (kt $CH_4/10^6 m^3$ CH_4)
i	:	interval of mine closure

Source : *2006 IPCC Guidelines, Vol.2, Ch.4, Equation 4.1.10*

3.3.1.2.2 Emission Factor

For coal mining and post-mining activities, default emission factors for CH_4 from the *2006 IPCC Guidelines* and CO_2 from the *2019 Refinement* were applied.

Emission factor for each abandoned mine decreases from the point of mine closure which makes emission factors vary depending on the year of mine closure and the inventory year of interest. Default emission factors for abandoned underground mines presented in the *2019 Refinement* were used.

Since emission factors in both the *2006 IPCC Guidelines* and *2019 Refinement* were expressed in volumetric units, the density of CH_4 (conversion factor) was applied to calculate emissions.

| Table 3-55 | CO_2 and CH_4 Emission Factors and Density for Solid Fuels

Fuel Type	Source	Emission Factor(m^3/t)		Density(kt/10^6 m^3)	
		CO_2	CH_4	CO_2	CH_4
Solid Fuels (Coal Mining and Handling - Underground Mines)	Mining Activities	5.9	18.0	1.84	0.67
	Post-mining Activities	NA	2.5		
	Abandoned Underground Mines	NA	See Table 3-56		

Source: *2006 IPCC Guidelines, Vol.2, Ch.4, p.4.12; 2019 Refinement, Vol.2, Ch.4, p.4.19*

| Table 3-56 | CH_4 Emission Factors for Abandoned Underground Mines in Solid Fuels

(Unit: CH_4 million m^3)

Interval of Mine Closure / Inventory Year	1951-1975	1976-2000	2001-2022
1990	0.478	1.561	NA
1991	0.469	1.334	NA
1992	0.461	1.183	NA
1993	0.453	1.072	NA
1994	0.446	0.988	NA
1995	0.439	0.921	NA
1996	0.432	0.865	NA
1997	0.425	0.818	NA
1998	0.419	0.778	NA
1999	0.413	0.743	NA
2000	0.408	0.713	NA
2001	0.402	0.686	5.735
2002	0.397	0.661	2.397
2003	0.392	0.639	1.762
2004	0.387	0.62	1.454
2005	0.382	0.601	1.265
2006	0.378	0.585	1.133
2007	0.373	0.569	1.035
2008	0.369	0.555	0.959
2009	0.365	0.542	0.896
2010	0.361	0.529	0.845
2011	0.357	0.518	0.801
2012	0.353	0.507	0.763
2013	0.35	0.496	0.73
2014	0.346	0.487	0.701
2015	0.343	0.478	0.675
2016	0.34	0.469	0.652
2017	0.336	0.439	0.625
2018	0.333	0.432	0.604
2019	0.33	0.425	0.586
2020	0.327	0.419	0.569
2021	0.324	0.413	0.555
2022	0.322	0.408	0.542

Source: *2019 Refinement, Vol.2, Ch.4, Table 4.1.6*

3.3.1.2.3 Activity Data

For coal mining and post-mining activities, activity data were based on domestic anthracite production reported in the *Energy Supply and Demand Statistics*. Due to declining demand for coal briquettes, anthracite production has steadily decreased since 1990. In 2022, total production of anthracite was 820 kt, decreasing by 8.7 percent from 2021.

For abandoned underground mines, activity data were derived from data collected by the Korea Mine Rehabilitation and Mineral Resources Corporation (KOMIR) which include the number of underground mines closed since 1989. A significant number of mines were closed between 1989 and 1996, followed by closures of one to two mines per year from 2001 onward with the most recent closure occurring in 2018. Data on the number of mines closed per year are not shown here in accordance with the data provider's request.

| Table 3-57 | Activity Data Source for Solid Fuels

Period	Activity Data	Name of Statistics	Published by	Gas
1990-2022	Domestic coal production	*Energy Supply and Demand Statistics*	Korea Energy Economics Institute (KEEI)	CO_2 CH_4
	Number of abandoned mines by year	*Data on Closure of Mines*	Korea Mine Rehabilitation and Mineral Resources Corporation (KOMIR)	

| Table 3-58 | Activity Data for Solid Fuels

(Unit: kt)

Amount	1990	2000	2010	2018	2021	2022
Anthracite Production	17,217.0	4,150.0	2,084.0	1,202.0	898.0	820.0

3.3.1.3 Uncertainty Assessment and Time-series Consistency

3.3.1.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

3.3.1.3.2 Time-series Consistency

Emissions from solid fuels were estimated using methodology and emission factors consistently across the entire time series, and used data sources consistently to ensure consistency in the time series.

3.3.1.4 QA/QC

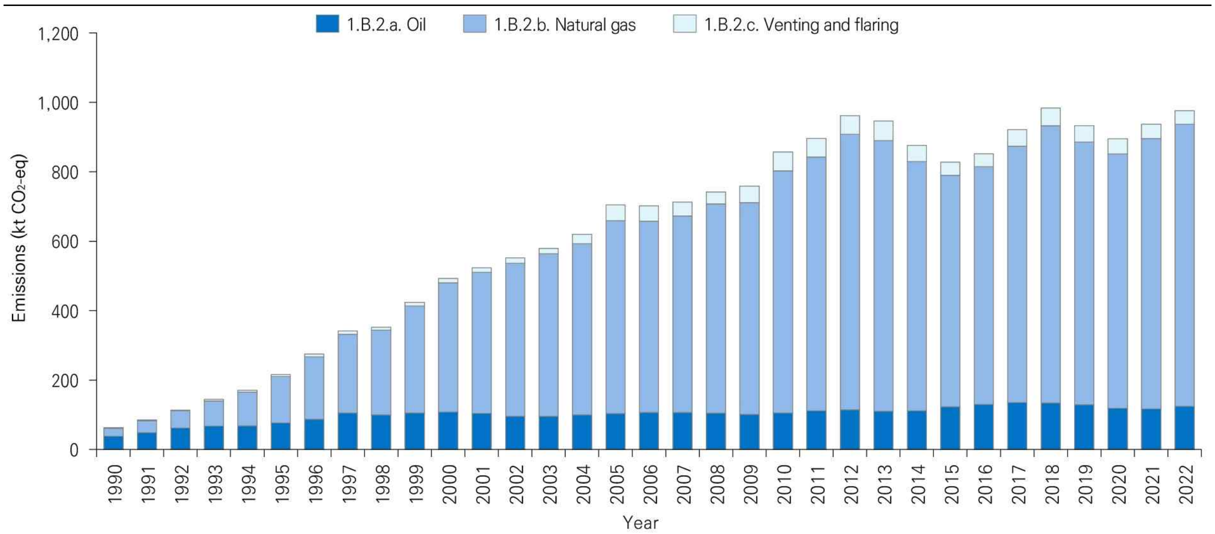
General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

3.3.2 Oil and Natural Gas (1.B.2.)

3.3.2.1 Category Overview

Emissions released from fugitive sources of oil and natural gas are reported under subcategories of Oil (1.B.2.a.), Natural gas (1.B.2.b.), and Venting and flaring (1.B.2.c.). Subcategories of oil and natural gas are further divided into exploration, production, transmission, refining, and distribution.

In 2022, emissions from oil and natural gas were 976 kt CO_2-eq, a 4.1 percent increase from 2021, and accounted for 28.7 percent of total fugitive emissions. Between 1990 and 2022, emissions increased by 1,456.3 percent, primarily due to the increased consumption of natural gas and city gas.



| Figure 3-14 | Trends in Emissions from Oil and Natural Gas (1990-2022)

| Table 3-59 | Emissions from Oil and Natural Gas

(Unit: kt CO_2-eq)

Sub-category	1990	2000	2010	2018	2021	2022
Oil	38	108	106	134	116	124
Natural Gas	23	372	697	799	779	813
Venting and Flaring	2	13	54	51	41	39
Total	63	493	857	984	937	976

3.3.2.2 Oil (1.B.2.a.)

3.3.2.2.1 Category Overview

2022	Gas	Method	Emission Factor	Activity Data
	CO_2, CH_4, N_2O	Tier 1	D	Fuel production, imports and input volume

Emissions from oil are produced from Exploration (1.B.2.a.i.), Production and upgrading (1.B.2.a.ii.), Transport (1.B.2.a.iii.), Refining and storage (1.B.2.a.iv.), Distribution of oil products (1.B.2.a.v.), and Other (1.B.2.a.vi.). In ROK, emissions from crude oil production, transport to refineries via pipeline or tank truck including imported crude, and fugitive emissions from refining processes were calculated. Exploration and other activities such as abandoned wells did not occur in ROK.[35] Emission factor for distribution of refined petroleum products are not available in the *2006 IPCC Guidelines.*

In 2022, emissions from oil were 124 kt CO_2−eq, an increase of 6.9 percent from 2021, and accounted for 3.7 percent of total fugitive emissions.

| Table 3−60 | Emissions from Oil

(Unit: kt CO_2−eq)

Source	1990	2000	2010	2018	2021	2022
Production	NO	NO	0.001	0.0005	0.0001	0.00004
Transport	7.4	21.6	21.0	26.9	23.2	24.9
Refining	30.3	86.6	84.6	107.4	93.3	99.6
Total	37.7	108.1	105.7	134.3	116.5	124.5

3.3.2.2.2 Methodology

1) Method

Emissions from oil were calculated using the Tier 1 methodology as outlined in the *2006 IPCC Guidelines* by multiplying activity data for each subcategory by the corresponding default emission factor.

Emissions from oil

$$E_i = \sum_j [A_j \times EF_{ij}]$$

E_i : GHG i emissions from the oil industry segment

A_j : activity data of emission source j

EF_{ij} : emission factor of GHG i from emission source j

i : gas type (CO_2, CH_4, N_2O)

j : emission source

Source: *2006 IPCC Guidelines, Vol.2, Ch.4, Equation 4.2.1*

2) Emission Factors

Emission factors for this subcategory of oil were based on the default values provided in the *2006 IPCC Guidelines.* As emission factors were expressed in volumetric units of 1,000 m^3 while activity data were provided in mass units of 1,000 barrels, emission factors were adjusted by multiplying by the crude oil volume conversion factor of 158.987295 m^3/1,000 bbl.

35) In ROK, oil exploration in the continental shelf began in 1979 leading to a total of 49 exploratory drillings conducted as of March 2025 (Source: KNOC, https://www.knoc.co.kr/sub03/sub03_1_2.jsp, Accessed on June 30, 2025).

| Table 3-61 | Emission Factors for Oil

CRT Code	Subcategory	Activity Data	Gas	Emission Factor	Unit
1.B.2.a.ii. Production and upgrading	Crude Oil	Crude oil production volume	CO_2	4.3×10^{-8}	kt $CO_2/10^3$ m^3
			CH_4	5.9×10^{-7}	kt $CH_4/10^3$ m^3
			N_2O	NA	
1.B.2.a.iii. Transport	Pipelines	Transport volume	CO_2	4.9×10^{-7}	kt $CO_2/10^3$ m^3
			CH_4	5.4×10^{-6}	kt $CH_4/10^3$ m^3
			N_2O	NA	
1.B.2.a.iv. Refining and storage[1)]	All	Refining volume	CO_2	Not Determined	
			CH_4	21.8×10^{-6}	kt $CH_4/10^3$ m^3
			N_2O	Not Determined	

Note: 1) For CH_4 from Refining and storage (1.B.2.a.iv.), the median from a range of $2.6\text{x}10^{-6}$ to $41.0\text{x}10^{-6}$ as suggested by the *2006 IPCC Guidelines* was used.

Source: *2006 IPCC Guidelines, Vol.2, Ch.4, Table 4.2.4*

3) Activity Data

Activity data for this subcategory of oil were based on domestic crude oil production, crude oil imports and crude oil input for refining as reported in the *Energy Supply and Demand Statistics*. In 2022, crude oil imports and input for refining increased by 7.4 percent and 6.7 percent respectively. Crude oil production began in 2005 with the development of the *Donghae* gas field, producing 406.7 thousand barrels, but has since declined. In 2022, domestic production fell by 52.8 percent from 2021.

| Table 3-62 | Activity Data Source for Oil

Period	Activity Data	Name of Statistics	Published by	Gas
1990-2022	Crude oil production	*Energy Supply and Demand Statistics*	Korea Energy Economics Institute (KEEI)	CO_2, CH_4, N_2O
	Crude oil import			
	Crude oil input for petroleum refining			

| Table 3-63 | Activity Data for Oil

(Unit: thousand bbl)

Amount	1990	2000	2010	2018	2021	2022
Crude Oil Production	NO	NO	379.7	188.7	35.5	16.8
Crude Oil Import	308,368.1	893,943.3	872,415.1	1,116,281.0	960,146.6	1,031,283.0
Crude Oil Input for Petroleum Refining	312,044.8	892,223.8	872,262.9	1,106,317.0	961,383.7	1,026,102.4

Source: *Energy Supply and Demand Statistics*, KEEI (2024)

3.3.2.2.3 Uncertainty and Time-series Consistency

3.3.2.2.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

3.3.2.2.3.2 Time-series Consistency

Emissions from the oil industry were estimated applying consistent methodology and emission factors across the entire time series, and data sources were used consistently to ensure consistency in the time series.

3.3.2.2.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

3.3.2.3 Natural Gas (1.B.2.b.)

3.3.2.3.1 Category Overview

	Gas	Methodology	Emission Factor	Activity Data
2022	CO_2, CH_4	Tier 1	D	Fuel production and supply
	CH_4(Transmission and Storage)	Tier 2	CS	Fuel supply

Emissions from natural gas occur during Exploration (1.B.2.b.i.), Production and gathering (1.B.2.b.ii.), Processing (1.B.2.b.iii.), Transmission and storage (1.B.2.b.iv.), Distribution (1.B.2.b.v.), and Other (1.B.2.b.vi.). No fugitive emissions occurred from gas exploration in ROK.[36]

In 2022, emissions from the natural gas industry were 813 kt CO_2-eq, a 4.3 percent increase from 2021, and accounted for 23.9 percent of total fugitive emissions. As natural gas and city gas consumption increased, associated emissions also continued to increase until 2012 and have since been fluctuating.

36) In ROK, oil exploration in the continental shelf began in 1979 leading to a total of 49 exploratory drillings conducted as of March 2025 (Source: KNOC, https://www.knoc.co.kr/sub03/sub03_1_2.jsp, Accessed on June 30, 2025).

| Table 3-64 | Emissions from Natural Gas

(Unit: kt CO_2-eq.)

Source	1990	2000	2010	2018	2021	2022
Production and Gathering	NO	NO	5.5	3.1	0.6	NO
Processing	NO	NO	2.2	1.2	0.2	NO
Transmission and Storage	1.2	8.1	17.4	22.9	24.7	24.5
Distribution	21.8	363.9	672.2	771.6	753.5	788.0
Total	**23.1**	**372.1**	**697.3**	**798.8**	**779.0**	**812.5**

3.3.2.3.2 Methodology

1) Method

The Tier 2 methodology from the *2006 IPCC Guidelines* was used for CH_4 emissions from transmission and storage while the remaining sources used the Tier 1 methodology.

Emissions from natural gas

$$E_i = \sum_j [A_j \times EF_{ij}]$$

E_i greenhouse gas i emissions from the natural gas industry segment

A_j activity data of emission source j

EF_{ij} emission factor of greenhouse gas i from emission source j

i gas type (CO_2, CH_4, N_2O)

j emission source

Source: *2006 IPCC Guidelines, Vol.2, Ch.4, Equation 4.2.1*

2) Emission Factor

For CH_4 emissions from transmission and storage, country-specific emission factors were applied. For the remaining sources and gases, default emission factors from the *2006 IPCC Guidelines* were used. As emission factors were expressed in volumetric units of 1,000 m^3 while activity data were expressed in mass units of kilotonne, conversion factors of 1,240 Nm^3/t were applied for the 1990 to 2007 period, and 1,254 Nm^3/t for the 2008 to 2022 period.[37]

37) Source: Korea Gas Corporation (KOGAS)

| Table 3-65 | Emission Factors for Natural Gas

CRT Code	Subcategory	Activity Data	Gas	Emission Factor	Unit
1.B.2.b.ii. Production and gathering[1]	All	Natural gas production	CO_2	1.4×10^{-5}	kt $CO_2/10^6$ m^3
			CH_4	3.8×10^{-4}	kt $CH_4/10^6$ m^3
			N_2O	NA	
1.B.2.b.iii. Processing[1]	Default Weighted Total	Natural gas production	CO_2	1.2×10^{-5}	kt $CO_2/10^6$ m^3
			CH_4	1.5×10^{-4}	kt $CH_4/10^6$ m^3
			N_2O	NA	
1.B.2.b.iv. Transmission and storage[1)2)]	Transmission	Natural gas supply	CO_2	8.8×10^{-7}	kt $CO_2/10^6$ m^3
			CH_4[3]	8.567×10^{-6}	kt $CH_4/10^6$ m^3
			N_2O	NA	
	Storage	Natural gas supply	CO_2	1.1×10^{-7}	kt $CO_2/10^6$ m^3
			CH_4	6.835×10^{-6}	kt $CH_4/10^6$ m^3
			N_2O	Not Determined	
1.B.2.b.v. Distribution	All	City gas production	CO_2	5.1×10^{-5}	kt $CO_2/10^6$ m^3
			CH_4	1.1×10^{-3}	kt $CH_4/10^6$ m^3
			N_2O	Not Determined	

Note: 1) The lowest value of default emission factors for fugitive emissions from production and gathering, processing, and transmission and storage in the *2006 IPCC Guidelines* in developed countries were used.

2) The CH_4 emission factor for transmission and storage is a country-specific emission factor which was developed in 2017 by applying total natural gas supply to total fugitive emissions estimated from the concentration of fugitive gas at domestic production and supply facilities.

3) Country-specific factors in grey shaded cells (▭)

Source: *2006 IPCC Guidelines, Vol.2, Ch.4, Table 4.2.4; Country-specific emission factors*, Greenhouse Gas Inventory and Research Center of Korea (GIR) (2017)

3) Activity Data

Activity data for the natural gas industry were sourced from the *Energy Supply and Demand Statistics* using natural gas production volumes for Production (1.B.2.b.ii.) and Processing and gathering (1.B.2.b.iii.) while total natural gas supply were used for Transmission and storage (1.B.2.b.iv.), and city gas supply for Distribution (1.B.2.b.v.).

In ROK, natural gas production began in 2004 with the development of the *Donghae* gas field which resulted in production volume of 414.8 kt in 2010. However, production gradually declined and ceased in 2021. In 2022, the supply of natural gas and city gas increased by 10.5 percent and 6.5 percent respectively from 2021.

| Table 3-66 | Activity Data Source for Natural Gas

Period	Activity Data	Name of Statistics	Published by	Gas
1990-2022	Natural gas production	*Energy Supply and Demand Statistics*	Korea Energy Economics Institute (KEEI)	CO_2, CH_4
	Natural gas supply			
	City gas supply			

| Table 3-67 | Activity Data for Natural Gas

(Unit: kt (natural gas production and supply); $10^6 m^3$ (city gas supply))

Amount	1990	2000	2010	2018	2021	2022
Natural Gas Production	NO	NO	414.8	233.9	42.1	NO
Natural Gas Supply	2,275.4	15,186.9	32,090.4	42,193.4	45,657.0	45,262.1
City Gas Supply	707.8	11,796.9	21,787.0	25,011.1	24,422.5	25,542.6

Source: *Energy Supply and Demand Statistics,* KEEI (2024)

3.3.2.3.3 Uncertainty and Time-series Consistency

3.3.2.3.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

3.3.2.3.3.2 Time-series Consistency

Emissions from the natural industry was estimated using methodology and emission factors consistently for the entire time series, and activity data were used consistently to ensure time-series consistency.

3.3.2.3.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

3.3.2.6 Venting and Flaring (1.B.2.c.)

3.3.2.6.1 Category Overview

	Gas	Methodology	Emission Factor	Activity Data
2022	CO_2, CH_4, N_2O	Tier 1	D	Fuel production and supply
	CH_4 (Natural Gas Transport and Storage)	Tier 2	CS	Fuel supply

Emissions released from venting and flaring of associated gas at oil and gas facilities, waste gas and natural gas are estimated under Venting (1.B.2.c.i.) which includes fugitive gas from oil production and natural gas processing, transmission, and storage, and Flaring (1.B.2.c.ii.) which includes gas from oil production and natural gas production and processing.

In 2022, emissions from venting and flaring were 39 kt CO_2−eq, a 6.9 percent decrease from 2021, and accounted for 1.1 percent of total fugitive emissions. Venting of relevant gas was the largest source of emissions. Due to the increased consumption of natural gas and city gas, emissions continued to increase until 2005 and since fluctuated until it peaked in 2013 with 56 kt CO_2−eq. The downward trend has been observed since 2018.

| Table 3−68 | Emissions from Venting and Flaring

(Unit: kt CO_2−eq)

Source	1990	2000	2010	2018	2021	2022
Venting	2	13	49	48	41	38
Flaring	NO	NO	5	3	0.5	0.1
Total	2	13	54	51	41	39

3.3.2.6.2 Methodology

1) Method

Emissions from venting and flaring were estimated using the same methodology as for Oil (1.B.2.a.) and Natural gas (1.B.2.b.) as described in Section 3.3.2.2.2 and Section 3.3.2.3.2.[38)]

2) Emission Factor

Emission factors used for venting and flaring were the same as for Oil (1.B.2.a.) and Natural gas (1.B.2.b.) as described in Section 3.3.2.2.2 and Section 3.3.2.3.2.

38) The Tier 1 methodology from the *2006 IPCC Guidelines* was applied except for CH_4 emissions from transport and storage of natural gas which were estimated using the Tier 2 methodology.

| Table 3-69 | Emission Factors for Venting and Flaring

CRT Code	Subcategory	Emission Source	Activity Data	Gas	Emission Factor	Unit
1.B.2.c.i. Venting	Crude oil	Production	Domestic crude oil production	CO_2	9.5×10^{-5}	kt $CO_2/10^3$ m^3
				CH_4	7.2×10^{-4}	kt $CH_4/10^3$ m^3
				N_2O	NA	
	Natural Gas	Processing[1)]	Domestic natural gas production	CO_2	4.2×10^{-2}	kt $CO_2/10^6$ m^3
				CH_4	NA	
				N_2O	NA	
		Transport	Domestic natural gas supply	CO_2	3.1×10^{-6}	kt $CO_2/10^6$ m^3
				CH_4[2)]	2.028×10^{-5}	kt $CH_4/10^6$ m^3
				N_2O	NA	
		Storage	Domestic natural gas supply	CO_2	NA	
				CH_4	3.756×10^{-6}	kt $CH_4/10^6$ m^3
				N_2O	NA	
1.B.2.c.ii. Flaring	Crude oil	Production	Domestic crude oil production	CO_2	4.1×10^{-2}	kt $CO_2/10^3$ m^3
				CH_4	2.5×10^{-5}	kt $CH_4/10^3$ m^3
				N_2O	6.4×10^{-7}	kt $N_2O/10^3$ m^3
	Natural Gas	Production	Domestic natural gas production	CO_2	1.2×10^{-3}	kt $CO_2/10^6$ m^3
				CH_4	7.6×10^{-7}	kt $CH_4/10^6$ m^3
				N_2O	2.1×10^{-8}	kt $N_2O/10^6$ m^3
		Processing[1)]	Domestic natural gas production	CO_2	3.0×10^{-3}	kt $CO_2/10^6$ m^3
				CH_4	2.0×10^{-6}	kt $CH_4/10^6$ m^3
				N_2O	3.3×10^{-8}	kt $N_2O/10^6$ m^3

Note: 1) Emission factors of default weighted total presented in the *2006 IPCC Guidelines* were applied.
2) Country-specific factors in grey shaded cells ( )

Source: *2006 IPCC Guidelines, Vol.2, Ch.4, Table 4.2.4*; *Country-specific emission factors*, Greenhouse Gas Inventory and Research Center of Korea (GIR) (2017)

3) Activity Data

Activity data for venting and flaring were sourced from the *Energy Supply and Demand Statistics* in line with data used for Oil (1.B.2.a.) and Natural gas (1.B.2.b.).

3.3.2.6.3 Uncertainty and Time-series Consistency

3.3.2.6.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

3.3.2.6.3.2 Time-series Consistency

The *Energy Supply and Demand Statistics* were used as activity data across the entire time series. Emissions were calculated using consistent emission factors and methodologies provided in the *2006 IPCC Guidelines* for the entire time series.

3.3.2.6.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

3.4 CO_2 Transport and Storage (1.C.)

3.4.1 Category Overview

Fugitive emissions of CO_2 from CO_2 transport and storage (1.C.) are reported under Transport of CO_2 (1.C.1.) and Injection and storage of CO_2 (1.C.2.). In ROK, respective activities do not occur.

SECTION 04 Industrial Processes and Product Use

4 Industrial Processes and Product Use

4.1 Overview

In the Industrial Processes and Product Use (IPPU) sector (hereinafter referred to as "IPPU"), greenhouse gas emissions occur from industrial processes that chemically or physically transform materials and from non-energy uses of fossil fuel carbon.[1] The reporting categories of the IPPU sector include Mineral Industry (2.A.), Chemical Industry (2.B.), Metal Industry (2.C.), Non-Energy Products from Fuels and Solvent Use (2.D.), Electronics Industry (2.E.), Product Uses as Substitutes for Ozone-Depleting Substances (ODS) (2.F.), Other Product Manufacture and Use (2.G.), and Other (2.H.).[2]

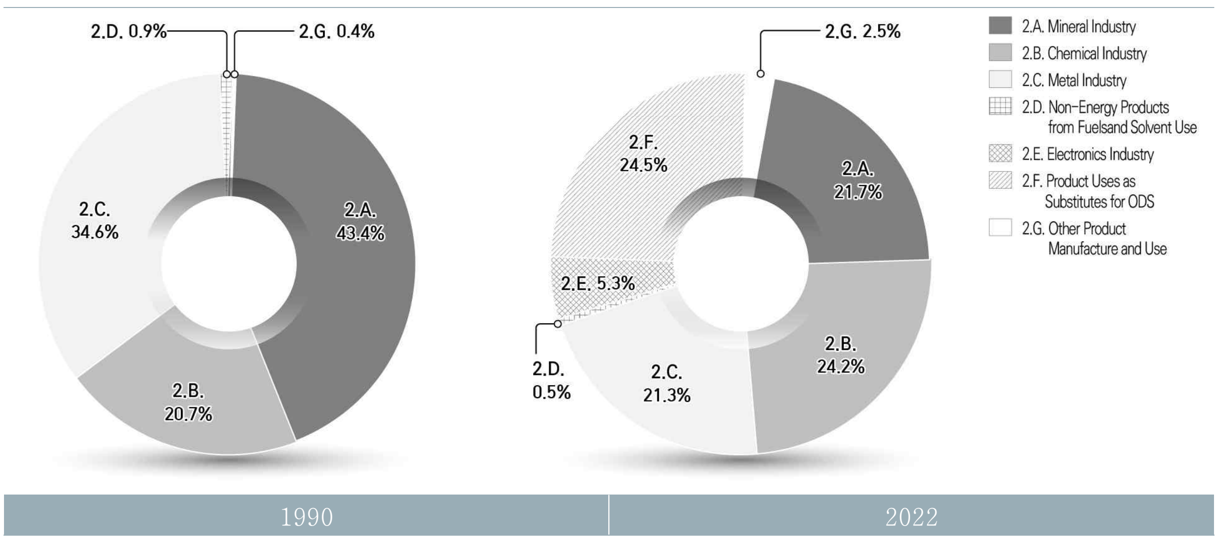
In the Mineral industry (2.A.), carbon dioxide (CO_2) is emitted through calcination of carbonate compounds during the production or consumption of minerals. In the Chemical industry (2.B.), all seven gases of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3) are emitted during the production of chemical products in the presence of a catalyst or released as by-product and fugitive emissions from chemical products. In the Metal industry (2.C.), emissions of CO_2, CH_4, HFCs, PFCs, and SF_6 occur from the consumption of raw materials, reducing agents and corrosion inhibitors during metal production. In Non-energy products from fuels and solvent use (2.D.), CO_2 is emitted in the process of the first use of fossil fuels as a product other than use as non-energy feedstocks. In the Electronics industry (2.E.), fluorinated greenhouse gases including HFCs, PFCs, SF_6, and NF_3 are emitted during the manufacture of electronic products such as semiconductors, displays and photovoltaic cells. In the Product uses as substitutes for ODS (2.F.), emissions of HFCs and PFCs occur from the processes of manufacturing, installation, operation and disposal of equipment or products that contain HFCs and PFCs. In Other product manufacture and use (2.G.), emissions of SF_6, PFCs, and N_2O occur during the processes of production and use of electrical equipment and other products.

1) Transitioning from the *Revised 1996 IPCC Guidelines* to the *2006 IPCC Guidelines*, non-energy use of fossil fuels and solvent which was previously reported under the Energy sector is now included in the IPPU sector.

2) The "Other" (2.H.) was reported as "NO" (Not Occurring) as neither relevant activities nor emissions occur in ROK.

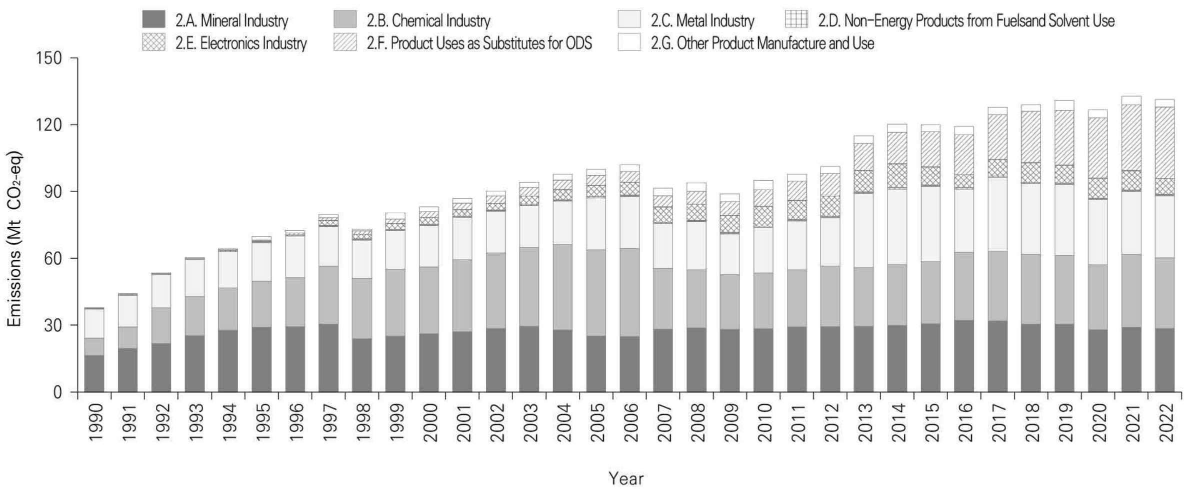
Emissions from the IPPU sector were estimated using activity data from a range of sources, but mostly from the Target Management System (TMS) and Emissions Trading Scheme (K-ETS). Data from TMS and K-ETS are verified by the third party and reviewed for its validity as activity data by the Greenhouse Gas Inventory and Research Center of Korea (GIR) and the corresponding governing ministry to ensure the completeness and time-series consistency of data, and adequacy of methodologies and emission factors. Categories that use TMS and K-ETS data include : Mineral industry (2.A.), Chemical industry (2.B.), Metal industry (2.C.), Electronics industry (2.E.) and Other product manufacture and use (2.G.). Since TMS and K-ETS data were available from 2007, activity data for emissions in years prior to 2007 were derived from other sources such as national statistics and field survey (see Section 1.3.2 Sources of Activity Data).

In 2022, greenhouse gas emissions from the IPPU sector were 131.3 Mt CO_2-eq, accounting for 18.1 percent of the national total. The majority of sectoral emissions was from the product uses of substitutes for ODS with 32.2 Mt CO_2-eq (24.5 percent), followed by the chemical industry with 31.8 Mt CO_2-eq (24.2 percent), the mineral industry with 28.4 Mt CO_2-eq (21.7 percent), the metal industry with 28.0 Mt CO_2-eq (21.3 percent), the electronics industry with 7.0 Mt CO_2-eq (5.3 percent), other product manufacture and use with 3.3 Mt CO_2-eq (2.5 percent), and non-energy products and solvent use with 0.6 Mt CO_2-eq (0.5 percent). Key categories in the IPPU sector include CO_2 emissions from cement production, CO_2 from lime production, CO_2 from petrochemical and carbon black production, flourinated gases from the electronics industry, fluorinated gases from refrigeration and air conditioning, and flourinated gases from other product manufacture and use (see Section 1.4 Key Category Analysis).



| Figure 4-1 | Category as a Portion of Total IPPU Emissions (1990 and 2022)

Emissions from the IPPU sector in 2022 increased by 247.3 percent from 1990. It was driven by a confluence of factors including the growth of the semiconductor and display industries, and increases in production of manufacturing industries such as cement, steel and petrochemicals as well as in the use of substitutes for ODS. The largest increase in emissions was observed from the category of product uses as substitutes for ODS due to the primary use of substitutes following the adoption of the Montreal Protocol and the Kigali Amendment. Emissions from electrical equipment were also significant in terms of trends over the time series compared to other subcategories.



| Figure 4-2 | Trends in Emissions from IPPU Sector (1990-2022)

| Table 4-1 | Emissions from IPPU Sector (1990-2022)

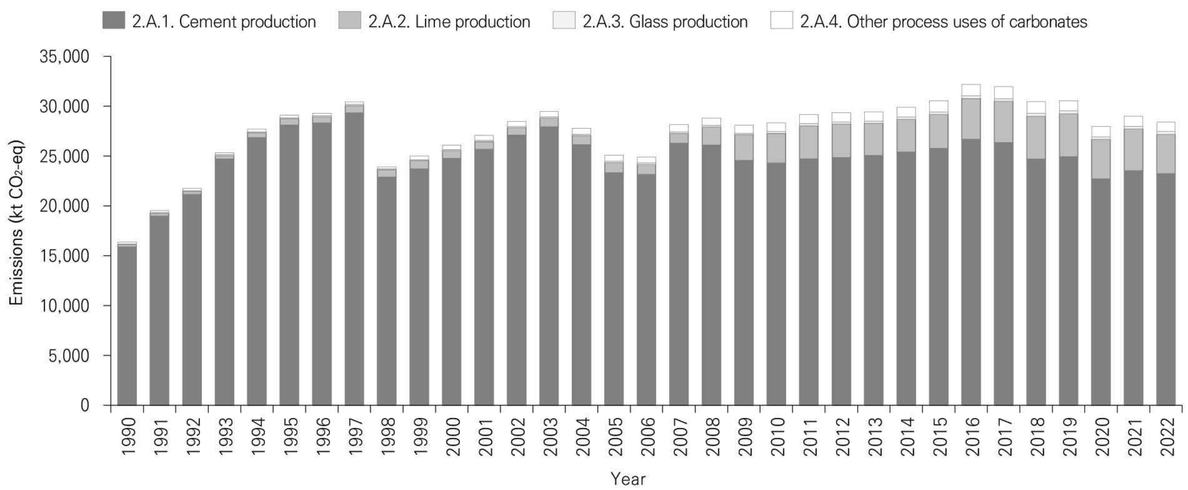
(Unit: Mt CO_2-eq)

Category	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
2.A. Mineral Industry	16.4	19.5	21.7	25.4	27.7	29.1	29.3	30.4	23.9	25.0	26.1
2.B. Chemical Industry	7.8	9.7	16.1	17.5	19.1	20.6	22.0	26.0	26.9	30.2	30.1
2.C. Metal Industry	13.1	14.3	14.9	16.7	16.3	17.5	18.6	17.8	17.4	17.3	18.5
2.D. Non-Energy Products and Solvent Use	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.4	0.5	0.5
2.E. Electronics Industry	IE,NA,NO	IE,NA,NO	IE,NA,NO	IE,NA,NO	IE,NA,NO	IE,NA,NO	IE,NA,NO	2.2	2.1	2.7	3.3
2.F. Product Uses as Substitutes for ODS	IE,NO	IE,NO	0.002	0.004	0.2	0.6	0.9	1.4	1.6	2.0	2.5
2.G. Other Product Manufacture and Use	0.2	0.3	0.3	0.4	0.5	1.5	1.1	1.3	0.8	2.6	2.2
Total	**37.8**	**44.2**	**53.5**	**60.4**	**64.3**	**69.7**	**72.6**	**79.6**	**73.2**	**80.3**	**83.1**
Category	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
2.A. Mineral Industry	27.1	28.5	29.5	27.8	25.1	24.9	28.2	28.8	28.1	28.3	29.2
2.B. Chemical Industry	32.3	34.0	35.5	38.5	38.8	39.4	27.2	26.0	24.7	25.1	25.6
2.C. Metal Industry	19.0	18.6	18.9	19.5	23.2	23.5	20.3	21.6	18.3	20.5	22.1
2.D. Non-energy Products and Solvent Use	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
2.E. Electronics Industry	3.0	3.1	3.6	4.6	5.1	5.9	6.9	7.4	7.8	8.9	8.6
2.F. Product Uses as Substitutes for ODS	2.9	3.4	3.9	4.3	4.6	4.8	5.1	5.8	6.1	7.4	8.7
2.G. Other Product Manufacture and Use	2.0	2.2	2.4	2.7	2.6	2.9	3.2	3.8	3.5	4.3	3.0
Total	**86.8**	**90.2**	**94.2**	**97.8**	**99.9**	**102.0**	**91.4**	**93.9**	**88.9**	**95.0**	**97.8**
Category	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
2.A. Mineral Industry	29.4	29.5	29.9	30.6	32.2	32.0	30.5	30.5	28.0	29.0	28.4
2.B. Chemical Industry	27.2	26.4	27.3	27.9	30.4	31.3	31.4	30.7	29.1	32.8	31.8
2.C. Metal Industry	21.8	33.3	33.9	33.7	28.5	33.1	31.7	31.9	29.3	28.2	28.0
2.D. Non-energy Products and Solvent Use	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.5	0.6	0.6
2.E. Electronics Industry	9.0	9.7	10.8	8.2	5.8	7.4	8.7	8.0	9.0	8.9	7.0
2.F. Product Uses as Substitutes for ODS	10.2	12.2	14.2	15.9	18.0	20.2	23.1	24.7	27.2	29.4	32.2
2.G. Other Product Manufacture and Use	3.2	3.3	3.5	2.9	3.7	3.3	2.9	4.4	3.7	3.9	3.3
Total	**101.3**	**115.0**	**120.2**	**119.9**	**119.3**	**127.9**	**128.9**	**130.9**	**126.8**	**132.8**	**131.3**

4.2 Mineral Industry (2.A.)

Under the mineral industry, CO_2 emissions resulting from the calcination of carbonate compounds during the production or consumption of minerals are reported[3]. Emissions are classified into subcategories of Cement Production (2.A.1.), Lime Production (2.A.2.), Glass Production (2.A.3.), and Other Process Uses of Carbonates (2.A.4.)[4].

In 2022, greenhouse gas emissions from the mineral industry were 28,421 kt CO_2-eq, accounting for 21.7 percent of the sectoral emissions. Cement production was the largest source accounting for 81.7 percent, followed by lime production of 13.9 percent, other process uses of carbonates of 3.4 percent, and glass production of 0.9 percent. A decrease of 585 kt CO_2-eq (2.0 percent) from 2021 was primarily driven by reduced emissions from cement production (289 kt CO_2-eq) and lime production (254 kt CO_2-eq).



| Figure 4-3 | Trends in Emissions from Mineral Industry (1990-2022)

3) In the IPPU sector, carbonate compounds used as raw materials include $CaCO_3$ (limestone), $CaMg(CO_3)_2$ (dolomite), and Na_2CO_3 (soda ash).

4) Under the *Revised 1996 IPCC Guidelines*, emissions from the consumption of limestone and dolomite were reported under the Limestone and Dolomite Use (2.A.3.). Under the *2006 IPCC Guidelines,* emissions from the consumption of carbonate compounds are included in the subcategory of the corresponding process (e.g. iron and steel production, and ferroalloy production in the metal industry). In the *2006 IPCC Guidelines*, subcategories of Glass production (2.A.3.) and Other process uses of carbonates (2.A.4.) are newly added.

| Table 4-2 | Emissions from Mineral Industry

(Unit: kt CO_2-eq)

Sub-category		1990	2000	2007	2010	2018	2021	2022
2.A.1.	Cement Production	15,871	24,754	26,273	24,294	24,700	23,516	23,227
2.A.2.	Lime Production	257	804	1,020	2,971	4,303	4,216	3,962
2.A.3.	Glass Production	57	110	136	224	303	255	260
2.A.4.	Other Process Uses of Carbonates	202	434	737	846	1,149	1,019	972

4.2.1 Cement Production (2.A.1.)

4.2.1.1 Category Overview

2022	Gas	Methodology	Emission Factor	Activity Data
	CO_2	Tier 2	CS, D	Clinker production

CO_2 is emitted during the production of clinker which involves the calcination of calcium carbonate ($CaCO_3$) in the form of limestone. In ROK, portland cement is predominantly produced while white portland cement is also produced in a small portion.

CO_2 emissions from cement manufacturing process

$CaCO_3$ (limestone) + heat → CaO (quicklime) + CO_2

In 2022, emissions from cement production were 23,227 kt CO_2-eq, representing a 1.2 percent decrease from 2021 due to less production of clinker.

| Table 4-3 | Emissions from Cement Production

(Unit: kt CO_2-eq)

Sub-category	1990	2000	2007	2010	2018	2021	2022
Cement Production	15,871	24,754	26,273	24,294	24,700	23,516	23,227

4.2.1.2 Methodology

4.2.1.2.1 Method

Emissions from cement production were estimated using the Tier 2 methodology of the *2006 IPCC Guidelines*.

CO₂ emissions from cement production		
$$CO_2\ Emissions = M_{cl} \times EF_{cl} \times CF_{ckd}$$		
CO_2 Emissions	:	CO_2 emissions from cement production (tonnes CO_2)
M_{cl}	:	clinker production (tonnes)
EF_{cl}	:	emission factor for clinker production (tonnes CO_2/tonne clinker production)
CF_{ckd}	:	correction factor for cement kiln dust (CKD, Cement Kiln Dust)

Source: *2006 IPCC Guidelines, Vol.3, Ch.2, Equation 2.2*

4.2.1.2.2 Emission Factor

For portland cement, the country-specific emission factor was used[5] while default values given in the *2006 IPCC Guidelines* were used for white portland cement as well as the CKD correction factor. As portland cement accounted for 99.7 percent of the total clinker production in 2022, the majority of emissions from cement production were estimated using the country-specific emission factor[6].

| Table 4-4 | Emission Factor for Cement Production

Type		Emission Factor	Source
Emission Factor	Portland Cement	0.5295 t CO_2/ t clinker	CS
	White Portland Cement	0.51 t CO_2/ t clinker	*2006 IPCC Guidelines*
Correction Factor (CF)	CKD	1.02	

Source: *2006 IPCC Guidelines, Vol.3, Ch.2, p.2.12*

5) The emission factor was developed in 2018 based on emissions in the 2013 to 2017 period reported by eight domestic clinker producers in their TMS and K-ETS data.

6) Emissions from white portland cement for which the default emission factor was used accounted for only 0.3 percent of cement production emissions.

4.2.1.2.3 Activity Data

For the 1990 to 2006 period, clinker production data were obtained from the *Statistical Yearbook of Cement* published by the Korea Cement Association (KCA) and from field surveys on non-member producers[7] collected by the Korea Energy Agency (KEA).[8] Data from 2007 onward were sourced from TMS and K-ETS.

| Table 4-5 | Activity Data Source for Cement Production

Period	Activity Data	Name of Statistics	Published by	Gas
1990-2006	Clinker production	*Statistical Yearbook of Cement*	Korea Cement Association (KCA)	CO_2
		Field surveys	Korea Energy Agency (KEA)	
2007-2022		TMS and K-ETS data	Ministry of Environment (MOE)	

| Table 4-6 | Activity Data for Cement Production

(Unit: kt)

Amount	1990	2000	2007	2010	2018	2021	2022
Clinker Production	29,390	45,837	48,650	44,988	45,737	43,546	43,011

4.2.1.3 Uncertainty and Time-series Consistency

4.2.1.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

4.2.1.3.2 Time-series Consistency

Emissions from cement production were estimated using consistent method and emission factors for the entire reporting period. Activity data for the 1990 to 2006 period were from *Statistical Yearbook of Cement* and field surveys conducted by KEA while data from 2007 onward were sourced from TMS and K-ETS. To maintain time-series consistency, the approach of tracking changes in activity data and emissions across the time series was used. Clinker production from all cement producers in ROK were incorporated into the inventory for all years in the time series to ensure time-series consistency.

7) Data from field surveys were used to ensure that clinker production of all domestic cement producers were incorporated into the inventory.

8) Since emissions of TMS and K-ETS entities have been submitted only after the implementation of respective systems, relevant data prior to TMS and ETS were collected from the existing statistics from KCA and field surveys from KEA.

4.2.1.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

4.2.1.5 Planned Improvements

Cement production was a key category in 2022 of which emissions were estimated using the Tier 2 method with both default factors and country−specific factor. As 99.7 percent of emissions from this category were estimated using the country−specific emission factor. there is no improvement plan for estimation of emissions that used default factors.

4.2.2 Lime Production (2.A.2.)

4.2.2.1 Category Overview

2022	Gas	Methodology	Emission Factor	Activity Data
	CO_2	Tier 2	D	Lime production

Lime is used across industries in alloy, pulp and paper, wastewater treatment, soil stabilization, and fertilizers. CO_2 is released during the process of lime calcination to decompose the carbonates. In ROK, only CaO (quicklime) and CaO·MgO (dolomitic lime) are produced.

CO_2 emissions from lime production process

$CaCO_3$ (limestone) + heat → CaO (quicklime) + CO_2

$CaCO_3 \cdot MgCO_3$ (dolomite) + heat → CaO·MgO (dolomitic lime) + $2CO_2$

In 2022, emissions from lime production were 3,962 kt CO_2−eq which was a decrease of 6.0 percent from 2021 due to reduced lime production.

| Table 4−7 | Emissions from Lime Production

(Unit: kt CO_2−eq)

Sub−category	1990	2000	2007	2010	2018	2021	2022
Lime Production	257	804	1,020	2,971	4,303	4,216	3,962

4.2.2.2 Methodology

4.2.2.2.1 Method

Emissions from lime production were estimated using the Tier 2 methodology of the *2006 IPCC Guidelines.*

CO_2 emissions from lime production

$$CO_2\ \text{Emissions} = \sum_i (EF_{lime,i} \times M_{1,i} \times CF_{lkd,i} \times C_{h,i})$$

CO_2 Emissions	:	CO_2 emissions from lime production (tonnes CO_2)
$EF_{lime,i}$	:	emission factor for lime of type i (high–calcium lime, dolomitic lime) (tonnes CO_2 / tonne lime produced of type $_i$)
$M_{1,i}$	:	amount of lime produced by type $_i$ (tonnes)
$CF_{lkd,i}$	:	correction factor for lime kiln dust (LKD)
$C_{h,i}$	:	correction factor for hydrated lime by type
i	:	lime by type (high–calcium lime, dolomitic lime)

Source: *2006 IPCC Guidelines, Vol.3, Ch.2, Equation 2.6*

4.2.2.2.2 Emission Factor

Default values of emission factors and correction factors provided in the *2006 IPCC Guidelines* were used.

| Table 4–8 | Emission Factor for Lime Production

Emission/Correction Factor		Factor Value	Source
Emission Factor	High–Calcium Lime	0.746 t CO_2/t Lime Production[1)]	*2006 IPCC Guidelines*
	Dolomitic Lime	0.776 t CO_2/t Lime Production[2)]	
Correction Factor	LKD	1.02	
	Hydrated Lime	0.97	

Note: 1) Emission factor (0.746) = stoichiometric ratio (0.785) × default value for CaO or CaO/MgO Content (0.95)
2) Emission factor (0.776) = stoichiometric ratio (0.913) × default value for CaO or CaO/MgO Content (0.85)
Source: *2006 IPCC Guidelines, Vol.3, Ch.2, Table 2.4; p.2.24*

4.2.2.2.3 Activity Data

Lime production data for years prior to 2006 were sourced from the Korea Limestone Industry Cooperative (KLIC) and from field surveys collected by KEA for producers that are not members of KLIC. Data from 2007 onward were sourced from TMS and K–ETS.

| Table 4-9 | Activity Data Source for Lime Production

Period	Activity Data	Name of Statistics	Published by	Gas
1990-2006	Production of high-calcium lime and dolomitic lime	Limestone production statistics	Korea Limestone Industry Cooperative (KLIC)	CO_2
		Field surveys	Korea Energy Agency (KEA)	
2007-2022		TMS and K-ETS data	Ministry of Environment (MOE)	

| Table 4-10 | Activity Data for Lime Production

(Unit: kt)

Production Amount	1990	2000	2007	2010	2018	2021	2022
High-calcium Lime	348	922	1,327	3,814	5,066	4,888	4,560
Dolomitic Lime	NO	160	53	204	736	793	778
Total	348	1,083	1,380	4,018	5,802	5,681	5,338

4.2.2.3 Uncertainty and Time-series Consistency

4.2.2.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

4.2.2.3.2 Time-series Consistency

Emissions from lime production were estimated using consistent method and emission factors for the entire reporting period. Activity data for the 1990 to 2006 period were from KLIC data and field surveys collected by KEA while data from 2007 onward were sourced from TMS and K-ETS. Lime production from all lime producers in ROK were incorporated into the inventory for all years in the time series to ensure time-series consistency.

4.2.2.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

4.2.2.5 Planned Improvements

Emissions from lime production which was a key category in 2022 were estimated using the Tier 2 method with default factors. ROK will explore the potential to develop the country-specific emission factor for this category.

4.2.3 Glass Production (2.A.3.)

4.2.3.1 Category Overview

2022	Gas	Methodology	Emission Factor	Activity Data
	CO_2	Tier 1	D	Glass production

Glass production results in CO_2 emissions during the melting process which employs the major raw materials of silicon dioxide (SiO_2), calcium carbonate ($CaCO_3$), calcium magnesium carbonate ($CaMg(CO_3)_2$), and sodium carbonate (Na_2CO_3).

CO_2 emissions from glass production process

$CaCO_3$ (Limestone) + heat → CaO (high−calcium lime) + CO_2

$CaMg(CO_3)_2$ (dolomite) + heat → CaO·MgO (dolomitic lime) + $2CO_2$

Na_2CO_3 (soda ash) + heat → Na2O (sodium oxide) + CO_2

In 2022, emissions from glass production were 260 kt CO_2−eq which increased by 2.0 percent from 2021 due to increased glass production.

| Table 4−11 | Emissions from Glass Production

(Unit: kt CO_2−eq)

Sub−category	1990	2000	2007	2010	2018	2021	2022
Glass Production	57	110	136	224	303	255	260

4.2.3.2 Methodology

4.2.3.2.1 Method

Emissions from glass production were estimated using the Tier 1 methodology of the *2006 IPCC Guidelines*.

CO$_2$ missions from glass production
$$CO_2\ Emissions = M_g \times EF \times (1-CR)$$
CO_2 Emissions : CO_2 emissions from glass production (tonnes CO_2)
M_g : mass of glass produced (tonnes)
EF : default emission factor for glass production(tonnes CO_2/tonne glass)
CR : cullet ratio for process (default value: 0.5)

Source: *2006 IPCC Guidelines, Vol.3, Ch.2, Equation 2.10*

4.2.3.2.2 Emission Factor

Default values for CO_2 emission factor and cullet ratio provided in the *2006 IPCC Guidelines* were used.

| Table 4-12 | Emission Factor for Glass Production

Emission Factor	Factor Value	Source
Emission Factor	0.20 t CO_2/t glass	*2006 IPCC Guidelines*
Cullet Ratio	0.50	

Source: *2006 IPCC Guidelines, Vol.3, Ch.2, Table 2.6*

4.2.3.2.3 Activity Data

For years prior to 2018, glass production data were sourced from field surveys by KEA. Those from 2018 onward were sourced from data on bottle glass production provided by the Korea Glass Industry Cooperative (KGIC) and data on non-bottle glass such as glass substrates, flat glass and glass fiber from TMS and K-ETS.

| Table 4-13 | Activity Data Source for Glass Production

Period	Activity Data	Name of Statistics	Published by	Gas
1990-2017	Glass production	Field surveys	Korea Energy Agency (KEA)	CO_2
2018-2022		TMS and K-ETS data	Ministry of Environment (MOE)	
		Bottle glass production statistics	Korea Glass Industry Cooperative (KGIC)	

| Table 4-14 | Activity Data for Glass Production

(Unit: kt)

Amount	1990	2000	2007	2010	2018	2021	2022
Glass Production	574	1,097	1,365	2,236	3,026	2,555	2,605

4.2.3.3 Uncertainty and Time-series Consistency

4.2.2.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

4.2.3.3.2 Time-series Consistency

Emissions from glass production were estimated using consistent method and emission factors for the entire reporting period. For the 1990 to 2017 period, field survey data were used. From 2018 onward, data were sourced from KGIC as well as TMS and K-ETS. Glass production of all domestic glass producers were incorporated into the inventory in order to ensure time-series consistency.

4.2.3.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

4.2.4 Other Process Uses of Carbonates (2.A.4.)

4.2.4.1 Category Overview

Carbonates such as limestone ($CaCO_3$), dolomite ($CaMg(CO_3)_2$), magnesite ($MgCO_3$), and sodium carbonate (Na_2CO_3, soda ash) are used across a range of industries including the metal industry as well as glass, ceramics and non-metallurgical magnesia production. Emissions from the process use of such carbonates are reported under either Ceramics (2.A.4.a.), Other uses of soda ash (2.A.4.b.), Non-metallurgical magnesia production (2.A.4.c.) or Other (2.A.4.d.).

Emission from carbonate consumption not included in Cement production (2.A.1.), Lime production (2.A.2.), Glass production (2.A.3.), Other uses of soda ash (2.A.4.) of the Mineral Industry as well as such consumption not included in the Metal Industry (2.C.) were included in Other (2.A.4.d). Emissions from the carbonate use for Ceramics (2.A.4.a.) of which processes cannot be disaggregated were also included in Other (2.A.4.d.). Non-metallurgical magnesia production (2.A.4.c.) does not occur in ROK. Accordingly, emissions from this subcategory were reported only under Other uses of soda ash (2.A.4.b.) and Other (2.A.4.d.).

In 2022, emissions from other process uses of carbonates were 972 kt CO_2-eq which decreased by 4.6 percent from 2021.

| Table 4-15 | Emissions from Other Process Uses of Carbonates

(Unit: kt CO_2-eq)

Sub-category		1990	2000	2007	2010	2018	2021	2022
2.A.4.a.	Ceramics[1]	IE	IE	IE	IE	IE	IE	IE
2.A.4.b.	Other Uses of Soda Ash	202	231	170	107	79	62	56
2.A.4.c.	Non-metallurgical Magnesia Production	NO	NO	NO	NO	NO	NO	NO
2.A.4.d.	Other	NE	203	567	739	1,069	956	916
Total		202	434	737	846	1,149	1,019	972

Note: 1) Emissions from Ceramics (2.A.4.a.) were included in Other (2.A.4.d.).

4.2.4.2 Other Uses of Soda Ash (2.A.4.b.)

4.2.4.2.1 Category Overview

	Gas	Methodology	Emission Factor	Activity Data
2022	CO_2	Tier 1	D	Soda ash production, imports and exports

Soda ash is used in the production of glass, soap, detergents, chemicals, pulp, and paper of which production and consumption results in CO_2 emissions during the calcination. Emissions from soda ash used in glass production were reported under the Glass production (2.A.3), not under this subcategory.

CO_2 Emissions from Other Uses of Soda Ash

$$Na_2CO_3 \text{ (soda ash)} + \text{heat} \rightarrow Na_2O \text{ (sodium oxide)} + CO_2$$

In 2022, emissions from other uses of soda ash were 56 kt CO_2-eq which decreased by 10.5 percent from 2021.

| Table 4-16 | Emissions from Other Uses of Soda Ash

(Unit: kt CO_2-eq)

Sub-category	1990	2000	2007	2010	2018	2021	2022
Other Uses of Soda Ash	202	231	170	107	79	62	56

4.2.4.2.2 Methodology

4.2.4.2.2.1 Method

Emissions from other uses of soda ash were estimated using the Tier 1 method of the *2006 IPCC Guidelines* by multiplying the amount of soda ash consumed by the emission factor.

CO_2 emissions from other uses of soda ash

$$CO_2\ Emissions = M \times EF$$

CO_2 Emissions	:	CO_2 emissions from other uses of soda ash (tonnes CO_2)
M	:	amount of soda ash consumed (tonnes)
EF	:	emission factor for soda ash consumption (tonnes CO_2 / tonne soda ash consumed)

Source: *2006 IPCC Guidelines, Vol.3, Ch.2, Equation 2.14*

4.2.4.2.2.2 Emission Factor

The default value of CO_2 emission factor provided in the *2006 IPCC Guidelines* was used.

| Table 4-17 | Emission Factor for Other Uses of Soda Ash

Emission Factor	Source
0.41492 t CO_2/t carbonate	*2006 IPCC Guidelines*

Source: *2006 IPCC Guidelines, Vol.3, Ch.2, Table 2.1*

4.2.4.2.2.3 Activity Data

Activity data were based on the amount of soda ash consumption[9] calculated using domestic production, and import and export volumes. For the 1990 to 2004 period, domestic production data were sourced from field surveys conducted by KEA on soda ash producers. In ROK, soda ash was produced until 2004 which was followed by the closure of the last producer in 2005. Import and export data for the entire time series were derived from the *Trade Statistics.*

9) Consumption = Production + Imports - Exports - Consumption for Glass production (2.A.3.)

| Table 4-18 | Activity Data Source for Other Uses of Soda Ash

Period	Activity Data	Name of Statistics	Published by	Gas
1990-2004	Soda ash production	Field surveys	Korea Energy Agency (KEA)	CO_2
1990-2022	Soda ash imports and exports	*Trade Statistics*	Korea Customs Service (KCS)	

| Table 4-19 | Activity Data for Other Uses of Soda Ash

(Unit: kt)

Amount	1990	2000	2007	2010	2018	2021	2022
Soda Ash Production[10] Ⓐ	335	341	NO	NO	NO	NO	NO
Soda Ash Imports Ⓑ	220	352	572	524	552	455	445
Soda Ash Exports Ⓒ	0.2	4.9	0.7	0.07	0.06	0.3	0.5
Consumption for Glass Production Ⓓ	68	131	162	266	360	304	310
Consumption (Ⓐ+Ⓑ-Ⓒ-Ⓓ)	**486**	**557**	**409**	**258**	**192**	**150**	**134**

4.2.4.2.3 Uncertainty and Time-series Consistency

4.2.4.2.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

4.2.4.2.3.2 Time-series Consistency

Emissions from other uses of soda ash were estimated using method and emission factors consistently for the entire reporting period. As the last domestic soda ash producer closed in 2005, production data for the 1990 to 2004 period were used.

4.2.4.2.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

10) Domestic soda ash production which was available until 2004 ceased in 2005.

4.2.4.3 Other (2.A.4.d.)

4.2.4.3.1 Category Overview

2022	Gas	Methodology	Emission Factor	Activity Data
	CO_2	Tier 2	D	Limestone, dolomite and magnesite consumption

CO_2 emissions from carbonate consumption that were not included in Cement production (2.A.1.), Lime production (2.A.2.), Glass production (2.A.3.), Other uses of soda ash (2.A.4.b.) and Metal industry (2.C.) were reported under this subcategory. Emissions from carbonate consumption for Ceramics (2.A.4.a.) were also included in this subcategory.

CO_2 emissions from carbonate consumption

$$CaCO_3 \text{ (limestone) } + \text{ heat} \rightarrow CaO \text{ (quicklime) } + CO_2$$
$$CaMg(CO_3)_2 \text{ (dolomite) } + \text{ heat} \rightarrow CaO{\cdot}MgO \text{ (dolomitic lime) } + 2CO_2$$

In 2022, emissions from this subcategory were 916 kt CO_2-eq, representing a decrease of 4.2 percent from 2021.

| Table 4-20 | Emissions from Other

(Unit: kt CO_2-eq)

Sub-category	1998[11]	2000	2007	2010	2018	2021	2022
Other	11	203	567	739	1,069	956	916

4.2.4.3.2 Methodology

4.2.4.3.2.1 Method

Emissions were estimated using the Tier 2 method of the *2006 IPCC Guidelines* by multiplying the amount of carbonates consumed by the emission factor.

11) Emissions from other uses of carbonates were estimated since 1998. As emissions in 1998 for which activity data were initially collected were insignificant accounting for less than 0.05 percent of total national emissions as defined in Article 32 of the Modalities, Procedures and Guidelines (MPGs), it was considered that the likely level of emissions prior to 1998 were zero or insignificant as well. Accordingly, emissions in the 1990 to 1997 period were not estimated.

CO₂ emissions from Other

CO₂ emissions from Other

$$CO_2 \text{ Emissions} = M \times EF$$

CO_2 Emissions : CO_2 emissions from other process uses of carbonates (tonnes CO_2)
M : amount of carbonates consumed (limestone, dolomite, magnesite) (tonnes)
EF : emission factor by carbonate type (tonnes CO_2 / tonne carbonate consumed)

Source: *2006 IPCC Guidelines, Vol.3, Ch.2, Equation 2.15*

4.2.4.3.2.2 Emission Factor

For CO_2 emission factors, default values provided in the *2006 IPCC Guidelines* were used.

| Table 4-21 | Emission Factor for Other

Type	Emission Factor	Source
Limestone	0.43971 t CO_2/t limestone	*2006 IPCC Guidelines*
Dolomite	0.47732 t CO_2/t dolomite	
Magnesite	0.52197 t CO_2/t magnesite	

Source: *2006 IPCC Guidelines, Vol.3, Ch.2, Table 2.1*

4.2.4.3.2.3 Activity Data

Carbonate consumption data for the 1998 to 2006 period were sourced from field surveys collected by KEA. From 2007 onward, data from TMS and K-ETS were used.[12)]

| Table 4-22 | Activity Data Source for Other

Period	Activity Data	Name of Statistics	Published by	Gas
1998-2006	Limestone, dolomite, and magnesite consumption	Field surveys	Korea Energy Agency (KEA)	CO_2
2007-2022		TMS and K-ETS data	Ministry of Environment (MOE)	

12) Field survey was conducted by KEA on carbonate-consuming sectors such as power generation and district energy supply.

| Table 4-23 | Activity Data for Other

(Unit: kt)

Amount	1998	2000	2007	2010	2018	2021	2022
Limestone Consumption	25	462	1,283	1,674	2,412	2,038	1,956
Dolomite Consumption	NO	NO	NO	NO	11	9	11
Magnesite Consumption	NO	NO	6	6	7	107	97
Total	25	462	1,289	1,680	2,429	2,154	2,064

4.2.4.3.3 Uncertainty and Time-series Consistency

4.2.4.3.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

4.2.4.3.3.2 Time-series Consistency

Emissions from this subcategory were estimated using method and emission factor consistently for the entire reporting period. For activity data, field surveys were used for the 1998 to 2006 period until TMS/K-ETS data were applied from 2007 onward. The volume of carbonates consumed by all domestic producers were incorporated into the inventory in order to ensure time-series consistency.

4.2.4.3.4 QA/QC

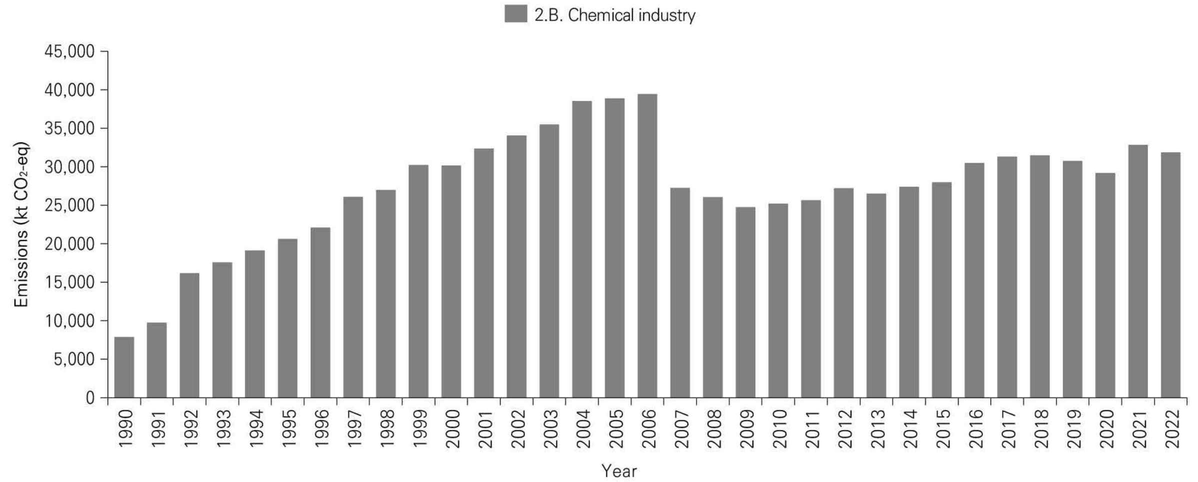
General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

4.3 Chemical Industry (2.B.)

Under the reporting category of chemical Industry, emissions of CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, and NF_3 from the manufacturing processes of chemical products are estimated and reported under Ammonia Production (2.B.1.), Nitric Acid Production (2.B.2.), Adipic Acid Production (2.B.3.), Caprolactam, Glyoxal, and Glyoxylic Acid Production (2.B.4.), Carbide Production (2.B.5.), Titanium Dioxide Production (2.B.6.), Soda Ash Production (2.B.7.), Petrochemical and Carbon Black Production (2.B.8.), and Fluorochemical Production (2.B.9.).

Emissions from titanium dioxide production do not occur as domestic producers use the sulfate process which does not produce CO_2 emissions. Similarly, emissions from soda ash production do not occur as domestic production which were available from 1990 to 2004 employed the Solvay process that did not result in CO_2 emissions. Emissions from ammonia production, adipic acid production, caprolactam, gyoxal and glyoxylic acid production, and carbide production were included in Other (2.B.10.) to protect confidential information of domestic chemical producers.

In 2022, emissions from the chemical industry were 31,824 kt CO_2-eq which accounted for 24.2 percent of sectoral emissions and represented a decrease of 3.0 percent from 2021. The largest source under this reporting category was the production of petrochemical products and carbon black which accounted for the majority share of 99.1 percent, followed by nitric acid production and fluorochemical production of 0.3 percent each. The overall reduction of 975 kt CO_2-eq from 2021 was primarily driven by a decrease of 774 kt CO_2-eq (3.5 percent) in emissions from ethylene production under the petrochemical and carbon black production. Emissions from the majority of the remaining subcategories under the chemical industry also declined from 2021.



| Figure 4-4 | Trends in Emissions from Chemical Industry (1990-2022)

| Table 4-24 | Emissions from Chemical Industry

(Unit: kt CO_2-eq)

	Sub-category	1990	2000	2007	2010	2018	2021	2022
2.B.1.	Ammonia Production	IE,NA	IE,NA	IE,NA	IE,NA	IE,NA	IE,NA	IE,NA
2.B.2.	Nitric Acid Production	219	1,064	464	160	292	190	96
2.B.3.	Adipic Acid Production	IE,NO	IE,NO	IE,NO	IE,NO	IE,NO	IE,NO	IE,NO
2.B.4.	Caprolactam Production	IE,NO	IE,NO	IE,NO	IE,NO	IE,NO	IE,NO	IE,NO
2.B.5.	Carbide Production	IE,NO	IE,NO	IE,NO	IE,NO	IE,NO	IE,NO	IE,NO
2.B.6.	Titanium Dioxide Production	NO	NO	NO	NO	NO	NO	NO
2.B.7.	Soda Ash Production	NO	NO	NO	NO	NO	NO	NO
2.B.8.	Petrochemical and Carbon Black Production	5,304	19,371	25,155	23,680	30,939	32,388	31,529
2.B.9.	Fluorochemical Production	1,042	3,430	0.12	29	88	96	95
2.B.10.	Other[1)]	1,256	6,234	1,590	1,264	126	124	105

Note: 1) Emissions from Ammonia production (2.B.1.), Adipic acid production (2.B.3.), Caprolactam, glyoxal, and glyoxylic acid production (2.B.4.), and Carbide production (2.B.5.) were included in Other (2.B.10.).

4.3.1 Ammonia Production (2.B.1.)

4.3.1.1 Category Overview

Ammonia (NH_3) is used as a raw material in the production of a range of nitrogen compound products such as fertilizers, heat treatment, paper pulping, nitric acid and nitrates manufacture, nitro compound manufacture, explosives and refrigerants. Ammonia is produced from natural gas, cokes or naphtha of which the process produces CO_2 emissions. In ROK, naphtha and butane are used as the primary feedstocks for ammonia production. Emissions of CH_4 and N_2O from ammonia production were reported as "Not Applicable (NA)" due to the absence of default emission factors in the *2006 IPCC Guidelines.*[13] .

4.3.1.2 Methodology

4.3.1.2.1 Method

CO_2 emissions from ammonia production were estimated using the Tier 1 method from the *2006 IPCC Guidelines* by multiplying the volume of ammonia production by the fuel requirement per unit of production, the carbon content and oxidation factor of the fuel.

CO_2 emissions from ammonia production

$$CO_2\ Emissions = AP \times FR \times CCF \times COF \times 44/12 - R_{CO2}$$

CO_2 Emissions	:	CO_2 emissions from ammonia production (kg CO_2)
AP	:	ammonia production (tonnes)
FR	:	fuel requirement per unit of production (GJ / t ammonia produced)
CCF	:	carbon content of the fuel (kg C / GJ)
COF	:	carbon oxidation factor of the fuel
R_{CO2}	:	CO_2 recovered (kg)

Source: *2006 IPCC Guidelines, Vol.3, Ch.3, Equation 3.1*

4.3.1.2.2 Emission Factor

For the fuel requirement per unit of production (FR), carbon content of the fuel (CCF), and carbon oxidation factor (COF), default emission factors from the *2006 IPCC Guidelines* were used.

13) Emissions from ammonia production were included in Other (2.B.10.) to protect confidential information of domestic producers.

| Table 4-25 | Emission Factor for Ammonia Production

Emission Factor	Factor Value	Source
Fuel Requirement per Unit of Production (FR)	37.5 GJ/t ammonia produced	*2006 IPCC Guidelines*
Carbon Content of Fuel (CCF)	15.3 kg C/GJ	
Carbon Oxidation Factor of Fuel (COF)	1	

Source: *2006 IPCC Guidelines, Vol.3, Ch.3, Table 3.1*

4.3.1.2.3 Activity Data

The volume of ammonia production was sourced from field surveys conducted by KEA on domestic ammonia producers.

|Table 4-26| Activity Data Source for Ammonia Production

Period	Activity Data	Name of Statistics	Published by	Gas
1990-2011	Ammonia production	Field surveys	Korea Energy Agency (KEA)	CO_2

4.3.1.3 Uncertainty and Time-series Consistency

4.3.1.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

4.3.1.3.2 Time-series Consistency

Emissions from ammonia production were estimated using method, emission factors and activity data consistently for the entire reporting period.

4.3.1.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

4.3.2 Nitric Acid Production (2.B.2.)

4.3.2.1 Category Overview

2022	Gas	Methodology	Emission Factor	Activity Data
	N_2O	Tier 2	PS	N_2O emissions

Nitric acid (HNO_3) is primarily used as a raw material for nitrogen fertilizers and production of adipic acid which is used in nylon and explosives. During the production of nitric acid, N_2O is generated as a by-product when ammonia (NH_3) is oxidized at high temperatures in the presence of a catalyst. Nitric acid is produced through either medium pressure or high pressure process. Since N_2O is more readily generated under high-pressure conditions, the high pressure process results in more emissions. In ROK, most plants produce nitric acid through the high pressure process while some plants employ the medium pressure process.

In 2022, emissions from nitric acid production were 96 kt CO_2-eq, representing a decrease of 49.2 percent from 2021. Since 2007, Clean Development Mechanism (CDM) projects implemented by nitric acid producers contributed to reduction in emissions, resulting in a decrease of 71.9 percent in emissions from 2006.

| Table 4-27 | Emissions from Nitric Acid Production

(Unit: kt CO_2-eq)

Sub-category	1990	2000	2007	2010	2018	2021	2022
Nitric Acid Production	219	1,064	464	160	292	190	96

4.3.2.2 Methodology

4.3.2.2.1 Method

For years prior to 2007, emissions were estimated using the Tier 1 method from the *2006 IPCC Guidelines*. From 2007 onward, emissions from TMS and K-ETS data were aggregated and reported[14].

14) Emissions from TMS and K-ETS data were estimated using Tier 2 methodology with the default emission factor in accordance with the *2006 IPCC Guidelines*.

N_2O emissions from nitric acid production

$$N_2O\ Emissions = EF \times NAP$$

N_2O Emissions	: N_2O emissions from nitric acid production (kg N_2O)
EF	: N_2O emission factor for nitric acid production (kg N_2O / tonne nitric acid produced)
NAP	: amount of nitric acid produced (tonnes)

Source: *2006 IPCC Guidelines, Vol.3, Ch.3, Equation 3.5*

4.3.2.2.2 Emission Factor

Default emission factors for each high- and medium- pressure processes provided in the *2006 IPCC Guidelines* were used.

| Table 4-28 | Emission Factor for Nitric Acid Production

Emission Factor	Factor Value	Source
Medium Pressure	7.0 kg N_2O/t Nitric Acid Production	*2006 IPCC Guidelines*
High Pressure	9.0 kg N_2O/t Nitric Acid Production	

Source: *2006 IPCC Guidelines, Vol.3, Ch.3, Table 3.3*

4.3.2.2.3 Activity Data

For years prior to 2007, nitric acid production data were based on field surveys collected by KEA. From 2007 onward, data from TMS and K-ETS and as well as CDM Monitoring Reports were used[15].

| Table 4-29 | Activity Data Source for Nitric Acid Production

Period	Activity Data	Name of Statistics	Published by	Gas
1990-2006	Nitric acid production	Field surveys	Korea Energy Agency (KEA)	N_2O
2007-2022	N_2O emissions from nitric acid production	TMS and K-ETS data	Ministry of Environment (MOE)	
		CDM Monitoring Report	UNFCCC	

15) · Project 0922: Catalytic N_2O Abatement Project in the Tail Gas of the Nitric Acid Plant of the Hanwha Corporation (HWC) in Ulsan, Republic of Korea (UNFCCC)
· Project 6637: Reduction of N2O emissions from the new nitric acid plant #5 of Hu-Chems Fine Chemical Corp (UNFCCC)
· Project 0765: Catalytic N2O destruction project in the tail gas of three Nitric Acid Plants at Hu-Chems Fine Chemical Corp (UNFCCC)
· Project 1443: Project for the catalytic reduction of N2O emissions with a secondary catalyst inside the ammonia reactor of the nitric acid plant at Dongbu Hannong Chemicals Ltd., Ulsan, Korea (UNFCCC)

| Table 4-30 | Activity Data for Nitric Acid Production

(Unit: kt)

Amount	1990	2000	2007	2010	2018	2021	2022
Nitric Acid Production	92	446	774	826	1,171	1,305	1,283

4.3.2.3 Uncertainty and Time-series Consistency

4.3.2.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

4.3.2.3.2 Time-series Consistency

Emissions from nitric acid production prior to 2007 were estimated using methodology, emission factors and activity data consistently in accordance with the *2006 IPCC Guidelines*. From 2007 onward, emissions were calculated using data from TMS and K-ETS to ensure accuracy and consistency across the time series.

4.3.2.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

4.3.3 Adipic Acid Production (2.B.3.)

4.3.3.1 Category Overview

2022	Gas	Methodology	Emission Factor	Activity Data
	N_2O	Tier 2	PS	N_2O emissions

Adipic acid ($C_6H_{10}O_4$) is a raw material used in the manufacture of products such as synthetic fibres, coatings, plastics, urethane foam, synthetic rubber and synthetic lubricants. During the production of adipic acid, N_2O is generated as a by-product in the process of nitric acid oxidation of cyclohexanone ($(CH_2)_5CO$) and cyclohexanol ($(CH_2)_5CHOH$).[16)]

16) As adipic acid is currently produced by a single company in ROK, activity data and emissions were included in "Other" (2.B.10.) to protect confidential information.

N_2O Emissions from Adipic Acid Production Process
$(CH_2)_5CO$ (cyclohexanone) + $(CH_2)_5CHOH$ (cyclohexanol) + $wHNO_3$
↓
$HOOC(CH_2)_4COOH$ (adipic acid) + xN_2O + yH_2O

4.3.3.2 Methodology

4.3.3.2.1 Method

For years prior to 2006, emissions were estimated using the Tier 1 method from the *2006 IPCC Guidelines*. From 2006 onward, emissions as reported in TMS and K-ETS data as well as *CDM Monitoring Reports* were aggregated to total emissions from this subcategory.[17]

N_2O emissions from adipic acid production

$$N_2O\ \text{Emissions} = EF \times AAP$$

N_2O Emissions	:	N_2O emissions from adipic acid production (kg N_2O)
EF	:	emission factor for adipic acid production (kg N_2O/ tonne adipic acid produced)
AAP	:	amount of adipic acid produced (tonnes)

Source: *2006 IPCC Guidelines, Vol.3, Ch.3, Equation 3.7*

4.3.3.2.2 Emission Factor

The default N_2O emission factor for the adipic acid production provided in the *2006 IPCC Guidelines* was used.

| Table 4-31 | Emission Factor for Adipic Acid Production

Emission Factor	Source
300 kg N_2O/tonne Adipic Acid Production	*2006 IPCC Guidelines*

Source: *2006 IPCC Guidelines, Vol.3, Ch.3, Table 3.4*

4.3.3.2.3 Activity Data

For years prior to 2006, activity data were based on field surveys collected by KEA. Data from 2006 onward were sourced from TMS, K-ETS and *CDM Monitoring Reports*.[18]

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17) Emissions reported for TMS and K-ETS were estimated using Tier 2 methodology with the default emission factor and plant-specific emission factor in accordance with the *2006 IPCC Guidelines*.

18) Project 0099: N2O Emission Reduction in Onsan, Republic of Korea (UNFCCC)

| Table 4-32 | Activity Data Source for Adipic Acid Production

Period	Activity Data	Name of Statistics	Published by	Gas
1990-2005	Adipic acid production	Field surveys	Korea Energy Agency (KEA)	N_2O
2006	N_2O emissions from adipic acid production	*CDM Monitoring Report*	UNFCCC	
2007-2022		TMS and K-ETS data	Ministry of Environment (MOE)	

4.3.3.3 Uncertainty and Time-series Consistency

4.3.3.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

4.3.3.3.2 Time-series Consistency

Emissions from adipic acid production prior to 2006 were estimated using methodology, emission factors and activity data consistently in accordance with the *2006 IPCC Guidelines*. From 2006 onward, as adipic acid producers implemented CDM projects, N_2O emissions that recognized the use of N_2O abatement technologies were reported in *CDM Monitoring Reports*. From 2007 onward, as adipic acid producers were identified as entities subject to TMS and K-ETS, emissions were calculated using TMS and K-ETS data. To maintain time-series consistency, the approach of tracking changes in activity data and emissions across the time series was used based on expert judgment.

4.3.3.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

4.3.4 Caprolactam, Glyoxal, and Glyoxylic Acid Production (2.B.4.)

4.3.4.1 Category Overview

2022	Gas	Methodology	Emission Factor	Activity Data
	N_2O	Tier 3	PS	N_2O emissions

Caprolactam ($C_6H_{11}NO$) is used as a raw material for nylon-6 fibers and plastics of which the production results in N_2O emissions through the process of the catalytic oxidation of cyclohexanol ($(CH_2)_5CHOH$). Glyoxal ($C_2H_2O_2$) is primarily used as a cross-linking agent in acrylic resins, disinfectants, and gelatin hardeners of which the production generates N_2O during the oxidation of acetaldehyde (CH_3CHO). Glyoxylic acid ($C_2H_2O_3$) is used in the manufacture of synthetic fragrances, pesticides, and pharmaceutical intermediates, and N_2O arises during the oxidation process of glyoxal for glyoxylic acid production.

As caprolactam is currently produced by a single company in ROK, emissions were included in Other (2.B.10.) to protect confidential information. Glyoxal and glyoxylic acid production do not occur in ROK.

4.3.4.2 Methodology

4.3.4.2.1 Method

For years prior to 2007, emissions were estimated using the Tier 1 method from the *2006 IPCC Guidelines*. From 2007 onward, emissions as reported in TMS and K-ETS data were aggregated to total emissions from this subcategory.[19)]

N_2O emissions from caprolactam production

$$N_2O\ Emissions = EF \times CP$$

N_2O Emissions	:	N_2O emissions from caprolactam production (kg N_2O)
EF	:	emission factor for caprolactam production (kg N_2O/ t caprolactam produced)
CP	:	amount of caprolactam produced (t)

Source: *2006 IPCC Guidelines, Vol.3, Ch.3, Equation 3.9*

19) Emissions reported for TMS and K-ETS were estimated using Tier 3 methodology with the plant-specific emission factor in accordance with the *2006 IPCC Guidelines*.

4.3.4.2.2 Emission Factor

The default N_2O emission factor for caprolactam production provided in the *2006 IPCC Guidelines* was used for years prior to 2007.

| Table 4-33 | Emission Factor for Caprolactam Production

Emission Factor	Factor Value	Source
Caprolactam Production (Raschig Process)	9 kg N_2O/tonne caprolactam produced	*2006 IPCC Guidelines*

Source: *2006 IPCC Guidelines, Vol.3, Ch.3, Table 3.5*

4.3.4.2.3 Activity Data

For years prior to 2007, caprolactam production data were based on *Petrochemical Statistics*. Data from 2007 onward were sourced from TMS and K-ETS.

| Table 4-34 | Activity Data Source for Caprolactam Production

Period	Activity Data	Name of Statistics	Published by	Gas
1990-2006	Caprolactam production	*Petrochemical Statistics*	Korea Chemical Industry Association (KCIA)[20]	N_2O
2007-2022	N_2O emissions from caprolactam production	TMS and K-ETS data	Ministry of Environment (MOE)	

4.3.4.3 Uncertainty and Time-series Consistency

4.3.4.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

4.3.4.3.2 Time-series Consistency

Emissions from caprolactam production prior to 2007 were estimated using methodology, emission factors and activity data consistently in accordance with the *2006 IPCC Guidelines*. From 2007 onward, as caprolactam producers were identified as entities under TMS and K-ETS, emissions were calculated using its data to ensure accuracy and consistency across the time series.

20) Formerly Korea Petrochemical Industry Association (KPIA)

4.3.4.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

4.3.5 Carbide Production (2.B.5.)

4.3.5.1 Category Overview

	Gas	Methodology	Emission Factor	Activity Data
2022	CO_2	Tier 2	D	Calcium carbide consumption

CO_2 emissions arise from production of silicon carbide (SiC) and calcium carbide (CaC_2). Since silicon carbide in ROK was produced using polisilicon (Si) as its feedstock, emissions did not occur. Calcium carbide production results in CO_2 emissions through the process of heating limestone and petroleum coke or being consumed as a feedstock for acetylene (C_2H_2). To protect confidential information, emissions from calcium carbide production were included in Other (2.B.10.).

4.3.5.2 Methodology

4.3.5.2.1 Method

Emissions from calcium carbide production were estimated using the Tier 1 method from the *2006 IPCC Guidelines*. Emissions from calcium carbide *consumption* were calculated using the Tier 2 method from the *2006 IPCC Guidelines* to estimate CO_2 emissions.

Emissions from carbide production (Tier 1)

$$CO_2\ Emissions = AP \times EF$$

CO_2 Emissions : CO_2 emissions from calcium carbide *production* (tonnes CO_2)
AP : amount of calcium carbide produced (tonnes)
EF : emission factor (tonnes CO_2/tonne calcium carbide produced)

Source: *2006 IPCC Guidelines, Vol.3, Ch.3, Equation 3.11*

Emissions from carbide consumption (Tier 2)		
CO_2 Emissions = AP x EF		
CO_2 Emissions	:	CO_2 emissions from calcium carbide *consumption* (tonnes CO_2)
AP	:	amount of calcium carbide consumed (tonnes)
EF	:	emission factor (tonnes CO_2/tonne calcium carbide consumed)

Source: *2006 IPCC Guidelines, Vol.3, Ch.3, Equation 3.11*

4.3.5.2.2 Emission Factor

Default emission factors for calcium carbide production and consumption provided in the *2006 IPCC Guidelines* were used.

| Table 4-35 | Emission Factor for Carbide Production

Emission Factor		Factor Value	Source
Calcium Carbide	Production	1.090 t CO_2/t Calcium Carbide Production	*2006 IPCC Guidelines*
	Consumption	1.100 t CO_2/t Calcium Carbide Consumption	

Source: *2006 IPCC Guidelines, Vol.3, Ch.3, Table 3.8*

4.3.5.2.3 Activity Data

The production and consumption volumes of calcium carbide were based on field surveys by KEA.

| Table 4-36 | Activity Data Source for Carbide Production

Period	Activity Data	Name of Statistics	Published by	Gas
1999-2005	Calcium carbide production	Field surveys	Korea Energy Agency (KEA)	CO_2
1990-2022	Calcium carbide consumption			

4.3.5.3 Uncertainty and Time-series Consistency

4.3.5.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

4.3.5.3.2 Time-series Consistency

Emissions from the carbide production were estimated using methodology, emission factors, and activity data consistently throughout the entire time series.

4.3.5.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

4.3.6 Petrochemical and Carbon Black Production (2.B.8.)

4.3.6.1 Category Overview

Petrochemical products are produced using fossil fuels (e.g. natural gas) or petroleum refinery products (e.g. naphtha) as feedstocks. In ROK, petrochemicals such as ethylene and propylene are produced by feeding naphtha into naphtha cracking centers which results in CO_2 and CH_4 emissions. Emissions are reported under either Methanol (2.B.8.a.), Ethylene (2.B.8.b.), Dichloroethylene and vinyl chloride monomer (2.B.8.c.), Ethylene oxide (2.B.8.d.), Acrylonitrile (2.B.8.e.), Carbon black (2.B.8.f.) or Other (2.B.8.g.). Methanol is not produced in ROK while emissions from BTX (benzene, toluene and xylene) production which are not identified as sources in the *IPCC Guidelines* were reported under Other (2.B.8.g.).

In 2022, greenhouse gas emissions from petrochemical and carbon black production were 31,529 kt CO_2-eq which was a decrease of 860 kt CO_2-eq (2.7 percent) from 2021. The biggest contributor to such decrease was ethylene production from which emissions declined by 774 kt CO_2-eq. From ethylene oxide, carbon black and styrene production, emissions also decreased by 169 kt CO_2-eq, 91 kt CO_2-eq, and 70 kt CO_2-eq, respectively. In contrast, emissions from acrylonitrile production increased by 138 kt CO_2-eq, other BTX by 83 kt CO_2-eq, and dichloroethylene and vinyl chloride monomer production by 23 kt CO_2-eq.

| Table 4-37 | Emissions from Petrochemical and Carbon Black Production

(Unit: kt CO_2-eq)

Sub-category		1990	2000	2007	2010	2018	2021	2022
2.B.8.a.	Methanol	NO	NO	NO	NO	NO	NO	NO
2.B.8.b.	Ethylene	4,072	15,655	20,271	15,605	19,861	22,007	21,233
2.B.8.c.	Dichloroethylene and Vinyl Chloride Monomer	135	270	244	442	959	1,267	1,290
2.B.8.d.	Ethylene Oxide	61	320	307	533	500	347	178
2.B.8.e.	Acrylonitrile	25	170	225	257	269	302	440
2.B.8.f.	Carbon Black	565	1,196	1,311	1,406	1,628	1,698	1,608
2.B.8.g.	Other	446	1,760	2,798	5,436	7,723	6,767	6,780
Total		**5,304**	**19,371**	**25,155**	**23,680**	**30,939**	**32,388**	**31,529**

4.3.6.2 Ethylene (2.B.8.b.)

4.3.6.2.1 Category Overview

2022	Gas	Methodology	Emission Factor	Activity Data
	CO_2	Tier 2	CS, D, OTH	Feedstock consumption

Ethylene (C_2H_4) is primarily used as a feedstock for the production of ethylene oxide, ethylbenzene, ethanol, and polyethylene, but most commonly used for manufacturing the synthetic resin polyethylene. In ROK, ethylene is produced through thermal cracking at naphtha cracking centers using naphtha, butane and propane as feedstocks of which the process generates CO_2 and CH_4 emissions. Based on the assumption that all of the carbon input to the process is converted into CO_2 as guided by the *2006 IPCC Guidelines*[21], emissions from the ethylene production were estimated using the Tier 2 methodology. Therefore, CH_4 emissions did not occur.

In 2022, emissions from ethylene production were 21,233 kt CO_2-eq which decreased by 3.5 percent from 2021.

| Table 4-38 | Emissions from Ethylene

(Unit: kt CO_2-eq)

Sub-category	1990	2000	2007	2010	2018	2021	2022
Ethylene	4,072	15,655	20,271	15,605	19,861	22,007	21,233

21) *2006 IPCC Guidelines, Vol.3, Ch.3, p.3.67*

4.3.6.2.2 Methodology

4.3.6.2.2.1 Method

Emissions from the ethylene production were estimated using the Tier 2 carbon mass balance method from the *2006 IPCC Guidelines*.

CO_2 emissions from ethylene

$$CO_2\ Emissions = \sum_k (FA_{i,k} \times FC_k) - [PP_i \times PC_i + \sum_j (SP_{i,j} \times SC_j)] \times \frac{44}{12}$$

CO_2 Emissions	: CO_2 emissions from ethylene production (tonnes CO_2)
$FA_{i,k}$	: annual amount of feedstock k used to produce i(ethylene)(t)
FC_k	: carbon content of feedstock k (tonnes C/t feedstock)
PP_i	: annual amount of i(ethylene) produced (t)
PC_i	: carbon content of i(ethylene) (tonnes C/t ethylene)
$SP_{i,j}$	: annual amount of by-product j produced during i(ethylene) production (tonnes)
SC_j	: carbon content of by-product j (tonnes C/tonne by-product)
44/12	: molecular weight ratio of carbon dioxide to carbon

Source: *2006 IPCC Guidelines, Vol.3, Ch.3, Equation 3.17*

4.3.6.2.2.2 Emission Factor

Default emission factors from the *2006 IPCC Guidelines* as well as country-specific emission factors were used to calculate carbon contents of feedstocks and products. The carbon content of raw pyrolysis gasoline[22] was calculated using data from domestic research report.

| Table 4-39 | Emission Factors for Ethylene

Feedstock and Product		Emission Factor (Carbon content)	Source
Ethylene		0.856 t C / t	*2006 IPCC Guidelines*
Propylene		0.8563 t C / t	
Butadiene		0.888 t C / t	
Naphtha	1990-2006	20.0 t C / TJ	*2006 IPCC Guidelines*
	2007-2011	18.6 t C / TJ	CS[1)]
	2012-2016	19.2 t C/ TJ	
	2017-2021	19.157 t C / TJ	
	2022	19.083 t C / TJ	

22) A liquid compound of hydrocarbons that is produced through the cracking of naphtha as a by-product of olefin (e.g. ethylene, propylene) production and used as a feedstock for aromatic compounds (e.g. benzene, toluene and xylene (BTX)).

Feedstock and Product		Emission Factor (Carbon content)	Source
Butane	1990–2006	17.2 t C / TJ	*2006 IPCC Guidelines*
	2007–2011	18.1 t C / TJ	CS[1]
	2012–2016	18.1 t C / TJ	
	2017–2021	18.107 t C / TJ	
	2022	18.094 t C / TJ	
Propane	1990–2006	17.2 t C / TJ	*2006 IPCC Guidelines*
	2007–2011	17.6 t C / TJ	CS[1]
	2012–2016	17.6 t C / TJ	
	2017–2021	17.641 t C / TJ	
	2022	17.630 t C / TJ	
Raw pyrolysis gasoline		0.8845 t C / t	Domestic research material[2]

Note: 1) See Section 3.2.4.2.1 for more information about energy calorific values and domestic energy conversion system.
2) *Study on naphtha modeling for analysis of greenhouse gas emissions in petrochemical industry* (Korea Environmental Industry and Technology Institute, 2015)

Source: *2006 IPCC Guidelines, Vol.2, Ch.1, Table 1.3; Vol.3, Ch.3, Table 3.10*

4.3.6.2.2.3 Activity Data

The volumes of butane and propane used for ethylene production were sourced from the *Energy Supply and Demand Statistics* while data on other feedstocks such as naphtha and the volumes of petrochemical products produced through the naphtha cracking process were sourced from the *Petrochemical Statistics.*

| Table 4–40 | Activity Data Source for Ethylene

Period	Activity Data	Name of Statistics	Published by	Gas
1990–2022	Consumption of Feedstock (naphtha) and production of petrochemical products (e.g. ethylene)	*Petrochemical Statistics*	Korea Chemical Industry Association (KCIA)	CO_2
	Consumption of Feedstock (butane, propane)	*Energy Supply and Demand Statistics*	Korea Energy Economics Institute (KEEI)	

| Table 4-41 | Activity Data for Ethylene

(Unit: kt)

Feedstock and Product		1990	2000	2007	2010	2018	2021	2022
Consumption	Naphtha	4,371	16,345	26,920	20,110	26,153	28,537	27,910
	Butane	NO	268	609	687	656	589	686
	Propane	NO	574	664	1,011	2,362	3,301	3,973
Production	Ethylene	1,399	5,500	9,022	6,979	9,335	10,377	10,422
	Propylene	699	2,750	4,511	3,489	4,667	5,188	5,211
	C4	437	1,719	2,819	2,181	2,917	3,243	3,257
	RPG	831	3,266	5,357	4,144	5,543	6,161	6,188
	Other Products	1,005	3,953	6,484	5,016	6,709	7,458	7,491

4.3.6.2.3 Uncertainty and Time-series Consistency

4.3.6.2.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

4.3.6.2.3.2 Time-series Consistency

Emissions from ethylene production were estimated using methodology, emission factors and activity data consistently across the entire time series.

4.3.6.2.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

4.3.6.2.5 Planned Improvements

As ethylene production was a key category in 2022, Tier 2 mass balance method was applied to estimate emissions. ROK plans to research further for its plant-specific carbon contents to refine its estimates of emissions from this subcategory.

4.3.6.3 Ethylene dichloride (EDC) and vinyl chloride monomer (VCM) (2.B.8.c.)

4.3.6.3.1 Category Overview

2022	Gas	Methodology	Emission Factor	Activity Data
	CO_2	Tier 2	D	Ethylene consumption, production volume of EDC and VCM

Ethylene dichloride (EDC) is used as a feedstock for vinyl chloride monomer (VCM) as well as for cleaning agents, solvents, insecticides, and fumigants. CO_2 emissions from EDC production arise either through the direct chlorination process which uses ethylene and chlorine as feedstocks, or the oxy-chlorination process which involves ethylene, anhydrous hydrogen chloride and oxygen. VCM is used as a feedstock for polyvinyl chloride (PVC) of which the production process thermally cracks EDC and results in CO_2 and CH_4 emissions. Based on the assumption that all of the carbon input to the process is converted into CO_2 as indicated in the *2006 IPCC Guidelines*, only CO_2 emissions from the EDC and VCM production were estimated.[23]

In 2022, greenhouse gas emissions from the EDC and VCM production were 1,290 kt CO_2-eq which was a increase of 1.8 percent from 2021.

| Table 4-42 | Emissions from EDC and VCM

(Unit: kt CO_2-eq)

Sub-category	1990	2000	2007	2010	2018	2021	2022
EDC and VCM	135	270	244	442	959	1,267	1,290

4.3.6.3.2 Methodology

4.3.6.3.2.1 Method

Emissions from the EDC and VCM production were estimated using the Tier 2 carbon mass balance method from the *2006 IPCC Guidelines*.

CO_2 emissions from EDC and VCM

$$CO_2\ Emissions = \sum_k (FA_{i,k} \times FC_k) - [PP_i \times PC_i + \sum_j (SP_{i,j} \times SC_j)] \times \frac{44}{12}$$

CO_2 Emissions	:	CO_2 emissions from EDC and VCM production (tonnes CO2)
$FA_{i,k}$	:	annual amount of feedstock k used to produce i (EDC, VCM) (tonnes)
FC_k	:	carbon content of feedstock k (tonnes C/tonne feedstock)
PP_i	:	annual amount of i (EDC, VCM) produced (tonnes)
PC_i	:	carbon content of i (EDC, VCM) (tonnes C/tonne EDC or VCM)
$SP_{i,j}$	:	annual amount of by-product j produced during i (EDC, VCM) production (tonnes)
SC_j	:	carbon content of by-product j (tonnes C/tonne by-product)
44/12	:	molecular weight ratio of carbon dioxide to carbon

Source: *2006 IPCC Guidelines, Vol.3, Ch.3, Equation 3.17*

23) *2006 IPCC Guidelines, Vol.3, Ch.3, p.3.67*

4.3.6.3.2.2 Emission Factor

Default values for carbon emission factors (carbon content) for feedstocks and products provided in the *2006 IPCC Guidelines* were used.

| Table 4-43 | Emission Factor for EDC and VCM

Feedstock and Product	Emission Factor (Carbon content)	Source
Ethylene	0.856 tonnes C / tonne Ethylene	*2006 IPCC Guidelines*
EDC	0.245 tonnes C / tonne EDC	
VCM	0.384 tonnes C / tonne VCM	

Source: *2006 IPCC Guidelines, Vol.3, Ch.3, Table 3.10*

4.3.6.3.2.3 Activity Data

The consumption of ethylene as a feedstock and the production volumes of EDC and VCM were based on data from the *Petrochemical Statistics*.

| Table 4-44 | Activity Data Source for EDC and VCM

Period	Activity Data	Name of Statistics	Published by	Gas
1990-2022	Ethylene consumption, production volume of EDC and VCM	*Petrochemical Statistics*	Korea Chemical Industry Association (KCIA)	CO_2

| Table 4-45 | Activity Data for EDC and VCM

(Unit: kt)

Amount		1990	2000	2007	2010	2018	2021	2022
Consumption	Ethylene	318	906	1,001	1,126	1,443	1,642	1,614
Production	EDC	352	781	804	985	1,423	1,634	1,632
	VCM	388	1,329	1,545	1,567	1,628	1,717	1,640

4.3.6.3.3 Uncertainty and Time-series Consistency

4.3.6.3.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

4.3.6.3.3.2 Time-series Consistency

Emissions from the EDC and VCM production were estimated using methodology, emission factors and activity data consistently across the entire time series.

4.3.6.3.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

4.3.6.4 Ethylene Oxide (2.B.8.d.)

4.3.6.4.1 Category Overview

2022	Gas	Methodology	Emission Factor	Activity Data
	CO_2	Tier 2	D	Ethylene consumption, ethylene oxide production

Ethylene oxide (C_2H_4O, EO) is used as a feedstock for glycols, glycol ethers, alcohols and amines. Emissions of CO_2 and CH_4 arise during the production process of ethylene oxide (C_2H_4O, EO) which involves ethylene oxidation via catalysts. Based on the assumption that all of the carbon input to the process is converted into CO_2 as indicated in the *2006 IPCC Guidelines*[24], only CO_2 emissions from the ethylene oxide production were estimated.

In 2022, emissions from the ethylene oxide production were 178 kt CO_2-eq which decreased by 48.6 percent from 2021.

| Table 4-46 | Emissions from Ethylene Oxide

(Unit: kt CO_2-eq)

Sub-category	1990	2000	2007	2010	2018	2021	2022
Ethylene Oxide Production	61	320	307	533	500	347	178

4.3.6.4.2 Methodology

4.3.6.4.2.1 Method

Emissions were estimated using the Tier 2 carbon mass balance method from the *2006 IPCC Guidelines*.

24) *2006 IPCC Guidelines, Vol.3, Ch.3, p.3.67*

CO_2 emissions from ethylene oxide

$$CO_2\ \text{Emissions} = \sum_k (FA_{i,k} \times FC_k) - [PP_i \times PC_i + \sum_j (SP_{i,j} \times SC_j)] \times \frac{44}{12}$$

CO_2 Emissions	:	CO_2 emission from ethylene oxide production (tonnes CO_2)
$FA_{i,k}$	:	annual amount of feedstock k used to produce i (ethylene oxide) (tonnes)
FC_k	:	carbon content of feedstock k (tonnes C/tonne feedstock)
PP_i	:	annual amount of i (ethylene oxide) produced (tonnes)
PC_i	:	carbon content of i (ethylene oxide) (tonnes C/tonne ethylene oxide)
$SP_{i,j}$	:	annual amount of by-product j produced during i (ethylene oxide) production (t)
SC_j	:	carbon content of by-product j (tonnes C/tonne by-product)
44/12	:	molecular weight ratio of carbon dioxide to carbon

Source: *2006 IPCC Guidelines, Vol.3, Ch.3, Equation 3.17*

4.3.6.4.2.2 Emission Factor

Default values for carbon emission factors (carbon content) for feedstocks and products in the ethylene oxide production from the *2006 IPCC Guidelines* were used.

| Table 4-47 | Emission Factor for Ethylene Oxide

Feedstock and Product	Emission Factor (Carbon content)	Source
Ethylene	0.856 tonnes C/tonne Ethylene	*2006 IPCC Guidelines*
Ethylene Oxide	0.545 tonnes C/tonne Ethylene Oxide	

Source: *2006 IPCC Guidelines, Vol.3, Ch.3, Table 3.10*

4.3.6.4.2.3 Activity Data

The consumption of ethylene as a feedstock and the production volume of ethylene oxide were based on data from the *Petrochemical Statistics*.

| Table 4-48 | Activity Data Source for Ethylene Oxide

Period	Activity Data	Name of Statistics	Published by	Gas
1990-2022	Ethylene consumption, ethylene oxide production	*Petrochemical Statistics*	Korea Chemical Industry Association (KCIA)	CO_2

| Table 4-49 | Activity Data for Ethylene Oxide

(Unit: kt)

Amount	1990	2000	2007	2010	2018	2021	2022
Ethylene Consumption	140	728	763	1,041	1,158	938	726
Ethylene Oxide Production	189	983	1,045	1,368	1,568	1,300	1,052

4.3.6.4.3 Uncertainty and Time-series Consistency

4.3.6.4.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

4.3.6.4.3.2 Time-series Consistency

Emissions from ethylene oxide production were estimated using methodology, emission factors and activity data consistently across the entire time series.

4.3.6.4.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

4.3.6.5 Acrylonitrile (2.B.8.e.)

4.3.6.5.1 Category Overview

2022	Gas	Methodology	Emission Factor	Activity Data
	CO_2	Tier 2	D	Propylene consumption, acrylonitrile production

Acrylonitrile (C_3H_3N, AN) which is used as a raw material for acrylic fiber and synthetic resin is made by ammoxidation of propylene (C_3H_6) with ammonia and oxygen in the presence of a catalyst. Such process produces acrylonitrile as its primary product, and acetonitrile as well as hydrogen cyanide as secondary products during which emissions of CO_2 and CH_4 are emitted. Based on the assumption that all of the carbon input to the process is converted into CO_2 as indicated in the *2006 IPCC Guidelines*[25], only CO_2 emissions from the acrylonitrile production were estimated.

In 2022, greenhouse gas emissions from acrylonitrile production were 440 kt CO_2-eq which increased by 45.5 percent from 2021.

| Table 4-50 | Emissions from Acrylonitrile

(Unit: kt CO_2-eq)

Sub-category	1990	2000	2007	2010	2018	2021	2022
Acrylonitrile Production	25	170	225	257	269	302	440

4.3.6.5.2 Methodology

4.3.6.5.2.1 Method

Emissions from the acrylonitrile production were estimated using the Tier 2 carbon mass balance method from the *2006 IPCC Guidelines*.

CO_2 emissions from acrylonitrile

$$CO_2\ Emissions = \sum_k (FA_{i,k} \times FC_k) - [PP_i \times PC_i + \sum_j (SP_{i,j} \times SC_j)] \times \frac{44}{12}$$

CO_2 Emissions	:	CO_2 emission from acrylonitrile production (tonnes CO_2)
$FA_{i,k}$	:	annual amount of feedstock k used to produce i (acrylonitrile)(tonnes)
FC_k	:	carbon content of feedstock k (tonnes C/tonne feedstock)
PP_i	:	annual amount of i (acrylonitrile) produced (tonnes)
PC_i	:	carbon content of i (acrylonitrile)(tonnes C/tonne acrylonitrile)
$SP_{i,j}$	:	annual amount of by-product j produced during i (acrylonitrile) production (tonnes)
SC_j	:	carbon content of by-product j (tonnes C/tonne by-product)
44/12	:	molecular weight ratio of carbon dioxide to carbon

Source: *2006 IPCC Guidelines, Vol.3, Ch.3, Equation 3.17*

4.3.6.5.2.2 Emission Factor

Default values for carbon emission factors (carbon content) of the raw materials and petrochemical products in the acrylonitrile production from the *2006 IPCC Guidelines* were used.

25) *2006 IPCC Guidelines, Vol.3, Ch.3, p.3.67*

| Table 4-51 | Emission Factor for Acrylonitrile

Substance	Emission Factor	Source
Propylene	0.8563 tonnes C/tonne Propylene	*2006 IPCC Guidelines*
Acrylonitrile	0.6664 tonnes C/tonne Acrylonitrile	
Acetonitrile	0.5852 tonnes C/tonne Acetonitrile	
Hydrogen Cyanide	0.4444 tonnes C/tonne Hydrogen Cyanide	

Source: *2006 IPCC Guidelines, Vol.3, Ch.3, Table 3.10*

4.3.6.5.2.3 Activity Data

The propylene consumption and acrylonitrile production were obtained from *Petrochemical Statistics*. The production volumes of the secondary products such as acetonitrile and hydrogen cyanide were estimated in accordance with the equation provided in the *2006 IPCC Guidelines*.

Estimate secondary product production from primary product (acrylonitrile) production

$$SP_{acrylonitrile,\,j} = \sum (FP_{acrylonitrile} \times SSP_j)$$

$SP_{acrylonitrile,\ j}$: annual amount of by-product j generated from acrylonitrile production (t)

SSP_j : by-product generation factor per tonne of acrylonitrile (t by-product j / t acrylonitrile produced)

Source: *2006 IPCC Guidelines, Vol.3, Ch.3, Equation 3.19*

| Table 4-52 | Production Factor for Acrylonitrile Production Process

Secondary Product	Production Factor	Source
Acetonitrile	18.5 kg Acetonitrile/tonne of Acrylonitrile	*2006 IPCC Guidelines*
Hydrogen Cyanide	105 kg Hydrogen Cyanide/tonne of Acrylonitrile	

Source: *2006 IPCC Guidelines, Vol.3, Ch.3, Table 3.26*

| Table 4-53 | Activity Data Source for Acrylonitrile

Period	Activity Data	Name of Statistics	Published by	Gas
1990-2022	Propylene consumption, acrylonitrile production	*Petrochemical Statistics*	Korea Chemical Industry Association (KCIA)	CO_2

| Table 4-54 | Activity Data for Acrylonitrile

(Unit: kt)

Amount		1990	2000	2007	2010	2018	2021	2022
Consumption	Propylene	52	355	520	593	724	761	720
Production	Acrylonitrile	52	356	530	604	755	786	686
	Acetonitrile	1	7	10	11	14	15	13
	Hydrogen Cyanide	6	37	56	63	79	83	72

4.3.6.5.3 Uncertainty and Time-series Consistency

4.3.6.5.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

4.3.6.5.3.2 Time-series Consistency

Emissions from acrylonitrile production were estimated using methodology, emission factors and activity data consistently across the entire time series.

4.3.6.5.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

4.3.6.6 Carbon black (2.B.8.f.)

4.3.6.6.1 Category Overview

2022	Gas	Methodology	Emission Factor	Activity Data
	CO_2, CH_4	Tier 1	D	Carbon black production

Carbon black which is used as a raw material for tires, rubber, ink and paint is produced from a partial combustion of creosote oil or heavy oil of which the process results in emissions of CO_2 and CH_4.

In 2022, emissions from carbon black production were 1,608 kt CO_2-eq which decreased by 5.3 percent from 2021 due to less production volume.

| Table 4-55 | Emissions from Carbon Black

(Unit: kt CO_2-eq)

Sub-category	1990	2000	2007	2010	2018	2021	2022
Carbon Black	565	1,196	1,311	1,406	1,628	1,698	1,608

4.3.6.6.2 Methodology

4.3.6.6.2.1 Method

CO_2 and CH_4 emissions from carbon black production were estimated using the Tier 1 method from the *2006 IPCC Guidelines*.

CO_2 emissions from carbon black

$$CO_2\ Emissions = PP_i \times EF_i$$

CO_2 Emissions : CO_2 emissions from carbon black production (tonnes CO_2)

PP_i : amount of carbon black produced (tonnes)

EF_i : CO_2 emission factor for carbon black (tonnes CO_2/tonne carbon black)

Source: *2006 IPCC Guidelines, Vol.3, Ch.3, Equation 3.15*

CH_4 emissions from carbon black

$$CH_4\ Emissions = PP_i \times EFp_i$$

CH_4 Emissions : CH_4 emissions from carbon black production (kg CH_4)

PP_i : amount of carbon black produced (tonnes)

EFp_i : CH_4 emission factor for carbon black(kg CH_4/tonne carbon black)

Source: *2006 IPCC Guidelines, Vol.3, Ch.3, Equation 3.24*

4.3.6.6.2.2 Emission Factor

Default values for CO_2 and CH_4 emission factors for carbon black production provided in the *2006 IPCC Guidelines* were used.

| Table 4-56 | Emission Factor for Carbon Black

Process Configuration	Emission Factor	Source
Furnace Black Process (Total Feedstock)	2.62 tonnes CO_2 / tonne	*2006 IPCC Guidelines*
Thermal Treatment	0.06 kg CH_4 / tonne	

Source: *2006 IPCC Guidelines, Vol.3, Ch.3, Table 3.23-3.24*

4.3.6.6.2.3 Activity Data

The volume of carbon black production was sourced from *Petrochemical Statistics*.

| Table 4-57 | Activity Data Source for Carbon Black

Period	Activity Data	Name of Statistics	Published by	Gas
1990-2022	Carbon black production	*Petrochemical Statistics*	Korea Chemical Industry Association (KCIA)	CO_2, CH_4

| Table 4-58 | Activity Data for Carbon Black

(Unit: kt)

Amount	1990	2000	2007	2010	2018	2021	2022
Carbon Black Production	215	456	500	536	621	648	613

4.3.6.6.3 Uncertainty and Time-series Consistency

4.3.6.6.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

4.3.6.6.3.2 Time-series Consistency

Emissions from carbon black production were estimated using methodology, emission factors and activity data consistently across the entire time series.

4.3.6.6.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

4.3.6.7 Other (2.B.8.g.)

4.3.6.7.1 Category Overview

	Gas	Methodology	Emission Factor	Activity Data
2022	CO_2, CH_4	Tier 1, 2	D, CS	Styrene production, naphtha consumption for BTX

Under this reporting subcategory, emissions from the production of styrene and BTX (benzene, toluene and xylene) were reported.

Production of styrene which is used as a raw material for polystyrene (PS), paints and coatings generates CH_4 emissions in the process of the dehydrogenation of ethylbenzene (C_8H_{10}) that is synthesized through the catalytic reaction process of ethylene (C_2H_4) and benzene (C_6H_6).

Benzene, toluene and xylene (BTX) are petrochemical feedstocks used for the production of pharmaceuticals, pesticides, fragrances, and explosives. CO_2 is emitted during the extraction process of BTX from cracked or reformed naphtha.

In 2022, emissions from styrene and BTX production were 6,780 kt CO_2-eq which increased by 0.2 percent from 2021. Emissions from styrene production decreased due to reduced production in 2022 while emissions from BTX production increased due to higher consumption of naphtha.

| Table 4-59 | Emissions from Other (Styrene and BTX)

(Unit: kt CO_2-eq)

Source	1990	2000	2007	2010	2018	2021	2022
Styrene Production	50	276	333	307	349	322	252
BTX Production	397	1,483	2,465	5,130	7,373	6,445	6,528
Total	**446**	**1,760**	**2,798**	**5,436**	**7,723**	**6,767**	**6,780**

4.3.6.7.2 Methodology

4.3.6.7.2.1 Method

Emissions from styrene production were estimated using the Tier 1 method from the *2006 IPCC Guidelines* by multiplying the styrene production volume by the CH_4 emission factor.

CH_4 emissions from other (Styrene)

$$CH_4\ Emissions = Activity\ data \times Emission\ factor$$

CH_4 Emissions : CH_4 emissions from styrene production (kg CH_4)

Activity data : amount of styrene produced (tonnes)

Emission factor : emission factor for styrene production (kg CH_4/tonne styrene produced)

Source: *2006 IPCC Guidelines, Vol.3, Ch.3, Equation 3.24*

Emissions from BTX production were estimated using the Tier 2 carbon mass balance method from the *2006 IPCC Guidelines* by calculating the difference between the carbon content of process materials used for the BTX production and that of petrochemical end-products, and then converting such difference value into CO_2 emissions. However, due to the absence of data on the production volume of petrochemical products from BTX, emissions were estimated assuming that 90 percent of raw materials were retained in the final products based on expert judgment.

CO_2 emissions from other (BTX)

$$CO_2\ Emissions = \sum_k (FA_{i,k} \times FC_k) - [PP_i \times PC_i + \sum_j (SP_{i,j} \times SC_j)] \times \frac{44}{12}$$

CO_2 Emissions	:	CO_2 emissions from BTX production (tonnes CO_2)
$FA_{i,k}$	:	annual amount of feedstock k used to produce i (BTX) (tonnes)
FC_k	:	carbon content of feedstock k (tonnes C / tonne feedstock)
PP_i	:	annual amount of i (BTX) produced (tonnes)
PC_i	:	carbon content of i (BTX) (tonnes C / tonne BTX)
$SP_{i,j}$	:	annual amount of by−product j produced during i (BTX) production (tonnes)
SC_j	:	carbon content of by−product j (tonnes C / tonne by−product)
44/12	:	molecular weight ratio of carbon dioxide to carbon

Source: *2006 IPCC Guidelines, Vol.3, Ch.3, Equation 3.17*

4.3.6.7.2.2 Emission Factor

Since the *2006 IPCC Guidelines* do not provide a method for estimation of emissions from styrene production, the default CH_4 emission factor from the *Revised 1996 IPCC Guidelines* was used. For BTX production, the default CO_2 emission factor for naphtha from the *2006 IPCC Guidelines* was used for years prior to 2007 and a country−specific emission factor from 2007 onward.

| Table 4−60 | Emission Factor for Styrene Production

Type	Emission Factor	Source
Styrene Production	4 kg CH_4/tonne Styrene Production	*Revised 1996 IPCC Guidelines*

Source: *Revised 1996 IPCC Guidelines, Vol.3, Ch.2, Table 2−10*

| Table 4−61 | Emission Factor for BTX Production

Emission Factor		Factor Value	Source
Carbon Content of Naphtha	1990−2006	20.0 t C / TJ	*2006 IPCC Guidelines*
	2007−2011	18.6 t C / TJ	CS[1)]
	2012−2016	19.2 t C / TJ	
	2017−2021	19.157 t C / TJ	
	2022	19.083 t C / TJ	

Note: 1) See Section 3.2.4.2.1 for more information about energy calorific values and domestic energy conversion system.
Source: *2006 IPCC Guidelines, Vol.2, Ch.1, Table 1.3*

4.3.6.7.2.3 Activity Data

The production volume of styrene and naphtha consumption for the BTX production were sourced from the *Petrochemical Statistics*.

| Table 4-62 | Activity Data Source for Other (Styrene and BTX production)

Period	Activity Data	Name of Statistics	Published by	Gas
1990-2022	Styrene production, naphtha consumption for BTX	*Petrochemical Statistics*	Korea Chemical Industry Association (KCIA)	CO_2, CH_4

| Table 4-63 | Activity Data for Other (Styrene and BTX production)

(Unit: kt)

Amount	1990	2000	2007	2010	2018	2021	2022
Styrene Production	443	2,467	2,970	2,738	3,117	2,874	2,246
Naphtha Consumption	1,196	4,470	7,925	16,492	23,955	20,939	21,399

4.3.6.7.3 Uncertainty and Time-series Consistency

4.3.6.7.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

4.3.6.7.3.2 Time-series Consistency

Emissions from styrene and BTX production were estimated using methodology, emission factors and activity data consistently across the entire time series.

4.3.6.7.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

4.3.6.7.5 Planned Improvements

ROK is exploring the potential to research further for the plant-specific carbon content of BTX process substances and to apply a higher tiered approach for estimates of emissions from styrene production.

4.3.7 Fluorochemical Production (2.B.9.)

4.3.7.1 Category Overview

Fluorinated gases that are released into the atmosphere during the production of fluorinated compounds such as HCFC−22, HFC−134a, SF_6, and NF_3 are estimated under either By−product emissions from HCFC−22 production (2.B.9.a.) or Fugitive emissions from the production of HFC−134a, SF_6, NF_3, and other fluorochemicals (2.B.9.b.).

In this inventory, emissions from HFC−23 by−products generated during the HCFC−22 production process (2.B.9.a.) and fugitive NF_3 emissions during the NF_3 production process (2.B.9.b.) were reported. HFC−134a is not produced in ROK while SF_6 emissions are not estimated due to lack of activity data[26]. ROK will continue to explore the potential to develop relevant statistics to enhance the completeness of data.

In 2022, emissions from fluorochemical production were 95 kt CO_2−eq which decreased by 1.6 percent from 2021.

| Table 4−64 | Emissions from Fluorochemical Production

(Unit: kt CO_2−eq)

Sub−category	1990	2000	2007	2010	2018	2021	2022
By−product Emissions	1,042	3,430	0.12	0.13	NO	NO	NO
Fugitive Emissions	NO	NO	NO	29	88	96	95
Total	1,042	3,430	0.12	29	88	96	95

4.3.7.2 By−product Emissions (2.B.9.a.)

4.3.7.2.1 Category Overview

Emissions of HFC−23, a by−product generated during the HCFC−22 production process were reported under this reporting subcategory. The amount of abated emissions by the Clean Development Mechanism (CDM) project[27], implemented from 2003 to April 2013, was considered in emissions with reference to the *CDM Monitoring Reports* and data from TMS and K−ETS. Since all HFC−23 emissions from the HCFC−22 production have been entirely recovered for sale from May 2013[28], by−product emissions did not occur from 2014.

26) SF_6 emissions were not estimated in accordance with Article 32 of MPGs as relevant activity data were not available and the level of emissions is likely below 0.05 percent of the national total emissions.

27) Project 0003: HFC Decomposition project in Ulsan (UNFCCC)

28) Emissions of HFC−23 from the production of HCFC−22 that was consumed or sold for purposes such as refrigerants were included in emissions reported under the Product uses as substitutes for ozone−depleting substances (2.F.).

| Table 4-65 | HFC-23 Emissions from By-product Emissions

(Unit: kt CO_2-eq)

Sub-category	1990	2000	2007	2010	2018	2021	2022
By-product Emissions	1,042	3,430	0.12	0.13	NO	NO	NO

4.2.7.2.2 Methodology

4.3.7.2.2.1 Method

By-product emissions were estimated using the Tier 1 method from the *2006 IPCC Guidelines*. From 2003, since HCFC-22 producers adopted abatement technologies to reduce HFC-23, emissions were estimated using the Tier 2 method of the *2006 IPCC Guidelines* which takes into account the volume of HCFC-22 produced, the emission factor, and the emission rate after the introduction of abatement technologies.

HFC-23 emissions from by-product emissions (Tier 1)

$$\text{HFC-23 Emissions} = EF \times P$$

HFC-23 Emissions : HFC-23 by-product emissions from HCFC-22 production (kg HFC-23)

EF : default emission factor for HFC-23 (kg HFC-23 / kg HCFC-22)

P : amount of HCFC-22 produced (kg)

Source: *2006 IPCC Guidelines, Vol.3, Ch.3, Equation 3.30*

HFC-23 emissions from by-product emissions (Tier 2)

$$\text{HFC-23 Emissions} = EF \times P \times F$$

HFC-23 Emissions : HFC-23 by-product emissions from HCFC-22 production (kg HFC-23)

EF : default emission factor for HFC-23 (kg HFC-23/kg HCFC-22)

P : amount of HCFC-22 produced (kg)

F : emission rate after abatement technology is applied

Source: *2006 IPCC Guidelines, Vol.3, Ch.3, Equation 3.31*

4.3.7.2.2.2 Emission Factor

For years prior to 2002, the default emission factor from the *2006 IPCC Guidelines* was used. From 2003 to 2013, emission factors reported by a HCFC-22 producer in its *CDM Monitoring Reports* were applied.

| Table 4-66 | Emission Factor for By-product Emissions from Fluorochemical Production

Gas	Emission Factor	Source
HFC-23	0.04 kg HFC-23/kg HCFC-22	*2006 IPCC Guidelines*

Source: *2006 IPCC Guidelines, Vol.3, Ch.3, Table 3.28*

4.3.7.2.2.3 Activity Data

The production volume of HCFC-22 from field surveys conducted by the Korea Specialty Chemical Industry Association (KSCIA) were used for the 1990 to 2006 period while data from *CDM Monitoring Reports* as well as TMS and K-ETS were used for years from 2007 to 2013.

| Table 4-67 | Activity Data Source for By-product Emissions

Period	Activity Data	Name of Statistics	Published by	Gas
1990-2006	HCFC-22 production	Fluorochemical statistics	Korea Specialty Chemical Industry Association (KSCIA)	HFC-23
2007-2013		*CDM Monitoring Report*	UNFCCC	
		TMS and K-ETS data	Ministry of Environment (MOE)	

| Table 4-68 | Activity Data for By-product Emissions

(Unit: kt)

Activity Data	1990	2000	2007	2010	2018	2021	2022
HCFC-22 Production	2.1	6.9	6.9	7.6	NO	NO	NO

4.3.7.2.3 Uncertainty and Time-series Consistency

4.3.7.2.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

4.3.7.2.3.2 Time-series Consistency

For the 1990 to 2002 period, emissions were estimated using tier 1 methodology with default values. From 2003 to 2013, a tier 2 method was used with plant-specific emission factors reported in *CDM Monitoring Reports*. Activity data were sourced from fluorochemical statistics published by KSCIA for the 1990 to 2006 period. TMS and K-ETS were used from 2007 onward. The accuracy and consistency of emissions were assured as there was only a single manufacturer of HCFC-22 in ROK.

4.3.7.2.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

4.3.7.3 Fugitive Emissions (2.B.9.b.)

4.3.7.3.1 Category Overview

2022	Gas	Methodology	Emission Factor	Activity Data
	NF_3	Tier 1	D	NF_3 production

Emissions from the release of NF_3 during its production process using a direct fluorination method were reported under this subcategory.

Fugitive emissions in 2022 were 95 kt CO_2-eq which decreased by 1.6 percent from 2021.

| Table 4-69 | NF_3 Emissions from Fugitive Emissions

(Unit: kt CO_2-eq)

Sub-category	1990	2000	2007	2010	2018	2021	2022
Fugitive Emissions	NO, NE	NO, NE	NO, NE	29	88	96	95

4.3.7.3.2 Methodology

4.3.7.3.2.1 Method

Fugitive emissions were estimated by multiplying the amount of NF_3 produced by the emission factor in accordance with the Tier 1 method of the *2006 IPCC Guidelines.*

NF_3 emissions from fugitive emissions

$$NF_3\ Emissions = EF \times P$$

NF_3 Emissions : fugitive NF_3 emissions from NF_3 production (kg NF_3)

EF : emission factor for NF_3 (kg NF_3 Fugitive emissions/kg NF_3 produced)

P : amount of NF_3 produced (kg)

Source: *2006 IPCC Guidelines, Vol.3, Ch.3, Equation 3.41*

4.3.7.3.2.2 Emission Factor

The default emission factor from the *2006 IPCC Guidelines* was used for fugitive emissions from NF_3 production.

| Table 4-70 | Emission Factor for Fugitive Emissions from Fluorochemical Production

Type	Emission Factor	Source
Fugitive Emission from NF_3 Production	0.005 kg NF_3/kg NF_3	*2006 IPCC Guidelines*

Source: *2006 IPCC Guidelines, Vol.3, Ch.3, p.3.104*

4.3.7.3.2.3 Activity Data

Data on the production volume of NF_3 were from field surveys conducted by KEA.

| Table 4-71 | Activity Data Source for Fugitive Emissions from Fluorochemical Production

Period	Activity Data	Name of Statistics	Published by	Gas
1990-2022	NF_3 production	Field surveys	Korea Energy Agency (KEA)	NF_3

| Table 4-72 | Activity Data for Fugitive Emissions

(Unit: kt)

Amount	1990	2000	2007	2010	2018	2021	2022
NF_3 Production	NO	NO	NO	0.4	1.1	1.19	1.17

4.3.7.3.3 Uncertainty and Time-series Consistency

4.3.7.3.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

4.3.7.3.3.2 Time-series Consistency

Fugitive emissions were estimated using methodology, emission factor and activity data consistently across the entire time series.

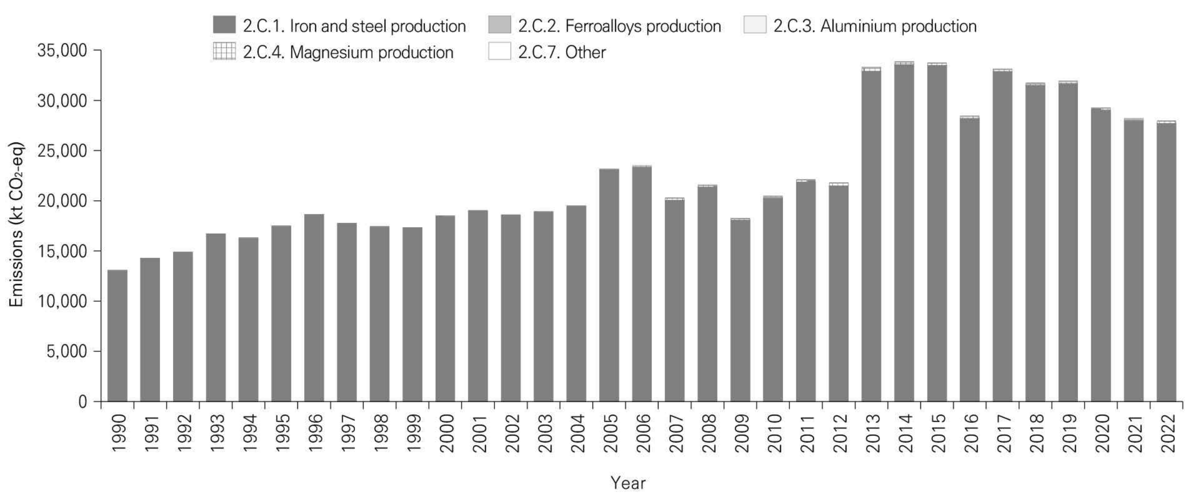
4.3.7.3.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

4.4 Metal Industry (2.C.)

In the metal industry, emissions of CO_2, CH_4, HFCs, PFCs, and SF_6 from metallurgical processes of extracting metals from ores are reported under Iron and Steel Production (2.C.1.), Ferroalloys Production (2.C.2.), Aluminium Production (2.C.3.), Magnesium Production (2.C.4.), Lead Production (2.C.5.), Zinc Production (2.C.6.) or Other (2.C.7.). To protect confidential information of domestic manufacturers, emissions from lead and zinc production were included in Other (2.C.7.).

In 2022, emissions from the metal industry were 27,975 kt CO_2-eq, accounting for 21.3 percent of total sectoral emissions. Iron and steel production was the biggest source as it produced 99.1 percent of emissions from the metal industry, indicating that emissions from the remaining subcategories remained below 1 percent. Emissions from the metal industry in 2022 decreased by 0.8 percent (215 kt CO_2-eq) from 2021, primarily due to a decrease of 258 kt CO_2-eq of emissions from iron and steel production. Magnesium production, however, emitted 59 kt CO_2-eq more emissions in 2022 from 2021.



| Figure 4-5 | Trends in Emissions from Metal Industry (1990-2022)

| Table 4-73 | Emissions from Metal Industry

(Unit: kt CO_2-eq)

Sub-category		1990	2000	2007	2010	2018	2021	2022
2.C.1.	Iron and Steel Production	13,041	18,481	20,056	20,255	31,512	27,968	27,710
2.C.2.	Ferroalloys Production	IE	IE	11	16	1	2	2
2.C.3.	Aluminium Production	23	NO	NO	NO	NO	NO	NO
2.C.4.	Magnesium Production	1	17	173	148	151	146	205
2.C.5.	Lead Production	IE	IE	IE	IE	IE	IE	IE
2.C.6.	Zinc Production	IE	IE	IE	IE	IE	IE	IE
2.C.7.	Other[1)]	NE,NO	NE,NO	57	72	84	75	59

Note: 1) Emissions from Lead production (2.C.5.) and Zinc production (2.C.6.) were included in Other (2.C.7.).

4.4.1 Iron and Steel Production (2.C.1.)

4.4.1.1 Category Overview

	Gas	Methodology	Emission Factor	Activity Data
2022	CO_2	Tier 2	CS, D	Input volume of process materials and carbonate consumption

CO_2 and CH_4 emissions occur during the production of steel and reported under Steel (2.C.1.a.), Pig iron (2.C.1.b.), Direct reduced iron (2.C.1.c.), Sinter (2.C.1.d.) or Pellets (2.C.1.e.). In ROK, there are two types of steel production processes, namely integrated steelmaking process and electric arc furnace process.

The integrated steel-making (blast furnace) process involves the production of pig iron by charging coke and sinter into a blast furnace which is then processed in the basic oxygen furnace to manufacture steel. During such process, CO_2 and CH_4 are emitted from the consumption of reducing agents. Based on the assumption that all of the carbon input to the process is converted into CO_2 as indicated in the *2006 IPCC Guidelines*[29)], only CO_2 emissions were estimated.

The electric arc furnace process involves charging scrap iron into an electric arc furnace which is then melted at high temperature to produce steel. CO_2 is emitted

29) *2006 IPCC Guidelines, Vol.3, Ch.3, p.3.67*

from the consumption of carbon electrodes and carbonates for the purpose of removing impurity during the production of iron and steel.

Activity data for CO_2 and CH_4 emissions from the production of Steel (2.C.1.a.), Pig iron (2.C.1.b.) and Sinter (2.C.1.d.) cannot be disaggregated into respective sources, and thus emissions were included in Steel (2.C.1.a.). Productions of direct reduced iron (2.C.1.c.) and pellet (2.C.1.e.) do not occur in ROK.

In 2022, emissions from iron and steel production were 27,710 kt CO_2−eq which decreased by 0.9 percent from 2021 due to reduced consumption of raw materials, carbonates and electrodes in steel production.

| Table 4−74 | Emissions from Iron and Steel Production

(Unit: kt CO_2−eq)

Source	1990	2000	2007	2010	2018	2021	2022
Blast Furnace	10,525	14,755	15,520	16,908	27,011	23,439	23,832
Electric Arc Furnace	59	123	150	148	133	127	107
Carbonate Consumption	2,457	3,603	4,385	3,198	4,368	4,401	3,771
Total	13,041	18,481	20,056	20,255	31,512	27,968	27,710

4.4.1.2 Methodology

4.4.1.2.1 Method

Emissions from iron and steel production were estimated using the Tier 2 carbon mass balance approach from the *2006 IPCC Guidelines*.

CO₂ emissions from iron and steel production

$$\begin{aligned}&CO_2 \text{ Emissions}\\&= [PC \times C_{pc} + \sum_a (COB_a \times C_a) + CI \times C_{CI} + CE \times C_{CE} + \sum_b (O_b \times C_b) + COG \times C_{COG}\\&- S \times C_S - IP \times C_{IP} - BG \times C_{BG}] \times \frac{44}{12} + L \times E_L + D \times E_D + M \times E_M\end{aligned}$$

CO_2 Emissions	:	CO_2 emissions from blast furnace (tonnes CO_2)
PC	:	mount of coke consumed during steel production (tonnes)
COB_a	:	amount of coke oven by-product (a) consumed in blast furnace (tonnes)
CI	:	amount of coal input to blast furnace (tonnes)
L	:	amount of limestone consumed during steel production (tonnes)
D	:	amount of dolomite consumed during steel production (tonnes)
M	:	amount of magnesite consumed during steel production (tonnes)
CE	:	amount of carbon electrode consumed in electric arc furnace (tonnes)
O_b	:	amount of other carbon materials and process materials (b) consumed during steel production (tonnes)
COG	:	amount of coke oven gas (COG) consumed in blast furnace (㎥)
S	:	amount of crude steel produced (tonnes)
IP	:	amount of unreduced iron (tonnes)
BG	:	amount of blast furnace gas transferred off-site (㎥)
C_x	:	carbon content of material x (tonnes C / tonne or ㎥)
E_i	:	emission factor by carbonate type (limestone, dolomite, magnesite) (tonnes CO_2/tonne)

Source: *2006 IPCC Guidelines, Vol.3, Ch.4, Equation 4.9*

4.4.1.2.2 Emission Factor

Default emission factors presented in the *2006 IPCC Guidelines* were used for electrodes and carbonates while country-specific emission factors[30] (carbon content) were used for the remaining process materials and end-products.

30) Country emissions factors were developed in 2021 based on values reported in TMS and K-ETS data from three domestic integrated steelmaking producers for the 2017 to 2019 period.

| Table 4-75 | Emission Factor for Iron and Steel Production

Process Materials and Carbonates		Emission Factor	Source
Carbon Content	Coke-oven Coke	0.8651 tonnes C/tonne	CS
	Other Bituminous Coal	0.7929 tonnes C/tonne	
	Coking Coal	0.7707 tonnes C/tonne	
	Blast Furnace Gas (BFG)	0.1873 tonnes C/tonne	
	Coke Oven Gas (COG)	0.4169 tonnes C/tonne	
	Other Off-gases (FOG)	0.2735 tonnes C/tonne	
Emission Factor	Carbon Electrodes	0.82 tonnes C/tonne	*2006 IPCC Guidelines*
	Limestone	0.43971 tonnes CO_2/tonne	
	Dolomite	0.47732 tonnes CO_2/tonne	
	Magnesite	0.52197 tonnes CO_2/tonne	

Source: *2006 IPCC Guidelines, Vol.3, Ch.3, Table 2.1; Ch.4, Table 4.3*

4.4.1.2.3 Activity Data

Activity data for blast furnace and electric arc furnace processes were sourced from the *Energy Supply and Demand Statistics* and the *Trade Statistics*. For carbonate consumption, data prior to 2006 were sourced from the *Steel Statistics Yearbook* while data from 2007 onward were from K-ETS data.

| Table 4-76 | Activity Data Source for Iron and Steel Production

Period	Activity Data	Name of Statistics	Published by	Gas
1990-2022	Input of coke, coking coal, other bituminous coal, COG, and BFG; production of BFG and FOG	*Energy Supply and Demand Statistics*	Korea Energy Economics Institute (KEEI)	CO_2
	Import and export of electrodes	*Trade Statistics*	Korea Customs Service (KCS)	
1990-2006	Carbonate consumption	*Steel Statistics Yearbook*	Korea Iron and Steel Association (KOSA)	
2007-2022		TMS and K-ETS data	Ministry of Environment (MOE)	

| Table 4-77 | Volume of Raw Material Input and End-Products for Blast Furnace Process

(Unit: ktoe)

Activity Data	1990	2000	2007	2010	2018	2021	2022
Coking Coal(+)	365	2,635	1,488	1,504	839	998	900
Other Bituminous Coal(+)	NO	NO	2,578	3,439	4,849	4,791	4,134
Cokes (+)	5,194	6,584	6,929	8,355	11,098	10,278	9,829
COG(+)	208	258	249	282	579	622	594
BFG(-)	1,331	2,114	2,473	3,319	4,241	4,242	3,819
FOG(-)	264	677	802	820	697	722	636

Note: (+) The amount of coking coal, other bituminous coal, coke and COG input into the blast furnace process.
(-) The amount of by-product gases (BFG, FOG) generated from the blast furnace process.

| Table 4-78 | Net Import Volume of Electrodes for Electric Arc Furnace Process

(Unit: kt)

Activity Data	1990	2000	2007	2010	2018	2021	2022
Net Imports of Electrodes	20	41	50	49	44	42	36

| Table 4-79 | Carbonate Consumption in Iron and Steel Production

(Unit: kt)

Amount	1990	2000	2007	2010	2018	2021	2022
Limestone	4,998	7,498	9,020	6,526	9,437	9,324	7,977
Dolomite	544	640	878	688	457	632	552
Magnesite	NO	NO	NO	NO	NO	NO	NO

4.4.1.3 Uncertainty and Time-series Consistency

4.4.1.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

4.4.1.3.2 Time-series Consistency

Emissions from the blast furnace and electric arc furnace processes were estimated using methodology, emission factors and activity data consistently across the entire time series. Emissions from the carbonate consumption process were also estimated using methodology and emission factors consistently for the entire time series. For activity data, values prior to 2006 were sourced from the *Steel Statistics Yearbook*. From 2007 onward, as all relevant businesses were identified as entities subject to K-ETS, K-ETS data were used to estimate emissions to ensure accuracy and consistency of the emissions estimates.

4.4.1.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

4.4.2 Ferroalloys Production (2.C.2.)

4.4.2.1 Category Overview

2022	Gas	Methodology	Emission Factor	Activity Data
	CO_2	Tier 2	D	Limestone and dolomite consumption

Ferroalloys are produced from iron and one or more metals such as silicon, manganese, and chromium of which the production process generates CO_2 emissions from the consumption of carbon electrodes, reducing agents and carbonates. Emissions from carbon electrodes consumption for ferroalloy production were included in Iron and steel production (2.C.1.), and emissions from reducing agent consumption for ferroalloy production were included in Iron and steel (1.A.2.a.) of the Energy sector as activity data cannot be disaggregated. Accordingly, only CO_2 emissions from the consumption of limestone and dolomite in the production process were reported under this subcategory from 2007 onward.[31)]

In 2022, emissions from ferroalloys production were 2 kt CO_2-eq which represented a 0.4 percent decrease from 2021, mainly due to a significant reduction in dolomite consumption.

| Table 4-80 | Emissions from Ferroalloys Production

(Unit: kt CO_2-eq)

Sub-category	1990	2000	2007	2010	2018	2021	2022
Ferroalloys Production	IE[1)],NO	IE,NO	11	16	0.91	1.92	1.91

Note: 1) Emissions from carbon electrode consumption were included in Iron and steel production (2.C.1.) while emissions from reducing agent consumption were included in Iron and steel (1.A.2.a.) of the Energy sector due to the absence of disaggregated activity data.

4.4.2.2 Methodology

4.4.2.2.1 Method

CO_2 emissions from ferroalloys production were estimated by multiplying the amount of carbonates consumed in the production process by the emission factor in accordance with the Tier 2 method of the *2006 IPCC Guidelines.*

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31) As emissions in 2007 for which activity data were initially collected were insignificant accounting for less than 0.05 percent of total national emissions as defined in Article 32 of the Modalities, Procedures and Guidelines (MPGs), it was considered that the likely level of emissions prior to 2007 were zero or insignificant as well. Accordingly, emissions in the 1990 to 2006 period were not estimated.

CO₂ emissions from ferroalloys production

$$CO_2 \text{ Emissions} = M \times EF$$

CO_2 Emissions : CO_2 emissions from carbonate consumption during ferroalloys production (tonnes CO_2)

M : amount of carbonates consumed (limestone, dolomite, magnesite) (tonnes)

EF : emission factor by carbonate type (tonnes CO_2/tonne carbonate consumed)

Source: *2006 IPCC Guidelines, Vol.3, Ch.4, Equation 4.16*

4.4.2.2.2 Emission Factor

Default emission factors from the *2006 IPCC Guidelines* were used for CO_2 emissions from the consumption of limestone and dolomite.

| Table 4-81 | Emission Factor for Ferroalloys Production

Carbonate	Emission Factor	Source
Limestone Consumption	0.43971 t CO_2/t Limestone Consumption	*2006 IPCC Guidelines*
Dolomite Consumption	0.47732 t CO_2/t Dolomite Consumption	

Source: *2006 IPCC Guidelines, Vol.3, Ch.2, Table 2.1*

4.4.2.2.3 Activity Data

From 2007 onward, carbonate consumption data reported by ferroalloy producers in TMS and K-ETS data were used.[32)]

| Table 4-82 | Activity Data Source for Ferroalloys Production

Period	Activity Data	Name of Statistics	Published by	Gas
2007-2022	Limestone and dolomite consumption	TMS and K-ETS data	Ministry of Environment (MOE)	CO_2

| Table 4-83 | Activity Data for Ferroalloys Production

(Unit: t)

Amount		1990	2000	2007	2010	2018	2021	2022
Consumption	Limestone	NE	NE	NE	NE	2,048	3,954	4,347
	Dolomite	NE	NE	23,485	32,842	25	378	NO

32) As emissions in 2007 for which activity data were initially collected were insignificant accounting for less than 0.05 percent of total national emissions as defined in Article 32 of the Modalities, Procedures and Guidelines (MPGs), it was considered that the likely level of emissions prior to 2007 were zero or insignificant as well. Accordingly, emissions in the 1990 to 2006 period were not estimated.

4.4.2.3 Uncertainty and Time-series Consistency

4.4.2.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

4.4.2.3.2 Time-series Consistency

Emissions from ferroalloys production were estimated using methodology, emission factors and activity data consistently across the entire time series.

4.4.2.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

4.4.3 Aluminium Production (2.C.3.)

4.4.3.1 Category Overview

Aluminium production generates emissions of CO_2 and PFCs during the process which involves the electrolysis reaction of the carbon anode with primary aluminium (Al_2O_3). In ROK, aluminium production ceased in 1990. PFCs were not estimated due to lack of data on the aluminium production process.

| Table 4-84 | Emissions from Aluminium Production

(Unit: kt CO_2-eq)

Sub-category	1990	2000	2007	2010	2018	2021	2022
Aluminium Production	23	NO	NO	NO	NO	NO	NO

4.4.3.2 Methodology

4.4.3.2.1 Method

CO_2 emissions were estimated by multiplying the amount of aluminium produced by the emission factor in accordance with the Tier 1 method of the *2006 IPCC Guidelines.*

CO_2 emissions from aluminium production
$$CO_2\ Emissions = EFs \times MPs$$
CO_2 Emissions : CO_2 emissions from aluminium production (tonnes CO_2)
EFs : emission factor (tonnes CO_2/tonne aluminium produced)
MPs : amount of aluminium produced (tonnes)

Source: *2006 IPCC Guidelines, Vol.3, Ch.4, Equation 4.20*

4.4.3.2.2 Emission Factor

The default emission factor for CO_2 emissions from the *2006 IPCC Guidelines* was used.

| Table 4-85 | Emission Factor for Aluminium Production

Technology	Emission Factor	Source
Soderberg	1.7 tonnes CO_2/tonne	*2006 IPCC Guidelines*

Source: *2006 IPCC Guidelines, Vol.3, Ch.4, Table 4.10*

4.4.3.2.3 Activity Data

Aluminium production data were sourced from relevant statistics published by the Korea Nonferrous Metals Association (KONMA).

| Table 4-86 | Activity Data Source for Aluminium Production

Period	Activity Data	Name of Statistics	Published by	Gas
1990	Aluminium production	Aluminium production statistics	Korea Nonferrous Metals Association (KONMA)	CO_2

| Table 4-87 | Activity Data for Aluminium Production

(Unit: t)

Amount	1990	2000	2007	2010	2018	2021	2022
Aluminium Production	13,684	NO	NO	NO	NO	NO	NO

4.4.3.3 Uncertainty and Time-series Consistency

4.4.3.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

4.4.3.3.2 Time-series Consistency

As aluminium production in ROK ceased in 1990 and emissions were available only for a single year, time series consistency was not considered.

4.4.3.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

4.4.4 Magnesium Production (2.C.4.)

4.4.4.1 Category Overview

	Gas	Methodology	Emission Factor	Activity Data
2022	SF_6, CO_2	Tier 1	D	Imported materials for magnesium casting, carbonate consumption

Magnesium production is divided into primary and secondary production processes. The primary production uses raw ore such as dolomite ($CaMg(CO_3)_2$) and magnesite ($MgCO_3$) while secondary production involves the recovery and recycling of magnesium containing scrap materials. In the primary production process, CO_2 is emitted during the thermal decomposition of carbonate ores at high temperature. In both primary and secondary production processes, SF_6 is used as a cover gas during the casting process to prevent oxidation of molten magnesium, and a portion of SF_6 is released into the atmosphere.

In ROK, a single company produced magnesium ingots and sheets from 2012 to 2014. Accordingly, CO_2 emissions from carbonate consumption in the primary production process were estimated only for 2013 and 2014. Currently, small-scale producers manufacture magnesium products using magnesium scrap through secondary production process.

In 2022, emissions from magnesium production were 205 kt CO_2-eq which increased by 40.8 percent from 2021 due to the increased casting volume.

| Table 4-88 | Emissions from Magnesium Production

(Unit: kt CO_2-eq)

Sub-category	1990	2000	2007	2010	2018	2021	2022
Magnesium Production	1	17	173	148	151	146	205

4.4.4.2 Methodology

4.4.4.2.1 Method

SF_6 emissions were estimated by multiplying the amount of magnesium cast by the SF_6 emission factor in accordance with the Tier 1 method of the *2006 IPCC Guidelines*. CO_2 emissions were estimated by multiplying the amount of carbonates consumed by the CO_2 emission factor in accordance with the Tier 2 method of the *2006 IPCC Guidelines*.

SF_6 emissions from magnesium production

$$SF_6 \text{ Emissions} = MGc \times EF \times 10^{-3}$$

SF_6 Emissions	:	SF_6 emissions from magnesium casting (tonnes SF_6)
MGc	:	amount of magnesium cast or processed (tonnes)
EF	:	emission factor for magnesium casting (kg SF_6 / tonne magnesium cast or processed)

Source: *2006 IPCC Guidelines, Vol.3, Ch.4, Equation 4.30*

CO_2 emissions from magnesium production

$$CO_2 \text{ Emissions} = M \times EF$$

CO_2 Emissions	:	CO_2 emissions from carbonates used during magnesium production (tonnes CO_2)
M	:	amount of carbonates consumed (limestone, dolomite, magnesite) (tonnes)
EF	:	emission factor by carbonate type (tonnes CO_2/tonne carbonate consumed)

Source: *2006 IPCC Guidelines, Vol.3, Ch.4, Equation 4.29*

4.4.4.2.2 Emission Factor

Default emission factors from the *2006 IPCC Guidelines* were used for SF_6 and CO_2 emissions from magnesium production.

| Table 4-89 | Emission Factor for Magnesium Production

Type	Emission Factor	Source
Magnesium Casting	1.0 kg SF_6/tonne Mg Magnesium Casting	*2006 IPCC Guidelines*
Dolomite Consumption	0.47732 tonnes CO_2/tonne Dolomite Consumption	

Source: *2006 IPCC Guidelines, Vol.3, Ch.2 Table 2.1; Ch.4, Table 4.20*

4.4.4.2.3 Activity Data

For magnesium casting data, the *Trade Statistics*[33] were used for the entire time series. For carbonate consumption in 2013 and 2014, K-ETS data were used.

| Table 4-90 | Activity Data Source for Magnesium Production

Period	Activity Data	Name of Statistics	Published by	Gas
1990-2022	Imported materials for magnesium casting	*Trade Statistics*	Korea Customs Service (KCS)	SF_6
2013-2014	Carbonate consumption	TMS and K-ETS data	Ministry of Environment (MOE)	CO_2

| Table 4-91 | Activity Data for Magnesium Production

(Unit: t)

Amount	1990	2000	2007	2010	2018	2021	2022
Magnesium Casting	34	739	7,371	6,306	6,411	6,194	8,723

4.4.4.3 Uncertainty and Time-series Consistency

4.4.4.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

4.4.4.3.2 Time-series Consistency

Emissions from magnesium production were estimated using methodology, emission factors and activity data consistently.

4.4.4.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

33) In secondary magnesium production, imported magnesium ingots were used as raw materials and fully consumed in ROK. Therefore, import data were used as sole activity data.

4.4.5 Lead Production (2.C.5.)

4.4.5.1 Category Overview

	Gas	Methodology	Emission Factor	Activity Data
2022	CO_2	Tier 2	D	Limestone consumption

Lead production is divided into the primary and secondary production processes. The primary process involves the production of rough lead bullion from lead concentrates while the secondary process consumes coke and carbonates as a reducing agent to process oxidized lead for reuse which generates CO_2 emissions. In ROK, lead is produced using a hydrometallurgical technique which does not result in emissions. Emissions from the use of reducing agents were reported under Iron and steel (1.A.2.a.) of the Energy sector. Accordingly, only CO_2 emissions from the consumption of carbonates were estimated.[34)]

As there is a single company in ROK that consumes carbonates for lead production, emissions were included in Other metal production (2.C.7.) to protect confidential information.

4.4.5.2 Methodology

4.4.5.2.1 Method

CO_2 emissions from lead production were estimated by multiplying the amount of carbonates consumed in the production process by the emission factor in accordance with the Tier 2 method of the *2006 IPCC Guidelines.*

CO_2 emissions from lead production

$$CO_2\ Emissions = M \times EF$$

CO_2 Emissions : CO_2 emissions from carbonate use during lead production (tonnes CO_2)
M : amount of carbonates consumed (tonnes)
EF : emission factor by carbonate type (tonnes CO_2/tonne carbonate consumed)

Source: *2006 IPCC Guidelines, Vol.3, Ch.2, Equation 2.15*

34) As emissions in 2007 for which activity data were initially collected were insignificant accounting for less than 0.05 percent of total national emissions as defined in Article 32 of the Modalities, Procedures and Guidelines (MPGs), it was considered that the likely level of emissions prior to 2007 were zero or insignificant as well. Accordingly, emissions in the 1990 to 2006 period were not estimated.

4.4.5.2.2 Emission Factor

The default emission factor from the *2006 IPCC Guidelines* was used for CO_2 emissions from carbonate consumption.

| Table 4-92 | Emission Factor for Lead Production

Carbonate	Emission Factor	Source
Limestone	0.43971 tonnes CO_2/tonne Limestone Consumption	*2006 IPCC Guidelines*

Source: *2006 IPCC Guidelines, Vol.3, Ch.2, Table 2.1*

4.4.5.2.3 Activity Data

From 2007 onward, the consumption volume of carbonates was sourced from TMS and K-ETS data were used.[35)]

| Table 4-93 | Activity Data Source for Lead Production

Period	Activity Data	Name of Statistics	Published by	Gas
2007-2022	Limestone consumption	TMS and K-ETS data	Ministry of Environment (MOE)	CO_2

4.4.5.3 Uncertainty and Time-series Consistency

4.4.5.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

4.4.5.3.2 Time-series Consistency

Emissions from lead production were estimated using methodology, emission factor and activity data consistently across the entire time series.

4.4.5.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

35) As emissions in 2007 for which activity data were initially collected were insignificant accounting for less than 0.05 percent of total national emissions as defined in Article 32 of the Modalities, Procedures and Guidelines (MPGs), it was considered that the likely level of emissions prior to 2007 were zero or insignificant as well. Accordingly, emissions in the 1990 to 2006 period were not estimated.

4.4.6 Zinc Production (2.C.6.)

4.4.6.1 Category Overview

	Gas	Methodology	Emission Factor	Activity Data
2022	CO_2	Tier 2	D	Limestone consumption

Zinc is produced from zinc concentrate for which carbonates are used and coke is consumed as a reducing agent. The process results in the release of CO_2 emissions. In ROK, zinc is produced using a hydrometallurgical technique which does not generate emissions. Emissions from the use of reducing agents were reported under Iron and steel (1.A.2.a.) of the Energy sector. Accordingly, only CO_2 emissions from the consumption of carbonates were estimated.[36)]

As there is a single company in ROK that consumes carbonates for zinc production, emissions were included in Other metal production (2.C.7.) to protect confidential information.

4.4.6.2 Methodology

4.4.6.2.1 Method

CO_2 emissions from zinc production were estimated by multiplying the amount of carbonates consumed in the production process by the emission factor in accordance with the Tier 2 method of the *2006 IPCC Guidelines.*

CO_2 emissions from zinc production

$$CO_2 \text{ Emissions} = M \times EF$$

CO_2 emissions	:	CO_2 emissions from carbonates use during zinc production (tonnes CO_2)
M	:	amount of carbonates consumed (tonnes)
EF	:	emission factor by carbonate type (tonnes CO_2/tonne carbonate consumed)

Source: *2006 IPCC Guidelines, Vol.3, Ch.2, Equation 2.15*

36) As emissions in 2007 for which activity data were initially collected were insignificant accounting for less than 0.05 percent of total national emissions as defined in Article 32 of the Modalities, Procedures and Guidelines (MPGs), it was considered that the likely level of emissions prior to 2007 were zero or insignificant as well. Accordingly, emissions in the 1990 to 2006 period were not estimated.

4.4.6.2.2 Emission Factor

The default emission factor from the *2006 IPCC Guidelines* was used for CO_2 emissions from carbonate consumption for zinc production.

| Table 4-94 | Emission Factor for Zinc Production

Carbonate	Emission Factor	Source
Limestone	0.43971 t CO_2/t Limestone Consumption	*2006 IPCC Guidelines*

Source: *2006 IPCC Guidelines, Vol.3, Ch.2, Table 2.1*

4.4.6.2.3 Activity Data

From 2007 onward, the consumption volume of carbonates was sourced from TMS and K-ETS data.[37]

| Table 4-95 | Activity Data Source for Zinc Production

Period	Activity Data	Name of Statistics	Published by	Gas
2007-2022	Limestone consumption	TMS and K-ETS data	Ministry of Environment (MOE)	CO_2

4.4.6.3 Uncertainty and Time-series Consistency

4.4.6.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

4.4.6.3.2 Time-series Consistency

Emissions from zinc production were estimated using methodology, emission factor and activity data consistently across the entire time series.

4.3.6.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

37) As emissions in 2007 for which activity data were initially collected were insignificant accounting for less than 0.05 percent of total national emissions as defined in Article 32 of the Modalities, Procedures and Guidelines (MPGs), it was considered that the likely level of emissions prior to 2007 were zero or insignificant as well. Accordingly, emissions in the 1990 to 2006 period were not estimated.

4.4.7 Other (2.C.7.)

4.4.7.1 Category Overview

2022	Gas	Methodology	Emission Factor	Activity Data
	CO_2	Tier 2	D	Limestone consumption

Under this reporting subcategory, CO_2 emissions from the consumption of carbonates for copper production and metal industries other than iron and steel, ferroalloys, aluminium, magnesium, lead and zinc were reported.[38] As there is a single company in ROK that consumes carbonates for lead and zinc production respectively, emissions from subcategories of Lead production (2.C.5.) and Zinc production (2.C.6.) were included in this subcategory to protect confidential information.

In 2022, emissions from other metal production were 59 kt CO_2-eq which represented a decrease of 21.8 percent from 2021 due to reduced consumption of carbonates in lead, zinc and copper production.

| Table 4-96 | Emissions from Other Metal Production

(Unit: kt CO_2-eq)

Sub-category	1990	2000	2007	2010	2018	2021	2022
Other Metal Production	NE,NO	NE,NO	57	72	84	75	59

4.4.7.2 Methodology

4.4.7.2.1 Method

CO_2 emissions from other metal production were estimated by multiplying the amount of carbonates consumed in the production process by the emission factor in accordance with the Tier 2 method of the *2006 IPCC Guidelines*.

38) As emissions in 2007 for which activity data were initially collected were insignificant accounting for less than 0.05 percent of total national emissions as defined in Article 32 of the Modalities, Procedures and Guidelines (MPGs), it was considered that the likely level of emissions prior to 2007 were zero or insignificant as well. Accordingly, emissions in the 1990 to 2006 period were not estimated.

CO_2 emissions from other metal production

$$CO_2 \text{ Emissions} = M \times EF$$

CO_2 Emissions	: CO_2 emissions from carbonate use during other metal production (t CO_2)
M	: amount of carbonates consumed (limestone, dolomite) (t)
EF	: emission factor by carbonate type (t CO_2/t carbonate consumed)

Source: *2006 IPCC Guidelines, Vol.3, Ch.2, Equation 2.15*

4.4.7.2.2 Emission Factor

The default emission factor from the *2006 IPCC Guidelines* was used for CO_2 emissions from carbonate consumption in other metal production.

| Table 4-97 | Emission Factor for Other Metal Production

Carbonate	Emission Factor	Source
Limestone	0.43971 t CO_2/t Limestone Consumption	*2006 IPCC Guidelines*

Source: *2006 IPCC Guidelines, Vol.3, Ch.2, Table 2.1*

4.4.7.2.3 Activity Data

From 2007 onward, the consumption volume of carbonates by copper producers[39] was sourced from TMS and K-ETS data.[40]

| Table 4-98 | Activity Data Source for Other Metal Production

Period	Activity Data	Name of Statistics	Published by	Gas
2007-2022	Limestone consumption	TMS and K-ETS data	Ministry of Environment (MOE)	CO_2

| Table 4-99 | Activity Data for Other Metal Production

(Unit: kt)

Amount	1990	2000	2007	2010	2018	2021	2022
Limestone Consumption	NE	NE	130	163	192	171	134

39) See Section 4.4.5.2.3 and 4.4.6.2.3 for activity data of lead and zinc production of which emissions were reported in this subcategory.

40) As emissions in 2007 for which activity data were initially collected were insignificant accounting for less than 0.05 percent of total national emissions as defined in Article 32 of the Modalities, Procedures and Guidelines (MPGs), it was considered that the likely level of emissions prior to 2007 were zero or insignificant as well. Accordingly, emissions in the 1990 to 2006 period were not estimated.

4.4.7.3 Uncertainty and Time-series Consistency

4.4.7.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

4.4.7.3.2 Time-series Consistency

Emissions from other metal production were estimated using methodology, emission factors and activity data consistently across the entire time series.

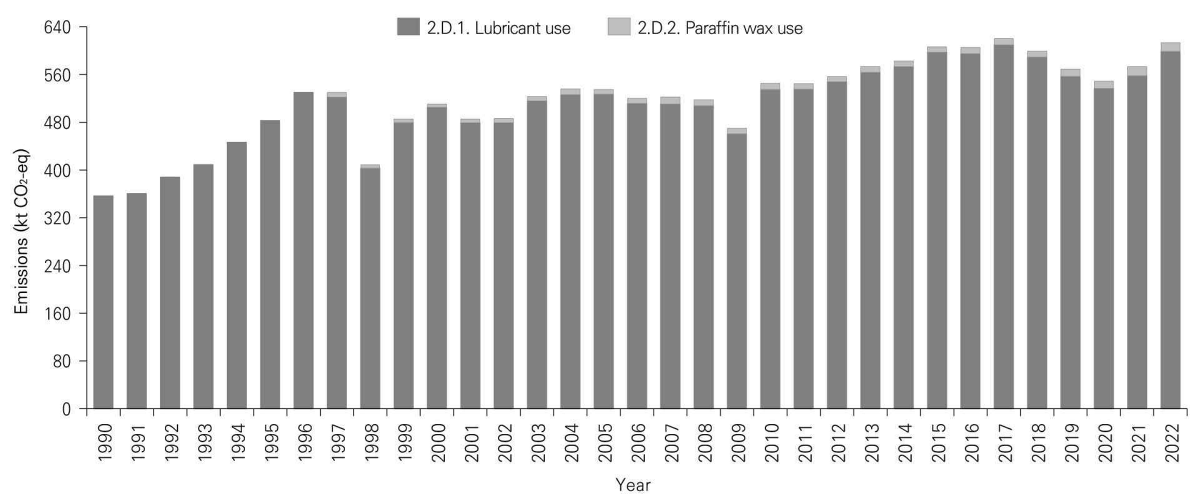
4.4.7.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

4.5 Non-Energy Products from Fuels and Solvent Use (2.D.)

Emissions from the use of fossil fuels as a product for primary purpose other than combustion for energy use or use as feedstock or reducing agent are reported under this reporting category which are subdivided into Lubricant Use (2.D.1.), Paraffin Wax Use (2.D.2.), and Other Non-energy Product Use (2.D.3.). The subcategory of Other Non-energy Product Use (2.D.3.) is further divided into Solvent Use (2.D.3.a.), Road Paving with Asphalt (2.D.3.b.), and Asphalt Roofing (2.D.3.c.). As the *2006 IPCC Guidelines* do not provide estimation methodologies for respective subcategories, emissions from other non-energy product use were reported as 'Not Applicable (NA)'. ROK will explore the potential to improve the accuracy and completeness of estimates for this subcategory as well as indirect emissions.

In 2022, emissions from non-energy products and solvent use were 613 kt CO_2-eq, accounting for 0.5 percent of total emissions from the IPPU sector. Lubricant use was the largest source accounting for 97.6 percent of emissions from this category while paraffin wax represented 2.4 percent. Emissions from this category increased by 7.0 percent (40 kt CO_2-eq) from 2021 which was largely contributed by an increase of 40 kt CO_2-eq in emissions from the lubricant use.



| Figure 4-6 | Trends in Emissions from Non-energy Products and Solvent Use (1990-2022)

| Table 4-100 | Emissions from Non-energy Products and Solvent Use

(Unit: kt CO_2-eq)

Sub-category	1990	2000	2007	2010	2018	2021	2022
2.D.1. Lubricant Use	357	505	511	535	590	558	599
2.D.2. Paraffin Wax Use	NO	6	12	11	9	15	15
2.D.3. Other Non-energy Product Use	NA	NA	NA	NA	NA	NA	NA

4.5.1 Lubricant Use (2.D.1.)

4.5.1.1 Category Overview

2022	Gas	Methodology	Emission Factor	Activity Data
	CO_2	Tier 2	D, CS	Lubricating oil and grease consumption

Lubricants are used in industrial facilities and transportation applications for its lubricating properties. The oxidation process of lubricating oil and greases consumed in machinery and vehicles results in CO_2 emissions. Such emissions are reported under this subcategory except for emissions from the use of two-stroke engines that consume lubricants mixed with other fuels for combustion which are reported under Road transportation (1.A.3.b.) of the Energy sector in accordance with the *2006 IPCC Guidelines*.

In 2022, emissions from the lubricant use were 599 kt CO_2-eq which increased by 7.2 percent from 2021 due to a rise in total consumption of lubricant. Although greases consumption decreased by 4.6 percent (757 kilolitres), lubricating oil consumption increased by 8.6 percent (87,656 kilolitres) which was the major driver of emissions increase under this reporting subcategory.

| Table 4-101 | Emissions from Lubricant Use

(Unit: kt CO_2-eq)

Source		1990	2000	2007	2010	2018	2021	2022
Consumption	Lubricating oil	354	502	508	532	587	556	597
	Grease	3	3	3	3	2	2	2
Total		357	505	511	535	590	558	599

4.5.1.2 Methodology

4.5.1.2.1 Method

Emissions from lubricant use were estimated using the Tier 2 method of the *2006 IPCC Guidelines* by multiplying the consumption of lubricating oil and grease by their carbon content and the oxidation rate.

CO_2 emissions from lubricant use

$$CO_2 \text{ Emissions } = \sum_i (LC_i \times CC_i \times ODU_i) \times \frac{44}{12}$$

CO_2 Emissions	: CO_2 emissions from lubricant use (tonnes CO_2)
LC_i	: consumption of lubricant type(i) (TJ)
CC_i	: carbon content of lubricant type i (kg C / GJ lubricant)
ODU_i	: oxidation rate (oxidation factor) during use of lubricant type i

Source: *2006 IPCC Guidelines, Vol.3, Ch.5, Equation 5.3*

4.5.1.2.2 Emission Factor

For the 1990 to 2006 period, default emission factors from the *2006 IPCC Guidelines* were used while country-specific emission factors were used from 2007 onward. For the oxidation factor, the default value provided in the *2006 IPCC Guidelines* was used.

| Table 4-102 | Emission Factor for Lubricant Use

Type		Emission Factor	Source
Carbon Content	1990-2006	20.000 kg C / GJ	*2006 IPCC Guidelines*
	2007-2011	19.700 kg C / GJ	CS[1]
	2012-2016	19.900 kg C / GJ	
	2017-2021	19.979 kg C / GJ	
	2022	19.897 kg C / GJ	
Oxidation Factor	Lubricating oil	0.2	*2006 IPCC Guidelines*
	Grease	0.05	

Note: 1) See Section 3.2.4.2.1 for more information about energy calorific values and domestic energy conversion system.
Source: *2006 IPCC Guidelines, Vol.2, Ch.1, Table 1.3; Vol.3, Ch.5, Table 5.2*

4.5.1.2.3 Activity Data

The consumption volume of lubricating oil (excluding two-stroke engines) and greases were sourced from statistics provided by the Korea Lubricating Oil Industries Association (KLOIA).

| Table 4-103 | Activity Data Source for Lubricant Use

Period	Activity Data	Name of Statistics	Published by	Gas
1990-2022	Lubricating oil, grease consumption	Lubricating oil and grease statistics	Korea Lubricating Oil Industries Association (KLOIA)	CO_2

| Table 4-104 | Activity Data for Lubricant Use

(Unit: kL)

Consumption	1990	2000	2007	2010	2018	2021	2022
Lubricating oil	654,612	928,261	971,575	1,018,102	1,074,608	1,017,571	1,105,227
Grease	21,329	23,729	20,598	19,322	17,008	16,309	15,552

4.5.1.3 Uncertainty and Time-series Consistency

4.5.1.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

4.5.1.3.2 Time-series Consistency

Emissions from lubricant use were estimated using methodology, emission factors and activity data consistently across the entire time series. To maintain consistency between default and country-specific emission factors, the approach of tracking changes in activity data and emissions across the time series was used based on expert judgment

4.5.1.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

4.5.2 Paraffin Wax Use (2.D.2.)

4.5.2.1 Category Overview

2022	Gas	Methodology	Emission Factor	Activity Data
	CO_2	Tier 1	D	Paraffin wax consumption

Paraffin waxes are used in applications such as candles, paper coating, adhesives and wax polishes. When the waxes are combusted during use, CO_2 emissions arise. In ROK, no paraffin wax was consumed from 1990 to 1996.

In 2022, emissions from paraffin wax use were 15 kt CO_2-eq which decreased by 2.6 percent from 2021 due to the reduced consumption of paraffin wax.

| Table 4-105 | Emissions from Paraffin Wax Use

(Unit: kt CO_2-eq)

Sub-category	1990	2000	2007	2010	2018	2021	2022
Paraffin Wax Use	NO	6	12	11	9	15	15

4.5.2.2 Methodology

4.5.2.2.1 Method

Emissions from paraffin wax use were estimated using the Tier 1 method of the *2006 IPCC Guidelines* by multiplying paraffin wax consumption by its carbon content and the oxidation rate.

CO_2 emissions from paraffin wax use

$$CO_2\ \text{Emissions} = PW \times CC_{Wax} \times ODU_{Wax} \times \frac{44}{12}$$

CO_2 Emissions : CO_2 emissions from paraffin wax use (tonnes CO_2)

PW : amount of paraffin wax consumed (TJ)

CC_{Wax} : carbon content of paraffin wax (tonnes C / TJ paraffin wax)

ODU_{Wax} : oxidation rate (oxidation factor) during use of paraffin wax

Source: *2006 IPCC Guidelines, Vol.3, Ch.5, Equation 5.4*

4.5.2.2.2 Emission Factor

The carbon emission factor (carbon content) and oxidation factor for paraffin wax use were based on the default values from the *2006 IPCC Guidelines.*

| Table 4-106 | Emission Factor for Paraffin Wax Use

Emission Factor		Factor Value	Source
Paraffin wax	Carbon Content	20 kg C/GJ	*2006 IPCC Guidelines*
	Oxidation Factor	0.2	

Source: *2006 IPCC Guidelines, Vol.3, Ch.5, p.5.12*

4.5.2.2.3 Activity Data

The consumption of paraffin wax was sourced from the *Energy Supply and Demand Statistics.*

| Table 4-107 | Activity Data Source for Paraffin Wax Use

Period	Activity Data	Name of Statistics	Published by	Gas
1990-2022	Paraffin wax consumption	*Energy Supply and Demand Statistics*	Korea Energy Economics Institute (KEEI)	CO_2

| Table 4-108 | Activity Data for Paraffin Wax Use

(Unit: ktoe)

Amount	1990	2000	2007	2010	2018	2021	2022
Paraffin Wax Consumption	NO	9.1	19.0	17.2	15.4	24.5	23.9

4.5.2.3 Uncertainty and Time-series Consistency

4.5.2.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

4.5.2.3.2 Time-series Consistency

Emissions from paraffin wax use were estimated using methodology, emission factors and activity data consistently across the entire time series.

4.5.2.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

4.6 Electronics Industry (2.E.)

The electronics industry emits fluorinated compounds including HFCs, PFCs, SF_6 and NF_3 from the manufacturing process of electronic devices such as semiconductors and displays. Such emissions are reported under Integrated circuit or semiconductor (2.E.1.), Thin-film-transistor (TFT) flat panel display (2.E.2.), Photovoltaics (2.E.3.), Heat transfer fluids (2.E.4.) or Other (2.E.5.). Emissions from Heat transfer fluids (2.E.4.) do not occur in ROK. To protect confidential business information of major industries in ROK, activity data were reported as "Confidential (C)," and emissions from each subcategory were included in Other (2.E.5.).

As the Greenhouse Gas Target Management System (TMS) and Emissions Trading Scheme (K-ETS) have been implemented since 2010, semiconductor and display manufacturers have been reporting fluorinated gas emissions (excluding NF_3) from 2007 onward under respective systems which were aggregated to obtain the total emissions of fluorinated gases from the electronics industry.[41] Emissions of NF_3 which were not presented in TMS and K-ETS data were estimated by using data on the consumption of NF_3 provided by the Korea Semiconductor Industry Association (KSIA) and Korea Display Industry Association (KDIA) along with default emission factors following the *2006 IPCC Guidelines* methodology.

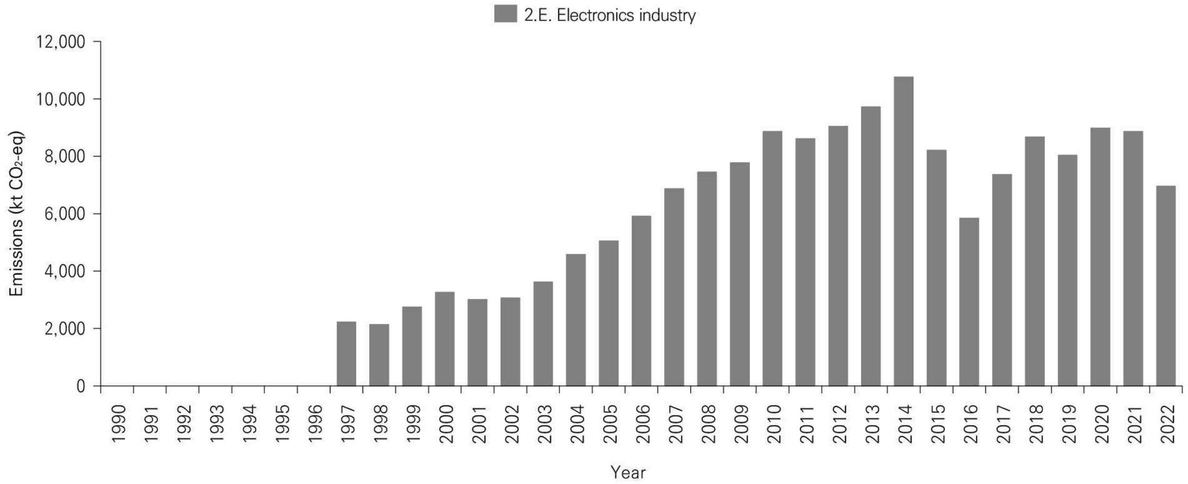
In 2022, emissions from the electronics industry were 6,956 kt CO_2-eq which accounted for 5.3 percent of total emissions from the IPPU sector. As semiconductor and display manufacturers increased the use of emissions control devices and improved efficiency of such devices, emissions decreased by 21.6 percent (1,911 kt CO_2-eq) from 2021.

| Table 4-109 | Emissions from Electronics Industry

(Unit: kt CO_2-eq)

Category	1990	2000	2007	2010	2018	2021	2022
Electronics Industry	IE,NA,NO	3,257	6,868	8,861	8,673	8,867	6,956

41) Emissions reported by semiconductor and display manufacturers under TMS and K-ETS were estimated using the default emission factor (Tier 1) and plant-specific emission factor (Tier 3).



| Figure 4-7 | Trends in Emissions from Electronics Industry (1990-2022)

4.6.1 Integrated Circuit or Semiconductor (2.E.1.)

4.6.1.1 Category Overview

	Gas	Methodology	Emission Factor	Activity Data
2022	HFCs, PFCs, SF_6, NF_3	Tier 2a	PS, D	Emission of HFCs, PFCs and SF_6, NF_3 Consumption

Semiconductors are manufactured through processes of etching and chemical vapour deposition (CVD) in which fluorinated gases including HFCs, PFCs, SF_6 and NF_3 are used. In the etching process, fluorinated gases are used to selectively remove substrate materials. The CVD process involves the use of fluorinated gases for the deposition of molecules or atoms as thin films on wafers and chamber cleaning thereafter. Emissions resulted from the consumption of such fluorinated gases for etching and CVD processes were estimated.

4.6.1.2 Methodology

4.6.1.2.1 Method

Emissions of fluorinated gases from the semiconductor industry were estimated using the Tier 2a method of the *2006 IPCC Guidelines*.[42]

42) Emissions reported in TMS and K-ETS data were estimated using the Tier2a method in accordance with the *2006 IPCC Guidelines*.

Emissions from integrated circuit or semiconductor (Tier 2a)

$$\text{Fluorinated Gas Emissions}_i = (1-h) \times FC_i \times (1-U_i) \times (1-a_i \times d_i)$$

$$\text{By-product Gas Emissions}_j = (1-h) \times B_{j,i} \times FC_i \times (1-a_i \times d_j)$$

$Emissions_{i,j}$	:	emission of greenhouse gas (i,j) (kg)
h	:	fraction of gas remaining in shipping container after use
FC_i	:	amount of greenhouse gas i consumed (kg)
$B_{j,i}$	:	emission factor, kg gas j created / gas i used
U_i	:	use rate of gas i (fraction destroyed or transformed during process)
a_i	:	fraction of greenhouse gas i volume used in processes with emission control technologies
d_i	:	fraction of gas i destroyed by the emission control technology
i	:	fluorinated gases incl. CF_4, C_2F_6, C_3H_8, c−C_4F_8, c−C_4F_9O, C_4F_6, C_5F_8, CHF_3. CH_2F_2, NF_3, SF_6 (kg)
j	:	by−product gases by type (CF_4, C_2F_6, C_3F_8)

Source: *2006 IPCC Guidelines, Vol.3, Ch.6, Equations 6.2−6.6*

4.6.1.2.2 Emission Factor

Prior to 2006, default emission factors from the *2006 IPCC Guidelines* were used for the fraction of gas remaining (*h*), by−product generation rate (*B*) and gas usage rate (*U*). From 2007 onward, default emission factors from the *2006 IPCC Guidelines* and plant−specific emission factors reported under TMS and K−ETS were used. The fraction of NF_3 volume used in processes with emission control technologies (*a*) was based on data provided by KSIA.

| Table 4−110 | Emission Factor for Semiconductor

<table>
<tr><th>Gas Type(i)</th><th>CF_4</th><th>C_2F_6</th><th>C_3F_8</th><th>C_4F_6</th><th>c−C_4F_8</th><th>C_5F_8</th><th>CHF_3</th><th>CH_2F_2</th><th>SF_6</th><th>NF_3</th><th>NF_3 remote</th></tr>
<tr><td>Method</td><td colspan="11">Tier 2a</td></tr>
<tr><td>h</td><td>0.1</td><td>0.1</td><td>0.1</td><td>0.1</td><td>0.1</td><td>0.1</td><td>0.1</td><td>0.1</td><td>0.1</td><td>0.1</td><td>0.1</td></tr>
<tr><td>1−U_i</td><td>0.9</td><td>0.6</td><td>0.4</td><td>0.1</td><td>0.1</td><td>0.1</td><td>0.4</td><td>0.1</td><td>0.2</td><td>0.2</td><td>0.02</td></tr>
<tr><td>$B_{CF4,i}$</td><td rowspan="3">NA</td><td>0.2</td><td>0.1</td><td>0.3</td><td>0.1</td><td>0.1</td><td>0.07</td><td>0.08</td><td rowspan="3">NA</td><td>0.09</td><td>0.02</td></tr>
<tr><td>$B_{C2F6,i}$</td><td rowspan="2">NA</td><td rowspan="2">NA</td><td>0.2</td><td>0.1</td><td>0.04</td><td rowspan="2">NA</td><td rowspan="2">NA</td><td rowspan="2">NA</td><td rowspan="2">NA</td></tr>
<tr><td>$B_{C3F8,i}$</td><td>NA</td><td>NA</td><td>NA</td></tr>
</table>

4.6.1.2.3 Activity Data

For the 1997 to 2006 period, emissions were estimated using data on the consumption of fluorinated gases (excluding NF_3) provided by KSIA. From 2007 onward, emissions reported under TMS and K−ETS were aggregated. Data on the NF_3 consumption were provided by KSIA from 2008 onward.

| Table 4-111 | Activity Data Source for Semiconductor

Period	Activity Data	Name of Statistics	Published by	Gas
1997-2006	HFCs, PFCs, SF_6 consumption	HFCs, PFCs, SF_6 statistics	Korea Semiconductor Industry Association (KSIA)	HFCs, PFCs, SF_6
2007-2022	HFCs, PFCs, SF_6 emissions	TMS and K-ETS data	Ministry of Environment (MOE)	
2008-2022	NF_3 consumption	NF_3 statistics	Korea Semiconductor Industry Association (KSIA)	NF_3

4.6.1.3 Uncertainty and Time-series Consistency

4.6.1.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

4.6.1.3.2 Time-series Consistency

Emissions of HFCs, PFCs and SF_6 were estimated using methodology, emission factors and activity data consistently based on the *2006 IPCC Guidelines*. From 2007 onward, semiconductor manufacturers were identified as entities subject to the K-ETS and required to report emissions under the respective system. Using data from K-ETS, the accuracy and consistency of associated emissions were improved. NF_3 emissions were also estimated using consistent methodology, emission factors and activity data.

4.6.1.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

4.6.1.5 Planned Improvements

Further assessment and research on the efficiency of NF_3 abatement system installed in domestic facilities are in process. ROK is implementing improvement efforts to develop country-specific emission factors to apply a higher tiered approach for this subcategory.

4.6.2 TFT Flat Panel Display (2.E.2.)

4.6.2.1 Category Overview

	Gas	Methodology	Emission Factor	Activity Data
2022	HFCs, PFCs, SF_6, NF_3	Tier 2a, 2b	PS, D	Emission of HFCs, PFCs and SF_6, NF_3 Consumption

In the process of manufacturing TFT flat panel display, fluorinated gases including HFCs, PFCs, SF_6, NF_3 are consumed during etching and CVD processes. In ROK, HFCs, PFCs and SF_6 are consumed only during the etching process while NF_3 is consumed in both etching and CVD processes. Accordingly, emissions of HFCs, PFCs and SF_6 were estimated using the Tier 2b method, and NF_3 emissions were estimated using the Tier 2a method in the *2006 IPCC Guidelines.*

4.6.2.2 Methodology

4.6.2.2.1 Method

Emissions of HFCs, PFCs, and SF_6 from TFT flat panel display were estimated using the Tier 2b method while NF_3 emissions were estimated using the Tier 2a method of the *2006 IPCC Guidelines*.

HFCs, PFCs, SF_6 emissions from TFT flat panel display (Tier 2b)

$$\text{Fluorinated Gas Emissions}_i = (1-h)\times\sum_p (FC_{i,p}\times(1-U_{i,p})\times(1-a_{i,p}\times d_{i,p}))$$

$$\text{By-product Gas Emissions}_j = (1-h)\times\sum_p (B_{j,i,p}\times FC_{i,p}\times(1-a_{i,p}\times d_{j,p}))$$

$Emissions_{i,j}$	:	emissions of greenhouse gas (i,j) (kg)
h	:	fraction of gas remaining in shipping container (heel) after use (default: 0.1)
FC	:	mass of gas i fed into process type p (kg)
U	:	use rate for each gas i and process type p (fraction destroyed or transformed during process)
B	:	emission factor for by-product emissions (amount of by-product gas / amount of gas used)
a	:	fraction of gas i volume fed into process type p with emission control technologies
d	:	fraction of gas i destroyed by the emission control technology used in process type p
p	:	process type (etching or CVD chamber cleaning)
i	:	fluorinated gases incl. CF_4, C_2F_6, C_3H_8, c-C_4F_8, c-C_4F_9O, C_4F_6, C_5F_8, CHF_3. CH_2F_2, SF_6 (kg)
j	:	by-product gases by type (CF_4, C_2F_6, CHF_3)

Source: *2006 IPCC Guidelines, Vol.3, Ch.6, Equation 6.7-6.11*

NF_3 emissions from TFT flat panel display (Tier 2a)

$$\text{Fluorinated Gas Emissions}_i = (1-h)\times FC_i\times(1-U_i)\times(1-a_i\times d_i)$$

$$\text{By-product Gas Emissions} = (1-h)\times B_{j,i}\times FC_i\times(1-a_i\times d_j)$$

$Emissions_{i,j}$	:	emission of greenhouse gas (i,j) (kg)
h	:	fraction of gas remaining in shipping container (heel) after use (default: 0.1)
FC	:	consumption of fluorinated compounds (kg)
B	:	by-product generation rate (amount of by-product (CF_4) gas / amount of gas used (NF_3))
U	:	use rate of gas (fraction destroyed or transformed during process)
a	:	fraction of greenhouse gas volume used in processes with emission control technologies
d	:	fraction of gas destroyed by the emission control technology
j	:	by-product gases (CF_4)
j	:	by-product gases by type (CF_4, C_2F_6, C_3F_8)

Source: *2006 IPCC Guidelines, Vol.3, Ch.6, Equation 6.2-6.6*

4.6.2.2.2 Emission Factor

Prior to 2006, default values from the *2006 IPCC Guidelines* were used for the fraction of gas remaining (*h*), by-product generation rate (*B*) and use rate of gas (*U*). From 2007 onward, default emission factors from the *2006 IPCC Guidelines* and plant-specific emission factors reported under TMS and K-ETS were used. The volumetric fraction of NF_3 used in processes with emission control technologies (*a*) was based on data provided by Korea Display Industry Association (KDIA).

| Table 4-112 | Emission Factor for TFT Flat Panel Display

Process Gas(i)	CF_4	C_2F_6	C_3F_8	$c-C_4F_8$	CHF_3	CH_2F_2	SF_6	NF_3	NF_3 remote
Method	Tier 2b; Etching							Tier 2a	
h	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
$1-U_i$	0.6	NA	NA	0.1	0.2	NA	0.3	0.3	0.03
$B_{CF4,i}$	NA			0.009	0.07		NA	NA	NA
$B_{CHF3,i}$				0.02	NA				
$B_{C2F6,i}$				NA	0.05				

4.6.2.2.3 Activity Data

For the 1999 to 2006 period, emissions were estimated using data on the consumption volume of fluorinated gases (excluding NF_3) provided by KDIA. From 2007 onward, emissions reported under TMS and K-ETS were aggregated. From 2008 onward, data on the consumption of NF_3 were provided by KDIA.

| Table 4-113 | Activity Data Source for TFT Flat Panel Display

Period	Activity Data	Name of Statistics	Published by	Gas
1999-2006	HFCs, PFCs, SF_6 consumption	HFCs, PFCs, SF_6 statistics	Korea Display Industry Association (KDIA)	HFCs, PFCs, SF_6
2007-2022	HFCs, PFCs, SF_6 emissions	TMS and K-ETS data	Ministry of Environment (MOE)	
2008-2022	NF_3 consumption	NF_3 statistics	Korea Display Industry Association (KDIA)	NF_3

4.6.2.3 Uncertainty and Time–series Consistency

4.6.2.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

4.6.2.3.2 Time–series Consistency

Emissions of HFCs, PFCs and SF_6 were estimated using methodology, emission factors and activity data consistently based on the *2006 IPCC Guidelines*. From 2007 onward, display manufacturers were identified as entities subject to the K–ETS and required to report emissions under the respective system. Using data from K–ETS, the accuracy and consistency of associated emissions were improved. NF_3 emissions were also estimated using consistent methodology, emission factors and activity data.

4.6.2.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

4.6.2.5 Planned Improvements

Further assessment and research on the efficiency of NF_3 abatement system installed in domestic facilities are in process. ROK is implementing improvement efforts to develop country–specific emission factors to apply a higher tiered approach for this subcategory.

4.6.3 Photovoltaics (2.E.3.)

4.6.3.1 Category Overview

2022	Gas	Methodology	Emission Factor	Activity Data
	PFCs, SF_6	Tier 2a	PS	Fluorinated gas emissions

Photovoltaic cells are produced through the polysilicon manufacturing and wafer processing during which fluorinated gases of HFCs, PFCs and SF_6 are consumed in etching and chemical vapour deposition (CVD) processes. In ROK, only PFCs and SF_6 are used for the processes, and thus emissions thereof were estimated.

4.6.3.2 Method

4.6.3.2.1 Method

Emissions from photovoltaics were derived from TMS and K-ETS data which were estimated using the Tier 2a method of the *2006 IPCC Guidelines*.

PFCs and SF_6 emissions from photovoltaics

$$\text{Fluorinated Gas Emissions}_i = (1-h)\times FC_i \times (1-U_i)\times(1-a_i\times d_i)$$

$$\text{By-product Gas Emissions} = (1-h)\times B_{j,i}\times FC_i\times(1-a_i\times d_j)$$

$\text{Emissions}_{i,j}$	:	emission of greenhouse gas (i,j) (kg)
h	:	fraction of gas remaining in shipping container after use
FC	:	amount of greenhouse gas consumed (kg)
B	:	by-product generation rate (amount of by-product gas / amount of gas used)
U	:	use rate of gas (fraction destroyed or transformed during process)
a	:	fraction of greenhouse gas used in processes with emission control technologies
d	:	fraction of gas destroyed by the emission control technology
i	:	fluorinated greenhouse gases used in the semiconductor sector incl. CF_4, C_2F_6
j	:	by-product gases by type (CF_4, C_2F_6, C_3F_8)

Source: *2006 IPCC Guidelines, Vol.3, Ch.6, Equation 6.2-6.6*

4.6.3.2.2 Emission Factor

Emission factors reported by photovoltaics manufacturers in TMS and K-ETS data were used.

4.6.3.2.3 Activity Data

Since 2011, data from TMS and K-ETS have been used for fluorinated gas emissions.

| Table 4-114 | Activity Data Source for Photovoltaics

Period	Activity Data	Name of Statistics	Published by	Gas
2011-2022	Emissions of fluorinated gases	TMS and K-ETS data	Ministry of Environment (MOE)	PFCs, SF_6

4.6.3.3 Uncertainty and Time-series Consistency

4.6.3.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

4.6.3.3.2 Time-series Consistency

Emissions from photovoltaics were estimated using methodology, emission factors and activity data consistently across the entire time series.

4.6.3.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

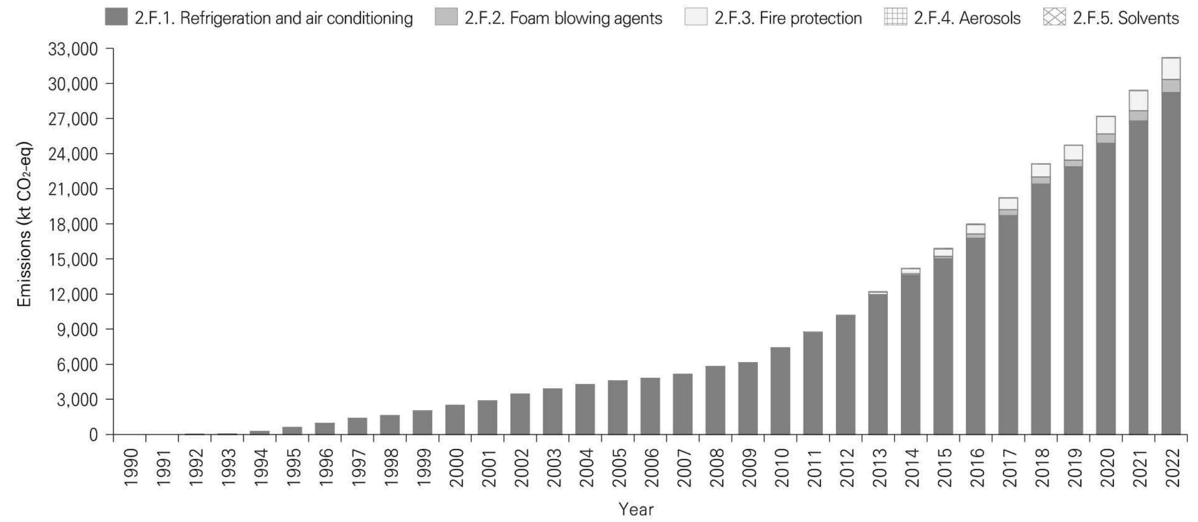
4.7 Product Uses as Substitutes for Ozone Depleting Substances (2.F.)

Alternatives to ozone-depleting substances (ODS) which include HFCs, PFCs and hydrofluoroolefins (HFOs) and natural refrigerants are used for a variety of applications such as refrigerants, foam blowing agents, fire extinguishing agents, aerosols and metal cleaning solvents. Emissions from the manufacturing, installation, operation and disposal of equipment or products that contain HFCs and PFCs are reported under this reporting category into Refrigeration and Air Conditioning (2.F.1.), Foam Blowing Agents (2.F.2.), Fire Protection (2.F.3.), Aerosols (2.F.4.) or Solvents (2.F.5.).

In 2016, the Parties to the Montreal Protocol adopted the Kigali Amendment to phase down the consumption of HFCs with developed countries starting in 2019 and developing countries including ROK in 2024. Accordingly, ROK added HFCs to the list of controlled substances under the *Act on the Control of Specific Substances for the Protection of the Ozone Layer* in 2022 and established a legal framework to collect data on production and imports of HFCs.

Currently, ROK collects data on the consumption of ODS substitutes for refrigeration and air conditioning, foam blowing agents, fire protection, aerosols and solvents of which emissions were estimated using the Tier 1a methodology of the *2006 IPCC Guidelines.*

In 2022, emissions from the use of ODS substitutes were 32,216 kt CO_2-eq which accounted for 24.5 percent of total emissions from the IPPU sector. Refrigeration and air conditioning was the largest source accounting for 90.8 percent which was followed by fire protection of 5.7 percent, foam blowing agents of 3.5 percent, aerosols of 0.05 percent, and solvents of 0.03 percent. Emissions from this reporting category increased by 9.5 percent (2,791 kt CO_2-eq) from 2021, primarily due to an increase of 2,437 kt CO_2-eq in refrigeration and air conditioning. Foam blowing agents and fire protection also contributed increases of 225 kt CO_2-eq and 128 kt CO_2-eq respectively.



| Figure 4-8 | Trends in Emissions from Product Uses as Substitutes for ODS (1990-2022)

| Table 4-115 | Emissions from Product Uses as Substitutes for ODS

(Unit: kt CO_2-eq)

Sub-category		1990	2000	2007	2010	2018	2021	2022
2.F.1.	Refrigeration and Air Conditioning	IE,NO	2,458	5,121	7,354	21,399	26,801	29,238
2.F.2.	Foam Blowing Agents	IE,NO	0.5	1	1	622	887	1,112
2.F.3.	Fire Protection	NO	NO	NO	26	1,104	1,709	1,837
2.F.4.	Aerosols	IE,NO	6	11	4	1	17	17
2.F.5.	Solvents	NO	NO	NO	NO	6	11	11

Note: Emissions from subcategories of Domestic refrigeration (2.F.1.b.), Industrial refrigeration (2.F.1.c.), Transport refrigeration (2.F.1.d.), Mobile air-conditioning (2.F.1.e.), Stationary air-conditioning (2.F.1.f.), Open cells (2.F.2.b.) and Other (2.F.4.b.) were included in Commercial refrigeration (2.F.1.a.), Closed cells (2.F.2.a.) and Metered dose inhalers (2.F.4.a.) as data cannot be disaggregated.

4.7.1 Refrigeration and Air Conditioning (2.F.1.)

4.7.1.1 Category Overview

2022	Gas	Methodology	Emission Factor	Activity Data
	HFCs, PFCs	Tier 1a	D	Production, imports and exports of HFCs and PFCs

Emissions from the use of HFCs and PFCs in refrigeration and air conditioning are reported under this subcategory. Since the production, use and export of CFCs and HCFCs, which were used as refrigerants, have been either already phased out or phased down under the Montreal Protocol, HFCs have become the primary ODS substitute used in refrigeration and air conditioning.

In 2022, emissions from refrigeration and air conditioning were 29,238 kt CO_2-eq, representing an increase of 2,437 kt CO_2-eq (9.1 percent) from 2021 which was contributed by a consistent growth in HFCs and PFCs consumption.

| Table 4-116 | Emissions from Refrigeration and Air Conditioning

(Unit: kt CO_2-eq)

Sub-category	1990	2000	2007	2010	2018	2021	2022
Refrigeration and Air Conditioning	IE[1],NO	2,458	5,121	7,354	21,399	26,801	29,238

Note: 1) Emissions from subcategories of Domestic refrigeration (2.F.1.b.), Industrial refrigeration (2.F.1.c.), Transport refrigeration (2.F.1.d.), Mobile air-conditioning (2.F.1.e.) and Stationary air-conditioning (2.F.1.f.) were included in Commercial refrigeration (2.F.1.a.) as data cannot be disaggregated.

4.7.1.2 Methodology

4.7.1.2.1 Method

Emissions from refrigeration and air conditioning were estimated using the Tier 1a method of the *2006 IPCC Guidelines*.[43]

43) While data on the consumption of each ODS substitute are available, statistics for six sub-application domains (2.F.1.a. Commercial refrigeration; 2.F.1.b. Domestic refrigeration; 2.F.1.c. Industrial refrigeration; 2.F.1.d. Transport refrigeration; 2.F.1.e. Mobile air-conditioning; 2.F.1.f. Stationary air-conditioning) are not available. Accordingly, the Tier 1a method from the *2006 IPCC Guidelines* was used.

HFCs and PFCs emissions from refrigeration and air conditioning	
$$\text{Annual Emissions} = \text{Net Consumption} \times EF_{FY} + \text{Total Banked Chemical} \times EF_B$$	
Annual emissions	: annual emissions from refrigeration and air conditioning (t)
Net consumption	: net consumption for refrigeration and air conditioning (t)
EF_{FY}	: composite emission factor for the first year (%)
Total banked chemical	: bank of the chemical for refrigeration and air conditioning (t)
EF_B	: composite emission factor for the bank (%)

Source: *2006 IPCC Guidelines, Vol.3, Ch.7. Equation 7.2B*

4.7.1.2.2 Emission Factor

The emission factor and average equipment lifetime were based on the default values from the *2006 IPCC Guidelines*.

| Table 4-117 | Emission Factor for Refrigeration and Air Conditioning

Type	Emission Factor	Source
Emission Factor (Annual Leakage Rate) (EF_{FY}, E_F)	15%	*2006 IPCC Guidelines*
Average Equipment Lifetime	15 years	

Source: *2006 IPCC Guidelines, Vol.3, Ch.7. p.7.45*

4.7.1.2.3 Activity Data

For years prior to 2010, the net consumption for refrigeration and air conditioning was based on the *Trade Statistics*. The consumption amount was estimated using data on import and export of HFC-134a and HFC-152a.

Since 2008, field surveys on HFCs and PFCs conducted by KEA have been used in addition to the *Trade Statistics*. Field surveys included data on production, import and export of HFC-134a and HFC-152a collected by KEA from manufacturers and importers of ODS substitutes which were used to calculate the net consumption of HFCs and PFCs for refrigeration and air conditioning.

| Table 4-118 | Activity Data Source for Refrigeration and Air Conditioning

Period	Activity Data	Name of Statistics	Published by	Gas
1992-2010	Imports and exports of gases	Trade Statistics	Korea Customs Service (KCS)	HFC-134a HFC-152a
2008-2022	Production, imports and exports of gases	Field surveys	Korea Energy Agency (KEA)	HFCs, PFCs

| Table 4-119 | Activity Data for Refrigeration and Air Conditioning

(Unit: t)

Amount	1990	2000	2007	2010	2018	2021	2022
Net Consumption of HFCs and PFCs	IE,NO	4,028	5,592	8,733	19,815	18,834	20,122

4.7.1.3 Uncertainty and Time-series Consistency

4.7.1.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

4.7.1.3.2 Time-series Consistency

Emissions from refrigeration and air conditioning were estimated using methodology and emission factors consistently. For activity data, import and export trade statistics were used to estimate the consumption of HFCs and PFCs for years prior to 2010. From 2008 onward, the accuracy and consistency of activity data were improved by using field surveys conducted by KEA.

4.7.1.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

4.7.1.5 Planned Improvements

Despite of being the key category in 2022, emissions from refrigeration and air conditioning were estimated using the Tier 1a methodology and default emission factors. Further research and review on statistics for HFCs and PFCs, as well as on the amount of consumed refrigerant charge and types of refrigerant per sub-application domains are in process. ROK is exploring the potential to apply a higher tiered approach for this category.

4.7.2 Foam Blowing Agents (2.F.2.)

4.7.2.1 Category Overview

2022	Gas	Methodology	Emission Factor	Activity Data
	HFCs	Tier 1a	D	Production, imports and exports of HFCs

Foam blowing agents are classified into open-cell and closed-cell. Open-cell foams are used for applications including furniture cushioning, mattresses and automotive seating. Emissions from open-cell foam occur during the manufacturing process and shortly thereafter. Closed-cell foams which are used for insulating applications result in emissions that occur throughout their entire life cycle of the manufacturing phase, operation and disposal. HCFCs were primarily used as foam blowing agents which are now replaced by HFCs to a limited extent under the Montreal Protocol.

In 2022, emissions from foam blowing agents were 1,112 kt CO_2-eq which increased by 25.4 percent from 2021 due to a consistent increase in HFCs consumption over time.

| Table 4-120 | Emissions from Foam Blowing Agents

(Unit: kt CO_2-eq)

Sub-category	1990	2000	2007	2010	2018	2021	2022
Foam Blowing Agents	IE[1],NO	0.5	1.4	1.3	622	887	1,112

Note: 1) Emissions from Open cells (2.F.2.b.) were included in Closed cells (2.F.2.a.) as data cannot be disaggregated.

4.7.2.2 Methodology

4.7.2.2.1 Method

Emissions from foam blowing agents were estimated using the Tier 1a method of the *2006 IPCC Guidelines*.[44]

44) While data on the consumption of HFCs are available, statistics by six sub-application domains (2.F.2.a. Closed cells; 2.F.2.b. Open cells) are not available. Therefore, the Tier 1a method from the *2006 IPCC Guidelines* was used.

HFCs emissions from foam blowing agents

$$\text{Emissions} = M_t \times EF_{FYL} + Bank_t \times EF_{AL} + DL_t - RD_t$$

Emissions : emissions from the foam blowing agents in year t

M_t : total HFCs used in manufacturing foam blowing agents in year t

EF_{FYL} : first year loss emission factor (fraction)

$Bank_t$: HFCs charge blown into foam manufacturing between year t and year t−n (tonnes)

EF_{AL} : annual loss emission factor (fraction)

DL_t : remaining losses of chemical at the end of service life that occur when the product/equipment is scrapped (tonnes)

RD_t : HFCs emissions prevented by recovery and destruction of foam blowing agents in year t (tonnes)

Source: *2006 IPCC Guidelines, Vol.3, Ch.7, Equation 7.7*

4.7.2.2.2 Emission Factor

Emission factors and product lifetime were based on the default values from the *2006 IPCC Guidelines*.

| Table 4-121 | Emission Factor for Foam Blowing Agents

Emission Factor	Factor Value	Source
First Year Losses (EF_{FYL})	10%	*2006 IPCC Guidelines*
Annual Losses (EF_{AL})	4.5%	
Product Lifetime	20 years	

Source: *2006 IPCC Guidelines, Vol.3, Ch.7, Table 7.5*

4.7.2.2.3 Activity Data

For years prior to 2010, the net consumption for foam blowing agents was based on the *Trade Statistics*. The consumption amount was estimated using data on import and export of HFC-134a and HFC-152a.

Since 2011, field surveys on HFCs conducted by KEA have been used. Field surveys included data on production, import and export of HFC-134a and HFC-152a collected by KEA from manufacturers and importers of ODS substitutes which were used to calculate the net consumption of HFCs for foam blowing agents.

| Table 4-122 | Activity Data Source for Foam Blowing Agents

Period	Activity Data	Name of Statistics	Published by	Gas
1992-2010	Imports and exports of gases	*Trade Statistics*	Korea Customs Service (KCS)	HFC-134a HFC-152a
2011-2022	Production, imports and exports of gases	Field surveys	Korea Energy Agency (KEA)	HFCs

| Table 4-123 | Activity Data for Foam Blowing Agents

(Unit: t)

Activity Data	1990	2000	2007	2010	2018	2021	2022
Net Consumption of HFCs	IE,NO	20	22	6	4,049	5,032	5,678

4.7.2.3 Uncertainty and Time-series Consistency

4.7.2.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

4.7.2.3.2 Time-series Consistency

Emissions from foam blowing agents were estimated using methodology and emission factors consistently. For activity data, import and export trade statistics were used to estimate the net consumption of HFCs for years prior to 2010. From 2011 onward, the accuracy and consistency of activity data were improved by using field surveys conducted by KEA.

4.7.2.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

4.7.3 Fire Protection (2.F.3.)

4.7.3.1 Category Overview

2022	Gas	Methodology	Emission Factor	Activity Data
	HFCs	Tier 1a	D	Production, imports and exports of HFCs

Under this reporting subcategory, emissions of HFCs that arise from the use of fire protection (suppression) equipment are reported. HFCs are mainly used as substitutes for halons since the production, use and export of halons are regulated by the Montreal Protocol. ROK prohibited the production and import of halons since 2010, leading to the use of HFC−23, HFC−125, HFC−227ea, HFC−236fa, FK−5−1−12 and IG−100 as replacements.

In 2022, emissions from fire protection were 1,837 kt CO_2−eq which increased by 7.5 percent from 2021 due to a consistent growth in HFCs consumption.

| Table 4−124 | Emissions from Fire Protection

(Unit: kt CO_2−eq)

Sub−category	1990	2000	2007	2010	2018	2021	2022
Fire Protection	NO	NO	NO	26	1,104	1,709	1,837

4.7.3.2 Methodology

4.7.3.2.1 Method

Emissions from fire protection were estimated using the Tier 1a method of the *2006 IPCC Guidelines*.

HFCs emissions from fire protection

$$\text{Emissions} = \text{Bank}_t \times \text{EF} + \text{RRL}_t$$

Emissions_t	:	emissions of agent from fire protection equipment in year t (tonnes)
Bank_t	:	bank of agent in fire protection equipment in year t (tonnes)
EF	:	fraction of agent in equipment emitted each year
RLL_t	:	Recovery Release or Loss: emissions of agent during recovery, recycling or disposal at the time of removal from use of existing fire protection equipment in year t (tonnes)

Source: *2006 IPCC Guidelines, Vol.3, Ch.7 Equation 7.17*

4.7.3.2.2 Emission Factor

The emission factor and average equipment lifetime were based on the default values from the *2006 IPCC Guidelines*.

| Table 4-125 | Emission Factor for Fire Protection

Emission Factor	Factor Value	Source
Emission Factor (EF)	2% (based on large-scale systems)	*2006 IPCC Guidelines*
Average Lifetime	20 years (based on large-scale systems)	

Source: *2006 IPCC Guidelines, Vol.3, Ch.7 p.7.64*

4.7.3.2.3 Activity Data

Net consumption was estimated using data on production, import and export that have been collected by KEA from manufacturers and importers of ODS substitutes since 2008.

| Table 4-126 | Activity Data Source for Fire Protection

Period	Activity Data	Name of Statistics	Published by	Gas
2008-2022	Production, imports and exports of gases	Field surveys	Korea Energy Agency (KEA)	HFCs

| Table 4-127 | Activity Data for Fire Protection

(Unit: t)

Amount	1990	2000	2007	2010	2018	2021	2022
Net Consumption of HFCs	NO	NO	NO	171	1,418	2,218	1,440

4.7.3.3 Uncertainty and Time-series Consistency

4.7.3.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

4.7.3.3.2 Time-series Consistency

Emissions from fire protection were estimated consistently using methodology, emission factors and activity data which have been available since 2008.

4.7.3.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

4.7.4 Aerosols (2.F.4.)

4.7.4.1 Category Overview

	Gas	Methodology	Emission Factor	Activity Data
2022	HFCs	Tier 1a	D	Production, imports and exports of HFCs

In this reporting subcategory, emissions of HFCs from the use of aerosols are reported. Liquefied petroleum gas (LPG) and HFCs are mainly used as substitutes for CFCs and HCFCs of which the production, use and export are regulated by the Montreal Protocol. In this inventory, emissions from the use of HFCs as propellants and solvents including metered dose inhalers and non-medical products were estimated.

In 2022, emissions from aerosols were 17 kt CO_2-eq, increasing by 3.6 percent from 2021.

| Table 4-128 | Emissions from Aerosols

(Unit: kt CO_2-eq)

Sub-category	1990	2000	2007	2010	2018	2021	2022
Aerosols	IE[1],NO	6	11	4	1	17	17

Note: 1) Emissions from Other (2.F.4.b.) were included in Metered dose inhalers (2.F.4.a.) as data cannot be disaggregated.

4.7.4.2 Methodology

4.7.4.2.1 Method

Emissions from aerosols were estimated using the Tier 1a method of the *2006 IPCC Guidelines*.

HFCs emissions from aerosols

$$Emissions_t = S_t \times EF + S_{t-1} \times (1-EF)$$

$Emissions_t$: emissions from aerosols in year t (tonnes)

S_t : quantity of HFCs contained in aerosol product sold in year t (tonnes)

EF : emission factor (fraction)

S_{t-1} : quantity of HFCs contained in aerosol product sold in year t-1 (tonnes)

Source: *2006 IPCC Guidelines, Vol.3, Ch.7, Equation 7.6*

4.7.4.2.2 Emission Factor

The emission factor and average equipment lifetime were based on the default values from the *2006 IPCC Guidelines*.

| Table 4-129 | Emission Factor for Aerosols

Emission Factor	Factor Value	Source
Emission Factor	50%	*2006 IPCC Guidelines*
Average Lifetime	2 years	

Source: *2006 IPCC Guidelines, Vol.3, Ch.7, p.7.29*

4.7.4.2.3 Activity Data

For years prior to 2010, the net consumption for aerosols was based on the *Trade Statistics*. The consumption amount was estimated using data on import and export of HFC-134a and HFC-152a.

Since 2011, field surveys on HFCs conducted by KEA have been used. Field surveys included data on production, import and export of HFC-134a and HFC-152a collected by KEA from manufacturers and importers of ODS substitutes which were used to calculate the net consumption of HFCs for aerosols.

| Table 4-130 | Activity Data Source for Aerosols

Period	Activity Data	Name of Statistics	Published by	Gas
1992-2010	Imports and exports of gases	*Trade Statistics*	Korea Customs Service (KCS)	HFC-134a HFC-152a
2011-2022	Production, imports and exports of gases	Field surveys	Korea Energy Agency (KEA)	

| Table 4-131 | Activity Data for Aerosols

(Unit: t)

Activity Data	1990	2000	2007	2010	2018	2021	2022
Net Consumption of HFCs	IE,NO	68	75	22	8	124	89

4.7.4.3 Uncertainty and Time-series Consistency

4.7.4.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

4.7.4.3.2 Time-series Consistency

Emissions from aerosols were estimated using methodology and emission factors consistently. For activity data, import and export trade statistics were used to estimate the net consumption of HFCs for years prior to 2010. From 2011 onward, the accuracy and consistency of activity data were improved by using field surveys conducted by KEA.

4.7.4.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

4.7.5 Solvents (2.F.5.)

4.7.5.1 Category Overview

	Gas	Methodology	Emission Factor	Activity Data
2022	HFCs	Tier 1a	D	Production, imports and exports of HFCs

Under this reporting subcategory, emissions of HFCs that arise from the use of solvents are reported. HFCs are mainly used as substitutes for CFC-113 of which the production, use and export are regulated by the Montreal Protocol.

In 2022, emissions from solvents were 11 kt CO_2-eq which increased by 2.7 percent from 2021.

| Table 4-132 | Emissions from Solvents

(Unit: kt CO_2-eq)

Sub-category	1990	2000	2007	2010	2018	2021	2022
Solvents	NO	NO	NO	NO	6	11	11

4.7.5.2 Methodology

4.7.5.2.1 Method

Emissions from solvents were estimated using the Tier 1a method of the *2006 IPCC Guidelines*.

HFCs emissions from solvent

$$Emissions_t = S_t \times EF + S_{t-1} \times (1-EF) - D_{t-1}$$

$Emissions_t$	:	emissions from solvents in year t (tonnes)
S_t	:	quantity of solvents sold in year t (tonnes)
EF	:	emission factor (fraction)
S_{t-1}	:	quantity of solvents sold in year $t-1$ (tonnes)
D_{t-1}	:	quantity of solvents destroyed in year $t-1$ (tonnes)

Source: *2006 IPCC Guidelines, Vol.3, Ch.7, Equation 7.5*

4.7.5.2.2 Emission Factor

The emission factor and average equipment lifetime were based on the default values from the *2006 IPCC Guidelines*.

| Table 4-133 | Emission Factor for Solvents

Emission Factor	Factor Value	Source
Emission Factor	50%	*2006 IPCC Guidelines*
Average Lifetime	2 Years	

Source: *2006 IPCC Guidelines, Vol.3, Ch.7, p.7.24*

4.7.5.2.3 Activity Data

Net consumption was estimated using data on production, import and export that have been collected by KEA from manufacturers and importers of ODS substitutes since 2011.

| Table 4-134 | Activity Data Source for Solvents

Period	Activity Data	Name of Statistics	Published by	Gas
2011-2022	Production, imports and exports of gases	Field surveys	Korea Energy Agency (KEA)	HFCs

| Table 4-135 | Activity Data for Solvents

(Unit: t)

Amount	1990	2000	2007	2010	2018	2021	2022
Net Consumption of HFCs	NO	NO	NO	NO	NO	6.1	7.5

4.7.5.3 Uncertainty and Time-series Consistency

4.7.5.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

4.7.5.3.2 Time-series Consistency

Emissions from solvents have been estimated consistently using methodology, emission factors and activity data which have been available since 2011.

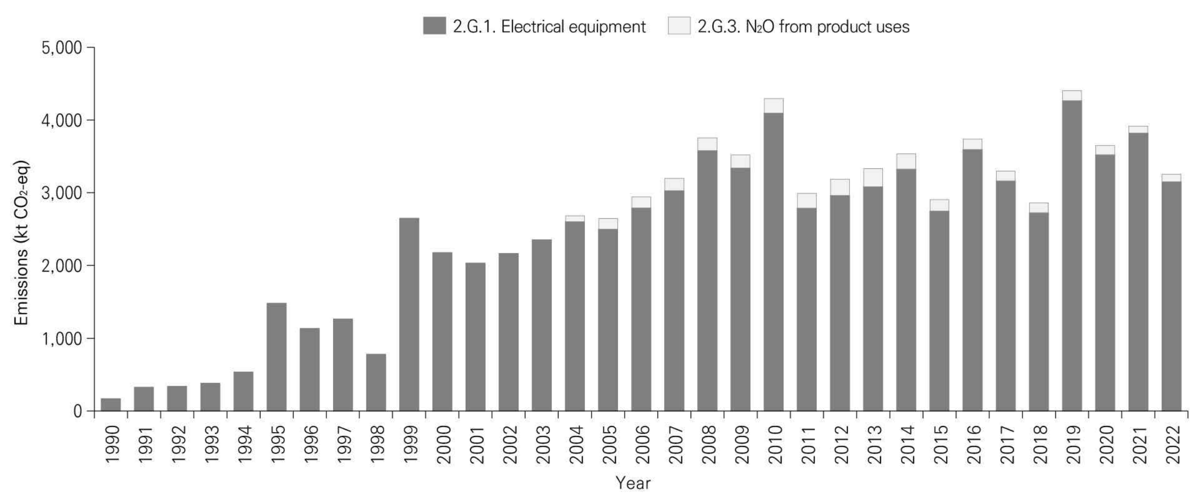
4.7.5.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

4.8 Other Product Manufacture and Use (2.G.)

Emissions of SF_6, PFCs, and N_2O from the production and use of electrical equipment and other products are reported under this reporting category which is categorized into Electrical Equipment (2.G.1.), SF_6 and PFCs from Other Product Use (2.G.2.), and N_2O from Product Uses (2.G.3.). Emissions from the use of SF_6 and PFCs in other products do not occur in ROK.

In 2022, emissions from this category were 3,256 kt CO_2-eq which accounted for 2.5 percent of total emissions from the IPPU sector. Emissions from electrical equipment accounted for 96.8 percent of total emissions from this category while N_2O emissions from product use accounted for 3.2 percent. Emissions from this category decreased by 16.9 percent (661 kt CO_2-eq), primarily due to a reduction of 669 kt CO_2-eq in the electrical equipment. N_2O emissions from product use for medical applications, on the other hand, increased by 8 kt CO_2-eq from 2021.



| Figure 4-9 | Trends in Emissions from Other Product Manufacture and Use (1990-2022)

| Table 4-136 | Emissions from Other Product Manufacture and Use

(Unit: kt CO_2-eq)

Sub-category		1990	2000	2007	2010	2018	2021	2022
2.G.1.	Electrical Equipment	168	2,178	3,029	4,099	2,727	3,822	3,153
2.G.2.	SF_6 and PFCs from Other Product Use	NO	NO	NO	NO	NO	NO	NO
2.G.3.	N_2O from Product Uses	NE, NO	NE, NO	169	199	132	96	104

4.8.1 Electrical Equipment (2.G.1.)

4.8.1.1 Category Overview

2022	Gas	Methodology	Emission Factor	Activity Data
	SF_6	Tier 1	D	Nameplate capacity

Sulphur hexafluoride (SF_6) is used for electrical insulation and current interruption in equipment to prevent damage from sparks and ensure quality performance of the equipment. Emissions of SF_6 were estimated for each phase of the equipment life cycle including production, installation, operation and disposal.

In 2022, emissions from electrical equipment were 3,153 kt CO_2-eq which decreased by 17.5 percent from 2021. The total SF_6 nameplate capacity at each phase of installation, use and disposal increased in 2022 from 2021. However, emissions at the disposal phase decreased due to a reduction in nameplate capacity at the disposal phase of equipment from private utilities in 2022 which contributed to the overall decrease in emissions under this subcategory.

| Table 4-137 | Emissions from Electrical Equipment

(Unit: kt CO_2-eq)

Phase	1990	2000	2007	2010	2018	2021	2022
Manufacturing (Installation)	154	1,923	1,843	2,652	944	1,501	1,666
Use	14	255	605	769	920	1,207	1,200
Disposal	NE	NE	581	679	863	1,114	286
Total	**168**	**2,178**	**3,029**	**4,099**	**2,727**	**3,822**	**3,153**

4.8.1.2 Methodology

4.8.1.2.1 Method

Emissions from electrical equipment were estimated using the Tier 1 method of the *2006 IPCC Guidelines*.

SF₆ emissions from electrical equipment	
Total Emissions = Manufacturing (Installation) Emissions + Equipment Use Emissions + Equipment Disposal Emissions	
Total Emissions	: total SF_6 emissions from the use of electrical equipment (t SF_6)
Manufacturing (Installation) Emissions	: manufacturing(installation) emission factor × total nameplate capacity of new equipment filled on site (not at the factory)
Equipment Use Emissions	: use emission factor × total nameplate capacity of installed equipment
Equipment Disposal Emissions	: total nameplate capacity of retiring equipment × fraction of SF_6 remaining at retirement

Source: *2006 IPCC Guidelines, Vol.3, Ch.8, Equation 8.1*

4.8.1.2.2 Emission Factor

Default emission factors from the *2006 IPCC Guidelines* were used for the manufacturing (installation) and use phases. At the disposal phase, the entire SF_6 nameplate capacity is assumed to be released except for facilities at which SF_6 was recovered from retiring equipment. A recovery rate was used to estimate emissions from such facilities.

| Table 4-138 | Emission Factor for Electrical Equipment

Emission Factor	Factor Value	Source
Manufacturing (Installation)	0.29	*2006 IPCC Guidelines*
Use	0.007	
Recovery Rate at Disposal Phase (1990-2010)	0.8	Field surveys
Recovery Rate at Disposal Phase (2011-2022)	0.97	

Source: *2006 IPCC Guidelines, Vol.3, Ch.8, Table 8.2*

4.8.1.2.3 Activity Data

Data on SF_6 nameplate capacity by each phase of manufacturing, installation, use and disposal were sourced from statistics on transmission and distribution facilities of Korea Electric Power Corporation (KEPCO) and its subsidiaries as well as private power plant operators and relevant data collected by the Korea Electrical Safety Corporation (KESCO).

| Table 4-139 | Activity Data Source for Electrical Equipment

Period	Activity Data	Name of Statistics	Published by	Gas
1990-2022	Nameplate capacity per phase (Manufacturing, installation, use, disposal)	Internal data	Korea Electric Power Corporation (KEPCO)	SF_6
		Field surveys	Subsidiary utilities of KEPCO	
		TMS and K-ETS data	Ministry of Environment (MOE)	
		Pre-use Inspection Report	Korea Electrical Safety Corporation (KESCO)	

| Table 4-140 | Activity Data for Electrical Equipment

(Unit: t)

Nameplate Capacity		1990	2000	2007	2010	2018	2021	2022
Phase	Manufacturing (Installation)	23	282	270	389	138	220	244
	Use	84	1,548	3,679	4,673	5,591	7,335	7,296
	Disposal	NE	NE	123	110	39	217	236

4.8.1.3 Uncertainty and Time-series Consistency

4.8.1.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

4.8.1.3.2 Time-series Consistency

Emissions from electrical equipment were estimated using methodology, emission factors and activity data consistently.

4.8.1.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

4.8.1.5 Planned Improvements

Despite of being a key category in 2022, emissions from the reporting category of Other product manufacture and use (2.G.) including the subcategory of electrical equipment were estimated using the Tier 1 methodology and default emission factors. ROK is implementing improvement efforts to analyze TMS and K-ETS data reported by each business entity to apply a higher tiered approach for this category.

4.8.2 N_2O from Product Uses (2.G.3.)

4.8.2.1 Category Overview

2022	Gas	Methodology	Emission Factor	Activity Data
	N_2O	Tier 1	D	Amount of N_2O supplied

Emissions of N_2O from product uses for medical applications such as anesthetics and analgesics, as well as propellants in aerosol products are reported under this subcategory. In this inventory, only the emissions of N_2O from product uses for Medical applications (2.G.3.a.) were estimated as N_2O under this subcategory is used only for medical applications in ROK.

In 2022, emissions of N_2O from product uses were 104 kt CO_2-eq which increased by 8.3 percent from 2021.

| Table 4-141 | Emissions from N_2O from Product Uses

(Unit: kt CO_2-eq)

Sub-category	1990	2000	2007	2010	2018	2021	2022
N_2O from product uses (Medical Applications)	NE,NO	NE,NO	169	199	132	96	104

4.8.2.2 Methodology

4.8.2.2.1 Method

Emissions of N_2O from product uses for medical applications were estimated using the Tier 1 method of the *2006 IPCC Guidelines.*

N_2O emissions from product uses for medical applications

$$N_2O\ Emissions = [(0.5 \times A(t)) + (0.5 \times A(t-1))] \times EF$$

N_2O Emissions	:	N_2O emissions from medical application (tonnes N_2O)
A	:	total quantity of N_2O supplied in year t
A(t−1)	:	total quantity of N_2O supplied in year t−1
EF	:	emission factor (fraction)

Source: *2006 IPCC Guidelines, Vol.3, Ch.8, Equation 8.24*

4.8.2.2.2 Emission Factor

The default emission factor from the *2006 IPCC Guidelines* was used.

| Table 4-142 | Emission Factor for N_2O from Product Uses

Emission Factor	Source
1 tonne N_2O/tonne N_2O supplied	*2006 IPCC Guidelines*

Source: *2006 IPCC Guidelines, Vol.3, Ch.8, p.8.36*

4.8.2.2.3 Activity Data

For years from 2004 onward, the amount N_2O supplied for medical applications provided by the Ministry of Food and Drug Safety (MFDS) was used.[45]

| Table 4-143 | Activity Data Source for N_2O from Product Uses

Period	Activity Data	Name of Statistics	Published by	Gas
2004-2022	Amount of N_2O supplied for medical applications	Statistics on N_2O supplied for medical applications	Ministry of Food and Drug Safety (MFDS)	N_2O

| Table 4-144 | Activity Data for N_2O from Product Uses

(Unit: t)

Amount	1990	2000	2007	2010	2018	2021	2022
N_2O supplied for Medical Applications	NE	NE	639	783	522	270	513

4.8.2.3 Uncertainty and Time-series Consistency

4.8.2.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

4.8.2.3.2 Time-series Consistency

Emissions of N_2O from product uses for medical applications were estimated using methodology, emission factors and activity data consistently.

4.8.2.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

45) As emissions in 2004 for which activity data were initially collected were insignificant accounting for less than 0.05 percent of total national emissions as defined in Article 32 of the Modalities, Procedures and Guidelines (MPGs), it was considered that the likely level of emissions prior to 2003 were zero or insignificant as well. Accordingly, emissions in the 1990 to 2003 period were not estimated.

SECTION

05 Agriculture

5 Agriculture

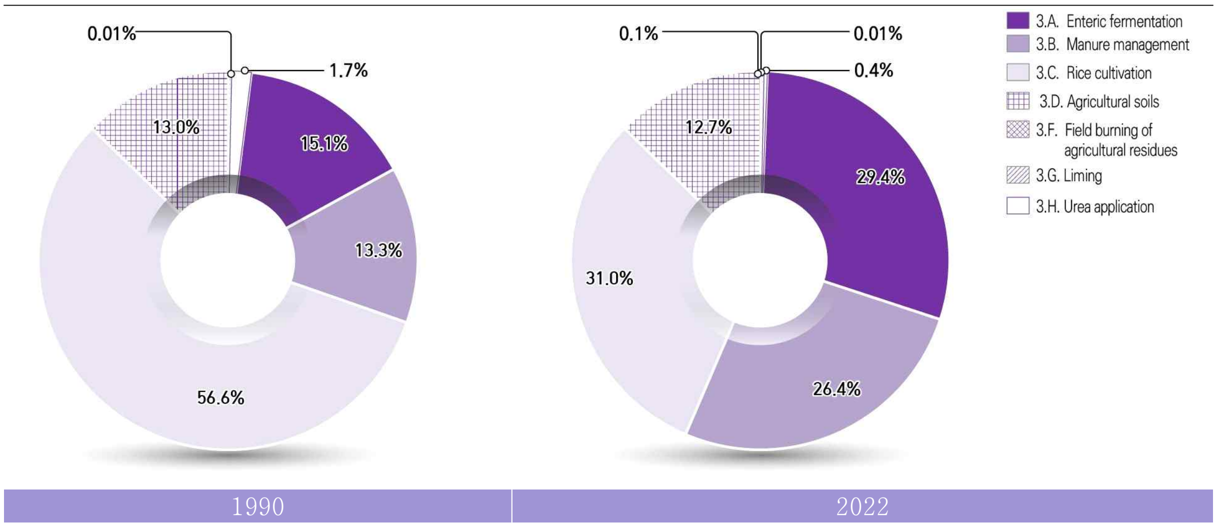
5.1 Overview

The Agriculture sector is categorized into Enteric fermentation (3.A.), Manure management (3.B.), Rice cultivation (3.C.), Agricultural soils (3.D.), Field burning of agricultural residues (3.F.), Liming (3.G.) and Urea application (3.H.).[1]

Emissions from the reporting category of enteric fermentation include methane (CH_4) produced during digestion which involves microbial fermentation, and emitted through exhalation or eructation by the animal. Manure management produces CH_4 and nitrous oxide (N_2O) emissions from the anaerobic decomposition of manure. From rice cultivation, CH_4 emissions were generated through a process of anaerobic decomposition of organic matter added to flooded paddy fields while N_2O emissions result from using human-induced net nitrogen additions to soils including application of synthetic nitrogen fertilizers, livestock manure and crop residues. Under the category of field burning of agricultural residues, CH_4 and N_2O which are released during combustion of crop residues such as rice and barley straw from crop production are reported. Liming and urea application produce CO_2 emissions from applying lime, dolomite and urea to agricultural lands during fertilisation.

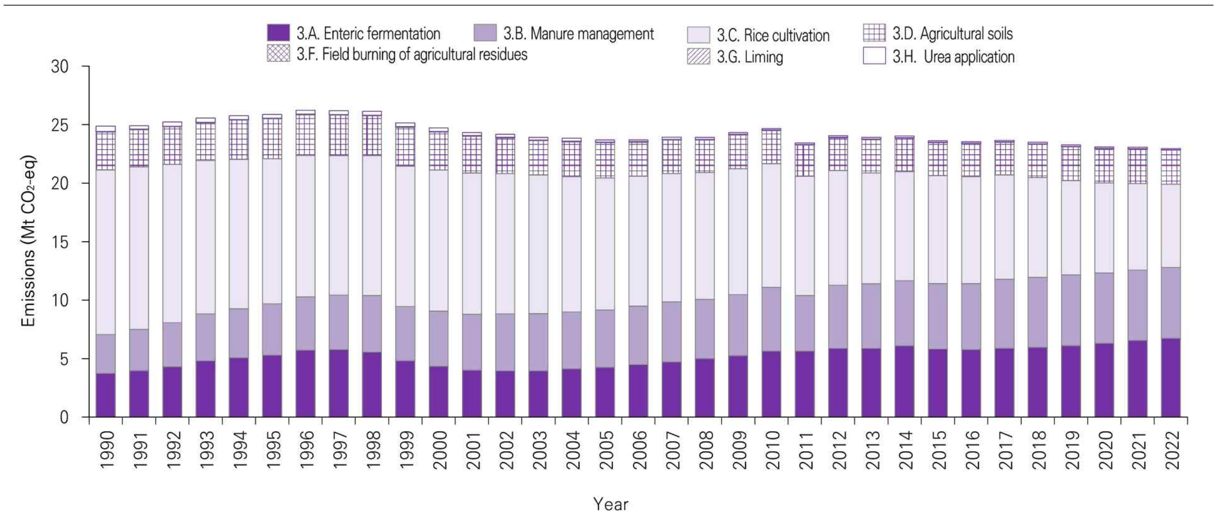
In 2022, the Agriculture sector generated emissions of 23.0 Mt CO_2-eq. The largest emission source was rice cultivation which emitted 7.1 Mt CO_2-eq, contributing 31.0 percent of the total sector emissions. The next largest source was enteric fermentation of 6.7 Mt CO_2-eq, followed by manure management of 6.1 Mt CO_2-eq, and agricultural soils of 2.9 Mt CO_2-eq. which account for 29.4 percent, 26.4 percent and 12.7 percent respectively. Accordingly, three largest sources in the Agriculture sector including rice cultivation (CH_4), enteric fermentation (CH_4) and manure management (CH_4) were identified as key categories (see Section 1.4 Key Category Analysis).

1) The prescribed burning of savannahs (3.E.) is not practiced in ROK.



| Figure 5-1 | Category as a Portion of Total Agriculture Emissions (1990 and 2022)

Between 1990 and 2022, total sector emissions decreased by 7.7 percent primarily due to a decrease of 41.5 percent[2] in the rice area which led to a decrease of 49.5 percent in emissions from rice cultivation compared to 1990. In contrast, emissions from enteric fermentation and manure management increased by 79.7 percent and 82.9 percent respectively which were largely contributed by growing populations of cattle and swine by 133.9 percent and 153.8 percent[3] respectively from 1990 to 2022.



| Figure 5-2 | Trends in Agriculture Sector Greenhouse Gas Emissions Sources (1990-2022)

2) Rice cultivation area was 1,242,000 hectares in 1990 which decreased to 727,000 hectares in 2022. (Source: *Agricultural Area Statistics,* Statistics Korea (KOSTAT))

3) Non-dairy cattle population was 1,579,000 in 1990 which increased to 3,693,000 in 2022, Swine population was 4,412,000 in 1990 which increased to 11,196,000 in 2022. (Source: *Livestock Statistics,* KOSTAT)

| Table 5-1 | Emissions from Agriculture Sector (1990-2022)

(Unit: Mt CO_2-eq)

Category	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
3.A. Enteric Fermentation	3.8	4.0	4.3	4.8	5.1	5.3	5.7	5.8	5.6	4.8	4.3
3.B. Manure Management	3.3	3.5	3.8	4.0	4.2	4.4	4.6	4.7	4.8	4.6	4.7
3.C. Rice Cultivation	14.1	13.9	13.5	13.1	12.7	12.4	12.1	11.9	11.9	12.0	12.0
3.D. Agricultural Soils	3.2	3.2	3.2	3.2	3.4	3.4	3.5	3.5	3.4	3.3	3.3
3.E. Prescribed Burning of Savannahs	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
3.F. Field Burning of Agricultural Residues	0.055	0.050	0.049	0.049	0.051	0.053	0.056	0.058	0.055	0.058	0.060
3.G. Liming	0.003	0.002	0.002	0.003	0.003	0.003	0.003	0.003	0.004	0.003	0.003
3.H. Urea Application	0.43	0.29	0.34	0.35	0.33	0.32	0.32	0.30	0.32	0.31	0.28
Total	24.9	24.9	25.2	25.5	25.8	25.9	26.2	26.2	26.1	25.1	24.7
Category	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
3.A. Enteric Fermentation	4.0	4.0	4.0	4.1	4.3	4.5	4.7	5.0	5.3	5.6	5.7
3.B. Manure Management	4.8	4.9	4.9	4.9	4.9	5.0	5.1	5.1	5.2	5.5	4.7
3.C. Rice Cultivation	12.1	12.0	11.8	11.6	11.3	11.1	11.0	10.8	10.7	10.6	10.2
3.D. Agricultural Soils	3.1	3.0	2.9	3.0	3.0	2.9	2.8	2.8	2.9	2.8	2.7
3.E. Prescribed Burning of Savannahs	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
3.F. Field Burning of Agricultural Residues	0.064	0.062	0.059	0.057	0.058	0.059	0.058	0.057	0.057	0.053	0.047
3.G. Liming	0.004	0.005	0.004	0.004	0.004	0.004	0.003	0.003	0.003	0.003	0.004
3.H. Urea Application	0.24	0.23	0.22	0.24	0.16	0.13	0.19	0.15	0.13	0.12	0.14
Total	24.3	24.2	23.9	23.8	23.7	23.7	23.9	23.9	24.3	24.7	23.4
Category	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
3.A. Enteric Fermentation	5.9	5.9	6.1	5.8	5.8	5.9	6.0	6.1	6.3	6.6	6.7
3.B. Manure Management	5.4	5.5	5.6	5.6	5.6	5.9	6.0	6.0	6.0	6.0	6.1
3.C. Rice Cultivation	9.8	9.5	9.3	9.2	9.2	8.9	8.5	8.0	7.7	7.4	7.1
3.D. Agricultural Soils	2.8	2.8	2.9	2.8	2.8	2.8	2.8	2.9	2.9	3.0	2.9
3.E. Prescribed Burning of Savannahs	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
3.F. Field Burning of Agricultural Residues	0.045	0.045	0.046	0.044	0.042	0.040	0.041	0.044	0.038	0.033	0.026
3.G. Liming	0.004	0.003	0.004	0.003	0.004	0.004	0.003	0.002	0.003	0.002	0.002
3.H. Urea Application	0.14	0.13	0.13	0.12	0.12	0.11	0.12	0.11	0.11	0.11	0.09
Total	24.1	23.9	24.0	23.6	23.5	23.7	23.5	23.3	23.1	23.1	23.0

5.2 Enteric Fermentation (3.A.)

Methane (CH_4) is produced during the microbial fermentation process of feed in the digestive tract which is then released by exhalation or eructation by the animal. Animals that produce CH_4 through such enteric fermentation are categorized into either ruminant animals (e.g. cattle, goats, sheep, and deer), non-ruminant herbivores (e.g. horses, mules, and asses) and monogastric animals (e.g. swine) based on the type of digestive system. A rumen in a ruminant animal is where the feed is broken down and fermented to volatile fatty acids, ammonia (NH_3), carbon dioxide (CO_2) and hydrogen (H_2) which are then utilized by methanogens to create methane. Ruminant animals are major sources of methane as they produce more CH_4 emissions than non-ruminant animals.

In 2022, total CH_4 emissions from enteric fermentation were 6,742 kt CO_2-eq, accounting for 29.4 percent of total sector emissions, and increased by 2.8 percent from 2021. Cattle emitted 6,343 kt CO_2-eq, representing 94.1 percent of CH_4 emissions from enteric fermentation while swine accounted for 4.6 percent with emissions of 308 kt CO_2-eq. Cattle and swine together were the largest contributors of emissions, accounting for 98.6 percent while sheep and other animals including goats, horses and deer contributed 1.4 percent.

| Figure 5-3 | Trends in Enteric Fermentation CH_4 Emissions (1990-2022)

| Table 5-2 | Emissions from Enteric Fermentation

(Unit: kt CO_2-eq)

Animal Type	1990	2000	2010	2018	2021	2022
Cattle	3,564	3,953	5,274	5,564	6,149	6,343
Sheep	0.5	0.1	0.6	0.3	0.3	0.3
Swine	137	241	282	317	310	308
Other livestock	51	154	91	90	99	91
Total	3,752	4,348	5,647	5,972	6,558	6,742

5.2.1. Cattle (3.A.1.)

5.2.1.1 Category Description

2022	Gas	Methodology	Emission Factor	Activity Data
	CH_4	Tier 1, 2	CS, D	Livestock population

In 2022, CH_4 emissions from enteric fermentation of Cattle (3.A.1.) amounted to 6,343 kt CO_2-eq, an increase of 3.1 percent from 2021. Non-dairy cattle (3.A.1.b.), contributed 81.4 percent with emissions of 5,165 kt CO_2-eq while Dairy cattle (3.A.1.a.) accounted for 18.6 percent with 1,178 kt CO_2-eq.

From 1990 to 2022, enteric fermentation emissions from non-dairy cattle increased significantly by 145.1 percent which was driven by an increase in meat consumption whereas emissions from dairy cattle decreased by 19.2 percent.

| Table 5-3 | Enteric Fermentation Emissions from Cattle

(Unit: kt CO_2-eq)

Animal Type	1990	2000	2010	2018	2021	2022
Dairy cattle	1,457	1,589	1,283	1,242	1,208	1,178
Non-dairy cattle	2,107	2,364	3,991	4,322	4,941	5,165
Total	3,564	3,953	5,274	5,564	6,149	6,343

5.2.1.2 Methodology

5.2.1.2.1 Method

CH_4 emissions from cattle were estimated following the Tier 1 and Tier 2 methodologies in the *2006 IPCC Guidelines* using national cattle population statistics that are disaggregated by age and gender as described in Table 5-4.

Enteric fermentation emissions from a livestock category

$$Emissions = EF_{(T)} \times \left(\frac{N_{(T)}}{10^6} \right)$$

Emissions	:	methane (CH_4) emissions from enteric fermentation [kt CH_4/yr]
$EF_{(T)}$	:	emission factor for the defined livestock population, [kg CH_4/head/yr]
$N_{(T)}$	:	the number of head of livestock species / category T in the country [head]
T	:	species/category of livestock

Source: *2006 IPCC Guidelines, Vol.4, Ch.10, Equation 10.19*

5.2.1.2.2 Emission Factor

Emissions from dairy cattle[4] *and Hanwoo*[5)6)] were estimated using country-specific emission factors while default emission factors provided in the *2006 IPCC Guidelines* were used for *Hanwoo* (Cow>1 year) and beef cattle.

| Table 5-4 | Emission Factor for Enteric Fermentation of Cattle

Animal Type			CH_4 Emission Factor (kg CH_4/head/yr)	EF Source
Dairy cattle		<1 year	33	CS (Developed in 2020)
		1-2 years	83	
		>2 years	139	
Non-dairy cattle	*Hanwoo*	Bull<1 year	39	CS (Developed in 2023)
		Bull>1 year	61	CS (Developed in 2018)
		Cow<1 year	33	CS (Developed in 2023)
		Cow>1 year	53	*2006 IPCC Guidelines* (North America)[1]
	Beef cattle		53	*2006 IPCC Guidelines* (North America)

Note: 1) ROK and North America are similar in beef cattle breeding and management e.g. feeding high-quality feed and grain as well as housing management.

Source: *2006 IPCC Guidelines, Vol.4, Ch.10, Table 10.11*

4) Country-specific CH_4 emission factors for dairy cattle according to age were developed using the Tier 2 method suggested by the *2006 IPCC Guidelines*.

5) *Hanwoo* : A native Korean brown cattle breed

6) Country-specific CH_4 emission factors for *Hanwoo* (Korean native cattle) per age and gender classes were developed using a respiration chamber technique to measure enteric methane emissions as suggested by the *2006 IPCC Guidelines*.

5.2.1.2.3 Activity Data

Cattle population data were obtained from *Livestock Statistics* which is released every quarter. Emission estimates for cattle were based on the annual average population of such quarterly data.

| Table 5-5 | Activity Data Source for Cattle

Period	Activity Data	Name of Statistics	Published by
1990-2022	Livestock population	*Livestock Statistics*	Statistics Korea (KOSTAT)

| Table 5-6 | Livestock Population for Enteric Fermentation : Cattle

(Unit: 1000 head)

Animal Type	1990	2000	2010	2018	2021	2022
Subtotal (Dairy cattle)	499.7	541.2	435.0	406.9	401.6	391.1
<1 year	116.5	111.4	84.0	76.7	79.6	77.3
1-2 years	90.6	119.0	102.7	72.4	75.3	73.2
>2 years	292.7	310.8	248.3	257.8	246.7	240.6
Subtotal (Non-dairy cattle)	1,579.0	1,730.7	2,866.6	3,086.4	3,538.4	3,692.7
Subtotal (*Hanwoo*)	1,410.8	1,530.5	2,709.2	2,939.4	3,367.4	3,523.4
Bull<1 year	277.7	270.5	420.3	432.0	509.5	527.6
Bull>1 year	80.1	177.2	549.8	635.5	710.8	757.8
Cow<1 year	261.1	246.3	394.5	412.8	482.0	496.9
Cow>1 year	789.8	836.5	1,344.5	1,459.1	1,665.2	1741.1
Subtotal (Beef cattle)	168.2	200.1	157.4	147.0	171.0	169.3
Total	2,078.7	2,271.9	3,301.6	3,493.2	3,939.9	4,083.8

5.2.1.3 Uncertainty and Time-series Consistency

5.2.1.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

5.2.1.3.2 Time-series Consistency

Cattle population for the 1990 to 2022 period were sourced from *Livestock Statistics*. Emissions were estimated using methodology and emission factors consistently from 1990 through 2022 to ensure time series consistency.

5.2.1.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

5.2.2 Sheep (3.A.2.), Swine (3.A.3.), Other livestock (3.A.4.)

5.2.2.1 Category Description

2022	Gas	Methodology	Emission Factor	Activity Data
	CH_4	Tier 1, 2	CS, D	Livestock population

Methane emissions from enteric fermentation of non-cattle livestock are estimated from Sheep (3.A.2.), Swine (3.A.3.) and Other livestock (3.A.4.) which includes deer, goats and horses.

In 2022, swine was the largest source of emissions with 308 kt CO_2-eq under this reporting subcategory. Goats were the second largest source emitting 65 kt CO_2-eq, followed by horses, deer and sheep.

From 1990 to 2022, emissions from horses, goats, and swine increased by 534.2 percent, 172.5 percent and 124.5 percent respectively. In contrast, emissions from deer and sheep decreased by 50.6 percent and 35.4 percent respectively.

| Table 5-7 | Enteric Fermentation Emissions from Sheep, Swine and Other Livestock

(Unit: kt CO_2-eq)

Animal Type		1990	2000	2010	2018	2021	2022
Sheep		0.5	0.1	0.6	0.3	0.3	0.3
Swine		137	241	282	317	310	308
Other livestock	Deer	25	80	41	16	14	13
	Goats	24	70	35	60	71	65
	Horses	2	5	15	14	14	14
	Mules and asses[1]	IE	IE	IE	IE	IE	IE
Total		189	395	373	408	409	400

Note: 1) Included in horses

5.2.2.2 Methodology

5.2.2.2.1 Method

CH_4 emissions from sheep, swine, other livestock were estimated as per the methodology in the *2006 IPCC Guidelines* using national livestock population statistics that were disaggregated by species. To estimate emissions from swine, its population was disaggregated by age and gender as described in Table 5−8.

5.2.2.2.2 Emission Factor

Emissions from swine were estimated using country−specific emission factors[7] while default emission factors provided in the *2006 IPCC Guidelines* were used for sheep and other livestock such as goats, horses and deer.

| Table 5−8 | CH_4 Emission Factor for Enteric Fermentation of Sheep, Swine and Other livestock

Animal Type		CH_4 Emission Factor ($kg\ CH_4$/head/yr)	EF Source
Sheep		5	*2006 IPCC Guidelines* (Developing Countries[1])
Swine	<2 months	0.16	CS (Developed in 2022)
	2−4 months	0.30	
	4−6 months	1.45	
	Male, 6−8 months	2.70	
	Female, 6−8 months	3.30	
	Male>8 months	3.78	
	Female>8 months	4.71	
Goats		5	*2006 IPCC Guidelines*
Horses		18	
Deer		20	

Note: 1) The average weight of sheep raised in ROK (45 kg) corresponds to the average weight of sheep in developing countries as specified in the *2006 IPCC Guidelines*.

Source: *2006 IPCC Guidelines, Vol.4, Ch.10, Table 10.10*

5.2.2.2.3 Activity Data

Swine population were sourced from *Livestock Statistics* which is released every quarter. Emission estimates for swine were based on the annual average population from such quarterly data.

7) Country−specific CH_4 emission factors for swine by age and gender classes were developed in 2022 using a respiration chamber technique to measure enteric methane emissions as suggested by the *2006 IPCC Guidelines.*

Population data of sheep, deer, goats and horses were from the *Statistical Yearbook of Agriculture, Food and Rural Affairs*. Emissions were estimated using the average population of three latest years of the inventory year t (t, $t-1$, $t-2$) of each livestock species.

| Table 5-9 | Activity Data Source for Sheep, Swine and Other livestock

Period	Activity Data	Name of Statistics	Published by	Gas
1990-2022	Livestock population (Swine)	*Livestock Statistics*	Statistics Korea (KOSTAT)	CH_4
1988-2022	Livestock population (Sheep, deer, goats, horses)	*Statistical Yearbook of Agriculture, Food and Rural Affairs*	Ministry of Agriculture, Food and Rural Affairs (MAFRA)	

| Table 5-10 | Livestock Population for Enteric Fermentation : Sheep, Swine and Other Livestock

(Unit: 1000 head)

Animal Type		1990	2000	2010	2018	2021	2022
Sheep		3.3	1.1	4.4	2.3	2.2	2.1
Swine	<2 months	1,315.1	2,433.8	2,996.9	3,539.9	3,542.0	3,517.3
	2-4 months	1,558.2	2,710.2	3,020.4	3,440.3	3,423.0	3,406.9
	4-6 months	883.6	2,029.8	2,780.3	3,278.8	3,212.0	3,221.6
	Female, 6-8 months	7.3	5.2	8.5	10.8	10.9	11.0
	Male, 6-8 months	63.2	72.7	96.5	114.2	112.5	108.6
	Female>8 months	39.6	42.9	19.7	18.4	17.9	17.2
	Male>8 months	545.2	855.2	897.0	956.0	926.2	913.8
	Subtotal	4,412.2	8,149.8	9,819.3	11,358.4	11,244.6	11,196.3
Other livestock	Deer	45.4	142.8	73.0	29.0	24.3	22.4
	Goats	169.1	497.7	253.2	428.3	507.5	461.0
	Horses	4.4	9.1	29.0	27.8	27.5	27.6
	Mules and asses[1]	IE	IE	IE	IE	IE	IE

Note: 1) Included in horses

5.2.2.3 Uncertainty and Time–series Consistency

5.2.2.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

5.2.2.3.2 Time–series Consistency

Emissions from enteric fermentation of sheep, swine and other livestock were estimated using methodology and emission factors consistently from 1990 through 2022 to ensure time series consistency.

5.2.2.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

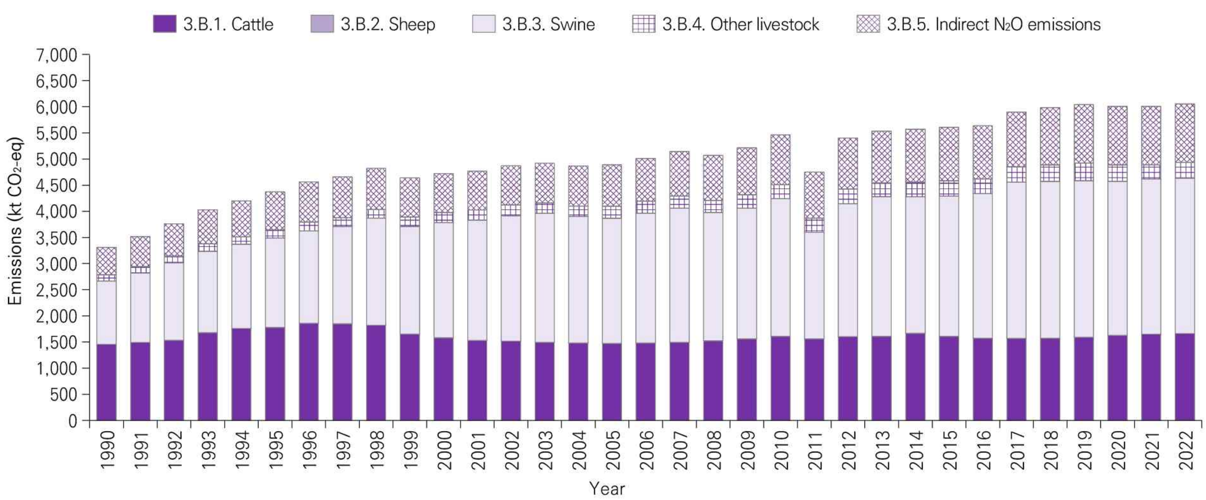
5.3 Manure Management (3.B.)

The anaerobic decomposition[8] of livestock manure produces CH_4 while N_2O is generated through both direct and indirect pathways during the processes of nitrification and denitrification[9] of nitrogen (N_2) in manure depending on the amount of oxygen.

For Cattle (3.B.1.), Sheep (3.B.2.), Swine (3.B.3.) and Other livestock (3.B.4.), CH_4 and direct N_2O emissions were estimated. Indirect N_2O emissions (3.B.5.) are produced when nitrogen losses occur through volatilization in the forms of either ammonia (NH_3) or nitrogen oxides (NO_x). Since indirect N_2O emissions from nitrogen losses through runoff and leaching of livestock manure do not occur in ROK[10], only the emissions from atmospheric deposition were estimated.

In 2022, total emissions from this reporting category were 6,055 kt CO_2−eq, representing a 0.8 percent increase from 2021, and accounted for 26.4 percent of total emissions from the Agriculture sector.

CH_4 and direct N_2O emissions from cattle, sheep, swine and other livestock were 4,935 kt CO_2−eq while indirect N_2O emissions were 1,120 kt CO_2−eq, accounting for 81.5 percent and 18.5 percent of total manure management emissions respectively.



| Figure 5-4 | Trends in Manure Management Emissions (1990-2022)

8) When livestock manure is stored or treated as a liquid without oxygen, anaerobic decomposition tends to produce more methane emissions. However, when manure is managed as a solid (e.g. composting) or deposited on pasture or paddock lands, it tends to decompose aerobically and produce less CH_4 emissions compared to anaerobic decomposition.

9) Nitrification of livestock manure occurs under aerobic conditions while denitrification takes place when manure is handled anaerobically. The amount of N_2O through such processes varies depending on the type of treatment and the duration of storage.

10) In accordance with 「*Ministerial Decree of Environment*」 under the 「*Act on the Management and Use of Livestock Excreta*」, every manure management facility in ROK must be designed and constructed to be covered with a tarp to prevent water contamination from spills, runoff and leaching.

| Table 5-11 | Emissions from Manure Management

(Unit: kt CO_2-eq)

Category	1990	2000	2010	2018	2021	2022
Cattle	1,457	1,583	1,610	1,575	1,651	1,664
Sheep	0.06	0.02	0.08	0.04	0.04	0.04
Swine	1,212	2,203	2,631	2,994	2,967	2,972
Other livestock	117	193	267	319	274	299
Indirect N_2O emissions	526	743	957	1094	1116	1,120
Total	3,311	4,721	5,465	5,983	6,008	6,055

5.3.1 Cattle (3.B.1.), Sheep (3.B.2), Swine (3.B.3.), Other livestock (3.B.4.)

5.3.1.1 Category Description

2022	Gas	Methodology	Emission Factor	Activity Data
	CH_4	Tier 1	D	Livestock population
	N_2O	Tier 2	CS, D	

CH_4 and direct N_2O[11] emissions from manure management were estimated per livestock category which include Cattle (3.B.1.), Sheep (3.B.2.), Swine (3.B.3.) and Other livestock (3.B.4.).

N_2O emission were estimated in accordance with the Tier 2 methodology as presented in the *2006 IPCC Guidelines* using country-specific data per manure management system for each livestock category while CH_4 emissions were calculated based on the Tier 1 method using IPCC default values.[12]

In 2022, CH_4 and direct N_2O emissions from manure management were 4,935 kt CO_2-eq, representing a 0.9 percent increase from 2021, and accounted for 81.5 percent of total emissions from manure management. Emissions from swine were 2,972 kt CO_2-eq while cattle produced 1,664 kt CO_2-eq, and 284 kt CO_2-eq from poultry, accounting for 49.1 percent, 27.5 percent, and 4.7 percent of total emissions from manure management respectively. Aggregated emissions from sheep, deer, goats and horses represented less than 1 percent.

11) N_2O emissions from manure management are produced through direct and indirect pathways. Indirect N_2O emissions are reported separately under 3.B.5. Indirect N_2O emissions.

12) The Tier 2 method requires data on the amount of volatile solids per livestock species which are not available in ROK (see Section 5.3.1.5 Planned Improvements).

| Table 5-12 | Manure Management Emissions from Cattle, Sheep and Other Livestock

(Unit: kt CO_2-eq)

Animal Type			1990	2000	2010	2018	2021	2022
Subtotal (Cattle)			1,457	1,583	1,610	1,575	1,651	1,664
	Dairy cattle		1,093	1,184	952	886	859	842
	Subtotal (Non-dairy cattle)		363	398	658	689	792	822
		Hanwoo	323	351	621	652	747	780
		Beef cattle	40	48	37	37	45	42
Sheep			0.06	0.02	0.08	0.04	0.04	0.04
Subtotal (Swine)			1,212	2,203	2,631	2,994	2,967	2,972
	Market		947	1,809	2,218	2,558	2,542	2,550
	Breeding		264	394	412	436	425	422
Deer			6	18	9	4	3	3
Goats			3	8	4	7	8	7
Horses			1	2	6	5	5	5
Mules and asses[1]			IE	IE	IE	IE	IE	IE
Subtotal (Poultry)			107	165	248	304	258	284
	Chicken	Layer hens	66	83	105	140	123	154
		Broiler	40	73	119	151	124	119
	Duck		1	9	25	12	11	11
Total			2,785	3,978	4,509	4,889	4,892	4,935

Note: 1) Included in horses

5.3.1.2 Methodology

5.3.1.2.1 Method

○ CH_4

CH_4 emissions from manure management were estimated using the Tier 1 method of the *2006 IPCC Guidelines* based on the livestock population and default CH_4 emission factors for each livestock category.

CH_4 emissions from manure management

$$CH_{4\,Manure} = \sum_T \left(\frac{EF_{(T)} \times N_{(T)}}{10^6} \right)$$

$CH_{4\ Manure}$: CH_4 emissions from manure management, for a defined population [kt CH_4/yr]

$EF_{(T)}$: emission factor for the defined livestock population [kg CH_4/head/yr]

$N_{(T)}$: the number of head of livestock species/category T in the country [head]

T : species/category of livestock

Source: *2006 IPCC Guidelines, Vol.4, Ch.10, Equation 10.22*

○ N_2O

N_2O emissions from manure management were estimated using the Tier 2 method presented in the *2019 Refinement to the 2006 IPCC Guidelines*.

Direct N_2O emissions from manure management

$$N_2O_{D(mm)} = \left[\sum_S \left\{\sum_{T,P}\left(N_{(T,P)} \times Nex_{(T,P)} \times AWMS_{(T,S,P)}\right) + N_{cdg(S)}\right\} \times EF_{3(S)}\right] \times \frac{44}{28}$$

$N_2O_{D(mm)}$	:	direct N_2O emissions from Manure Management in the country [kg N_2O/yr]
$N_{(T,P)}$	:	number of head of livestock species/category T in the country [head]
$Nex_{(T,P)}$	:	annual average N excretion per head of species/category T in the country, for productivity system P, when applicable in kg N animal yr [kg N/head/yr]
$AWMS_{(T,S,P)}$	:	fraction of total annual nitrogen excretion for each livestock species/category T that is managed in manure management system S in the country, dimensionless; to consider productivity class P, if using a Tier 1a approach
$N_{cdg(S)}$	:	annual nitrogen input via co-digestate in the country, kg N yr, where the system(s) refers exclusively to anaerobic digestion[13)]
$EF_{3(S)}$	:	emission factor for direct N_2O emissions from manure management system S in the country [kg N_2O-N/kg N in S]
S	:	manure management system
P	:	productivity class, high or low, to be considered if using the Tier 1a approach
T	:	species/category
44/28	:	conversion of N_2O-N emissions to N_2O emissions

Source: *2019 Refinement, Vol.4, Ch.10, Equation 10.25*

5.3.1.2.2 Emission Factor

○ CH_4

To estimate CH_4 emissions from manure management, IPCC default emission factors for cool region[14)] in which the average annual temperature is below 15°C were used.

13) No available domestic activity data on nitrogen input ($N_{cdg(S)}$) in digestate in ROK

14) The annual average temperature of ROK in 2022 was 12.9℃. Since 1990, the annual average temperature has remained below 15℃. (Source: *Annual Climatological Report*, Korea Meteorological Administration)

| Table 5-13 | CH_4 Emission Factor for Manure Management ($EF_{(T)}$)

(Unit: kg CH_4/head/year)

Animal Type			CH_4 Emission Factor	EF Source	
Cattle	Dairy cattle		58	*2006 IPCC Guidelines*	North America[1)]
	Non-dairy cattle		1		North America[2)]
Sheep			0.10		Developing Countries[3)]
Swine	Market		8		Western Europe[4)]
	Breeding		12		
Deer			0.22		All regions
Goats			0.11		Developing Countries[5)]
Horses			1.09		
Poultry	Chicken	Layer hens	0.03		Developed Countries[6)]
		Broiler	0.02		
	Duck		0.02		

Note: 1) The average milk production of dairy cattle in ROK (9,000 kg/head/year) is similar to that in North America (8,400 kg/head/year).
2) ROK and North America are similar in non-dairy cattle breeding and management such as feeding high-quality feed and grain as well as housing management.
3) The average weight of sheep raised in ROK (45 kg) corresponds to the liveweight value of sheep in developing countries.
4) Swines raised in ROK is three tertiary hybrids (crossbreeds) of Landrace, Yorkshire and Duroc (LYD) which is similar to those in Western Europe.
5) The average weight of goat and horse raised in ROK correspond to that of goat (30 kg) and horse (238 kg) in developing countries.
6) Chicken breed and poultry farming in ROK are similar to those in Western Europe.

Source: *2006 IPCC Guidelines, Vol.4, Ch.10, Table 10.14-10.16 (for default EF)*
2006 IPCC Guidelines, Vol.4, Ch.10, Table 10.10 (for Note 3)
2006 IPCC Guidelines, Vol.4, Ch.10, Table 10A.1 and 10A.9 (for Note 1 and Note 5)

○ N_2O

To estimate direct N_2O emissions from manure management, the annual average nitrogen excretion rate per head (*Nex*) and the N_2O emission factor for each manure management system ($EF_{3(S)}$) were used. The annual average nitrogen excretion rate was calculated using the equation presented in the *2019 Refinement.* For N_2O direct emission factor ($EF_{3(S)}$), default values in the *2019 Refinement* were used. For *Hanwoo* (Korean native cattle) and market swine, country-specific[15)] values for the annual average nitrogen excretion rate were used.

15) In 2022, country-specific values for *Hanwoo* (Korean native cattle) and market swine were developed using the Kjeldahl method.

Annual N excretion rates

$$Nex_{(T,P)} = N_{rate(T,P)} \times \frac{TAM_{(T,P)}}{1000} \times 365$$

$Nex_{(T,P)}$	:	annual N excretion for livestock category T [kg N/animal/yr]
$N_{rate(T,P)}$	:	default N excretion rate [kg N/1,000 kg/day]
$TAM_{(T,P)}$	:	average animal mass for livestock category T [kg/animal]
P	:	livestock productivity
T	:	species/category of livestock

Source: *2019 Refinement, Vol.4. Ch.10. Equation 10.30*

| Table 5-14 | Annual Average Nitrogen (N) Excretion Rate (Nex)

(Unit: kg/head/year)

Animal Type		Annual Average N Excretion Rate	Nex Source
Dairy cattle		142.35	Calculated using the equation in the *2019 Refinement*
Non-dairy cattle		50.13[2)]	
	Hanwoo	49.68	CS (Developed in 2022)[1)]
	Beef cattle	59.42	Calculated using the equation in the *2019 Refinement*
Sheep		3.62	
Swine		12.41[2)]	
	Swine (Market)	10.97	CS (Developed in 2022)[1)]
	Swine (Breeding)	26.35	Calculated using the equation in the *2019 Refinement*
Deer		29.35	
Goats		2.98	
Horses		39.96	
Poultry		0.55[2)]	
	Layer hens	0.60	
	Broiler	0.31	
	Duck	0.82	

Note: 1) The annual average nitrogen excretion rate was calculated using the Kjeldahl method.
2) A weighted average of annual nitrogen excretion rate was calculated based on the livestock population of the species in the respective year.

| Table 5-15 | N_2O Direct Emission Factor per Manure Management System

(Unit : kg N_2O-N/kg N)

<table>
<tr><th colspan="3" rowspan="2">Animal Type</th><th colspan="4">N_2O Emission Factor ($EF_{3(S)}$)</th></tr>
<tr><th>Solid storage</th><th>Composting-in-vessel</th><th>Poultry manure with/without litter</th><th>Aerobic treatment</th></tr>
<tr><td rowspan="3">Cattle</td><td colspan="2">Dairy cattle</td><td rowspan="5">0.01</td><td rowspan="3">0.006</td><td rowspan="5">NA</td><td rowspan="8">0.005</td></tr>
<tr><td rowspan="2">Non-dairy cattle</td><td>Hanwoo (Korean native cattle)</td></tr>
<tr><td>Beef cattle</td></tr>
<tr><td rowspan="2">Swine</td><td colspan="2">Market</td><td rowspan="2">0.005</td></tr>
<tr><td colspan="2">Breeding</td></tr>
<tr><td rowspan="3">Poultry</td><td colspan="2">Layer hens</td><td rowspan="3">NA</td><td rowspan="3">0.006</td><td rowspan="3">0.001</td></tr>
<tr><td colspan="2">Broiler</td></tr>
<tr><td colspan="2">Duck</td></tr>
<tr><td colspan="3">Sheep</td><td rowspan="4">0.01</td><td colspan="4" rowspan="4">NA[1)]</td></tr>
<tr><td colspan="3">Goats</td></tr>
<tr><td colspan="3">Horses</td></tr>
<tr><td colspan="3">Deer</td></tr>
</table>

Note: 1) All manure from sheep, goats, horses and deer were considered to be entirely composted by solid storage as there is no collection and treatment facility for respective animal types.

Source: *2019 Refinement, Vol.4. Ch.10. Table 10.21*

Parameters used to calculate the annual average nitrogen excretion rate (*Nex*) for livestock category include default nitrogen excretion rate ($N_{rate(T)}$) and typical animal mass (*TAM*) for each species as follows.

- N excretion rate($N_{rate(T)}$) for livestock category

The IPCC default nitrogen excretion rates presented in the *2019 Refinement* were used.

| Table 5-16 | Nitrogen Excretion Rate for Livestock Category ($N_{rate(T)}$)

(Unit: kg N/1,000kg/day)

Animal Type			Nitrogen Excretion Rate ($N_{rate(T)}$)	$N_{rate(T)}$ Source	
Cattle	Dairy cattle		0.60	*2019 Refinement*	North America[1]
	Non-dairy cattle		0.40		
Sheep			0.32		Asia
Swine	Breeding		0.38		Western Europe[2]
Deer			0.67		All regions
Goats			0.34		Asia
Horses			0.46		
Poultry	Chicken	Layer hens	0.87		Western Europe[3]
		Broiler	1.14		
	Duck		0.83		All regions

Note: 1) The average milk production of dairy cows in ROK (9,000 kg/head/year) is similar to that in North America (8,400 kg/head/year).
2) Swine raised in ROK is three tertiary hybrids (crossbreeds) of Landrace, Yorkshire and Duroc (LYD) which is similar to those in Western Europe.
3) Chicken breed and poultry farming in ROK are similar to those in Western Europe.

Source: *2019 Refinement, Vol.4, Ch.10, Table 10.19 (for default values of* $N_{rate(T)}$*)*
2006 IPCC Guidelines, Vol.4, Ch.10, Table 10A.1 (for Note 1)

Typical animal mass (TAM) for livestock category

The IPCC default values for weights for livestock category presented in the *2019 Refinement* were used.

| Table 5-17 | Typical Animal Mass (TAM) for Livestock Category

(Unit: kg/head)

Animal Type			Typical Animal Mass (TAM)	TAM Source	
Cattle	Dairy cattle		650	*2019 Refinement*	North America[1]
	Non-dairy cattle		407		
Sheep			31		Developing Countries
Swine	Breeding		190		Western Europe[2]
Deer			120		All regions
Goats			24		Developing Countries
Horses			238		
Poultry	Chicken	Layer hens	1.9		Western Europe[3]
		Broiler	1.2		
	Duck		2.7		All regions

Note: 1) The average milk production of dairy cows in ROK (9,000 kg/head/year) is similar to that in North America (8,400 kg/head/year).
2) Swine raised in ROK is three tertiary hybrids (crossbreeds) of Landrace, Yorkshire and Duroc (LYD) which is similar to those in Western Europe.
3) Chicken breed and poultry farming in ROK are similar to those in Western Europe.

Source: *2019 Refinement, Vol.4, Ch.10, Table 10A.5 (for default values of TAM)*
2006 IPCC Guidelines, Vol.4, Ch.10, Table 10A.1 (for Note 1)

5.3.1.2.3 Activity Data

○ CH_4

Activity data used to estimate CH_4 emissions from manure management of cattle, sheep, swine, goats, deer and horses were the same as for enteric fermentation (CRT 3.A.1.–3.A.4.) described in Section 5.2.1.2.3 and Section 5.2.2.2.3. For poultry population, data from *Livestock Statistics* which is released every quarter were used. As *Livestock Statistics* collected data on duck population only since 2011, *Statistical Yearbook of Agriculture, Food and Rural Affairs* was used for duck population for the 1990 to 2010 period.

| Table 5-18 | Activity Data Source for Poultry

Period	Activity Data	Name of Statistics		Published by	Gas
1990–2022	Livestock population[1]	Chicken	*Livestock Statistics*	Statistics Korea (KOSTAT)	CH_4 N_2O
1988–2010		Duck	*Statistical Yearbook of Agriculture, Food and Rural Affairs*[2]	Ministry of Agriculture, Food and Rural Affairs (MAFRA)	
2011–2022			*Livestock Statistics*	Statistics Korea (KOSTAT)	

Note: 1) Using *Livestock Statistics*, chicken and duck populations were based on the average value of population per quarter.
2) For duck population for the 1988 to 2010 period derived from *Statistical Yearbook of Agriculture, Food and Rural Affairs*, the average value of annual population of three latest years of the inventory year t (t, t−1, t−2) was used as activity data.

| Table 5-19 | Livestock Population for Manure Management

(Unit: 1000 head)

Animal Type	1990	2000	2010	2018	2021	2022
Total (Cattle)	**2,078.7**	**2,271.9**	**3,301.6**	**3,493.2**	**3,939.9**	**4,083.8**
Dairy cattle	499.7	541.2	435.0	406.9	401.6	391.1
Subtotal (Non-dairy cattle)	**1,579.0**	**1,730.7**	**2,866.6**	**3,086.4**	**3,538.4**	**392.7**
Hanwoo	1,410.8	1,530.5	2,709.2	2,939.4	3,367.4	3,523.4
Beef cattle	168.2	200.1	157.4	147.0	171.0	169.3
Sheep	3.3	1.1	4.4	2.3	2.2	2.1
Total (Swine)[1]	**4,412.2**	**8,149.8**	**9,819.3**	**11,358.4**	**11,244.6**	**11,196.3**
Swine (Market)	3,757	7,174	8,798	10,259	10,177	10,146
Swine (Breeding)	655	976	1,022	1,099	1,068	1,051
Deer	45.4	142.8	73.0	29.0	24.3	22.4
Goats	169.1	497.7	253.2	428.3	507.5	461.0
Horses	4.4	9.1	29.0	27.8	27.5	27.6
Mules and asses[2]	IE	IE	IE	IE	IE	IE
Total (Poultry)	**69,794.9**	**108,615.0**	**164,208.9**	**184,721.6**	**180,930.1**	**185,398.1**
Chicken[1] Layer hens	38,690.5	48,761.7	61,217.6	69,890.2	66,735.3	70,551.1
Chicken[1] Broiler	30,499.2	55,490.7	90,713.8	106,071.4	107,762.6	107,181.7
Duck	605.2	4,363.6	12,277.6	8,760.0	6,432.1	7,665.3

Note: 1) Populations of swine and chicken used as activity data are as follows: market swine (<6 months), breeding swine (>6 months), layer hens (>3 months) and broiler (<3 months).

2) Included in horses

○ N_2O

To estimate direct N_2O emissions from manure management, livestock population by species and fraction of total annual nitrogen excretion for each livestock species per manure management system ($AWMS_{(T)}$) are required.

The number of head per livestock species were sourced from *Livestock Statistics* while the fraction of total annual nitrogen excretion were calculated using livestock population from *Annual Agriculture, Forestry and Fisheries Survey*.

As data on annual nitrogen excretion have been available since 2011, the fraction of total annual nitrogen excretion for 2011 was used for the 1990 to 2010 period. As the annual survey was not conducted in 2015 and 2020, respective fractions for 2015 and 2020 were interpolated using figures from 2014 and 2016, and from 2019 and 2021.[16]

16) *Annual Agriculture, Forestry and Fisheries Survey* (KOSTAT) is not conducted in the years in which the *Census of Agriculture, Forestry and Fisheries* (KOSTAT) is conducted. Since the *Census* is conducted every five years and does not collect some data (e.g. total annual nitrogen excretion per manure management system) which are covered in *the Annual Survey,* interpolation method was used to determine required values for 2015 and 2020 in which *the Census* was conducted.

| Table 5-20 | Fraction of Total Annual Nitrogen Excretion ($AWMS_{(T)}$)

(Unit: %)

Animal Type		Manure Management System	1990	2000	2010	2018	2021	2022
Cattle	Dairy cattle	Solid Storage	88.69	88.69	88.69	84.43	68.21	73.82
		Aerobic treatment_forced aeration systems	2.85	2.85	2.85	0.00	5.46	4.90
		Composting-in-vessel	8.46	8.46	8.46	16.56	26.34	21.28
	Hanwoo (Korean native cattle)	Solid Storage	93.17	93.17	93.17	84.30	84.60	84.07
		Aerobic treatment_forced aeration systems	0.52	0.52	0.52	0.49	1.03	1.29
		Composting-in-vessel	6.31	6.31	6.31	15.21	14.36	14.64
	Beef cattle	Solid Storage	65.29	65.29	65.29	78.04	87.56	73.39
		Aerobic treatment_forced aeration systems	9.76	9.76	9.76	0.00	2.68	6.83
		Composting-in-vessel	24.95	24.95	24.95	21.96	9.76	19.79
Swine (Market, breeding)		Solid Storage	23.29	23.29	23.29	10.96	12.84	19.66
		Aerobic treatment_forced aeration systems	76.71	76.71	76.71	89.04	87.17	80.33
Poultry	Chicken (Layer hens)	Poultry manure without litter	50.30	50.30	50.30	27.05	39.86	13.63
		Aerobic treatment_forced aeration systems	2.86	2.86	2.86	0.02	0.03	0.02
		Composting-in-vessel	46.83	46.83	46.83	72.93	60.11	86.33
	Chicken (Broiler)	Poultry manure with litter	47.71	47.71	47.71	35.89	63.17	66.68
		Aerobic treatment_forced aeration systems	0.83	0.83	0.83	4.80	0.19	0.18
		Composting-in-vessel	51.47	51.47	51.47	59.32	36.64	33.14
	Duck	Poultry manure with litter	33.70	33.70	33.70	71.18	54.87	69.33
		Aerobic treatment_forced aeration systems	0.04	0.04	0.04	0.00	0.00	0.00
		Composting-in-vessel	66.25	66.25	66.25	28.82	45.13	30.67
Sheep, goat, horses, deer[1]		Solid Storage	100.00	100.00	100.00	100.00	100.00	100.00

Note: 1) All manure from sheep, goat, horse and deer were considered to be entirely composted as there is no collection and treatment facility for respective animal types.

Source: *2011-2022 Annual Agriculture, Forestry and Fisheries Survey* (KOSTAT)

5.3.1.3 Uncertainty and Time-series Consistency

5.3.1.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

5.3.1.3.2 Time-series Consistency

CH_4 and N_2O direct emissions from manure management were estimated using methodology and emissions factors consistently from 1990 through 2022 to ensure time series consistency. For livestock population of cattle, swine and poultry, data from *Livestock Statistics* were used across the 1990 through 2021 time series.

For duck population, data from *Statistical Yearbook of Agriculture, Food and Rural Affairs* were used across the 1990 through 2010 time series and *Livestock Statistics* for the 2011 to 2022 period. Switching from annual statistics to quarterly statistics, the accuracy of data on duck population has been improved. To maintain time-series consistency, the approach of tracking changes in activity data and emissions across the time series was used.

For other livestock species, activity data from *Statistical Yearbook of Agriculture, Food and Rural Affairs* were used for the entire time series. The fraction of total annual nitrogen excretion per manure management system was calculated using livestock population from *Annual Agriculture, Forestry and Fisheries Survey*. As the respective annual survey has been conducted since 2011, the fraction of annual nitrogen excretion for 2011 were used for the 1990 to 2010 period. For 2015 and 2020, respective fractions were interpolated using figures from 2014 and 2016, and from 2019 and 2021 respectively.

5.3.1.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

5.3.1.5 Planned Improvements

Activity data for the fraction of total annual nitrogen excretion were from the *Annual Agriculture, Forestry and Fisheries Survey* in which all domestic manure treatment facilities that use composting methods are grouped under the "Composting" category. ROK is assessing the possibility of categorizing such facilities and activity data therefrom by different composting methods to enhance the accuracy of emissions. ROK is also exploring the potential to collect data on volatile solids and nitrogen content per livestock species to develop country-specific factors for higher tier calculations of CH_4 emissions.

5.3.2 Indirect N_2O Emissions (3.B.5.)

5.3.2.1 Category Description

2022	Gas	Methodology	Emission Factor	Activity Data
	N_2O	Tier 1, 2	CS, D	Livestock population

Indirect N_2O emissions (3.B.5.) are produced when nitrogen losses occur through volatilization and subsequent deposition in the forms of either ammonia (NH_3) or nitrogen oxides (NO_x). Since indirect N_2O emissions from nitrogen losses through runoff and leaching do not occur in ROK, only the emissions from atmospheric deposition were estimated.[17)]

In 2022, indirect N_2O emissions amounted to 1,120 kt CO_2-eq, representing a 0.4 percent increase from 2021, and accounted for 18.5 percent of the total manure management emissions.

| Table 5-21 | Indirect N_2O Greenhouse Gas Emissions

(Unit: kt CO_2-eq)

Category	1990	2000	2010	2018	2021	2022
Indirect N_2O emissions	526	743	957	1,094	1,116	1,120

5.3.2.2 Methodology

5.3.2.2.1 Method

Indirect N_2O emissions from atmospheric deposition were calculated by applying fractions of nitrogen losses from manure management systems due to volatilization and the amount of nitrogen excreted per livestock category for each manure management system as suggested by the *2019 Refinement*.

17) In accordance with 「*Ministerial Decree of Environment*」 under the 「*Act on the Management and Use of Livestock Excreta*」, every manure management facility in ROK must be designed and constructed to be covered with a tarp to prevent water contamination from spills, runoff and leaching.

Indirect N_2O emissions due to volatilisation of N from manure management		
$$N_2O_{G(mm)} = (N_{volatilization-MMS} \times EF_4) \times \frac{44}{28}$$		
$N_2O_{G(mm)}$	:	indirect N_2O emissions due to nitrogen volatilization from manure management [kg N_2O/yr]
$N_{volatilization-MMS}$	:	amount of manure nitrogen that is lost due to volatilisation of NH_3 and NO_x, [kg N/yr]
EF_4	:	emission factor for N_2O emissions from atmospheric depositioin of nitrogen on soils and water surfaces [kg N_2O−N/(kg NH_3−N+NO_x−N volatilised)]
44/28	:	N_2O conversion factor

Source: *2019 Refinement, Vol.4. Ch.10, Equation 10.28*

Nitrogen losses (N) due to volatilisation from manure management		
$$N_{volatilization-MMS} = \sum_S \left[\sum_{T,P} (((N_{(T,P)} \times Nex_{(T,P)}) \times AWMS_{(T,S,P)}) + N_{cdg(s)}) \times Frac_{GasMS(T,S)} \right]$$		
$N_{volatilization-MMS}$	:	amount of manure nitrogen that is lost due to volatilisation of NH_3 and NO_x, [kg N/yr]
$N_{(T,P)}$	:	number of livestock species T in the country [head]
$Nex_{(T,P)}$	:	annual average N excretion per head of species/category T in the country [kg N/head/yr]
$AWMS_{(T,S,P)}$	:	fraction of total annual nitrogen excretion for each livestock species/category T that is managed in manure management system S in the country
$N_{cdg(s)}$	:	amount of nitrogen from co−digestates added to biogas plants[18]
$Frac_{GasMS(T,S)}$	:	fraction of managed manure nitrogen for livestock category T that volatilises as NH_3 and NO_x in the manure management system S
S	:	manure management system
P	:	productivity class
T	:	species/category of livestock

Source: *2019 Refinement, Vol.4. Ch.10, Equation 10.26*

18) There is no available data in ROK on the amount of nitrogen from co−digestate to biogas plants ($N_{cdg(S)}$) where the system refers exclusively to anaerobic digestion.

5.3.2.2.2 Emission Factor

Default emission factors for N_2O emissions from atmospheric deposition of nitrogen (EF_4) and fractions of nitrogen loss from volatilization rate ($Frac_{GasMS}$) presented in the *2019 IPCC Refinement* were used. Annual average nitrogen excretion per head of species (*Nex*) used for indirect N_2O emissions was the same as that for direct N_2O emissions presented in Table 5-14.

| Table 5-22 | Emission Factor for N_2O Emissions from Atmospheric Deposition of Nitrogen

(Unit : kg N_2O-N/kg NH_3-N+NO_x-N volatilised)

Gas Type	Emission Factor(EF_4)	EF Source
Indirect N_2O emissions from atmospheric deposition of nitrogen	0.01	*2019 Refinement*

Source: *2019 Refinement, Vol.4. Ch.11, Table 11.3*

| Table 5-23 | Fractions of Managed Manure Nitrogen that volatilises as NH_3 and NO_x ($Frac_{GasMS}$)

<table>
<tr><th colspan="3" rowspan="2">Animal Type</th><th colspan="4">Fractions of Manure Nitrogen Loss ($Frac_{GasMS}$)</th></tr>
<tr><th>Solid storage</th><th>Composting-in-vessel</th><th>Poultry manure with/without litter</th><th>Aerobic treatment</th></tr>
<tr><td rowspan="3">Cattle</td><td colspan="2">Dairy cattle</td><td>0.30</td><td>0.45</td><td rowspan="5">NA</td><td rowspan="8">0.85</td></tr>
<tr><td rowspan="2">Non-dairy cattle</td><td>Hanwoo (Korean native cattle)</td><td rowspan="4">0.45</td><td rowspan="2">0.60</td></tr>
<tr><td>Beef cattle</td></tr>
<tr><td rowspan="2">Swine</td><td colspan="2">Market</td><td rowspan="2">0.35</td></tr>
<tr><td colspan="2">Breeding</td></tr>
<tr><td rowspan="3">Poultry</td><td colspan="2">Layer hens</td><td rowspan="3">NA</td><td rowspan="3">0.60</td><td>0.48</td></tr>
<tr><td colspan="2">Broiler</td><td rowspan="2">0.40</td></tr>
<tr><td colspan="2">Duck</td></tr>
<tr><td colspan="3">Sheep</td><td rowspan="4">0.12</td><td colspan="3" rowspan="4">NA[1)]</td></tr>
<tr><td colspan="3">Goats</td></tr>
<tr><td colspan="3">Horses</td></tr>
<tr><td colspan="3">Deer</td></tr>
</table>

Note: 1) All manure from sheep, goat, horse and deer were assumed to be entirely composted by solid storage based on expert judgment as there is no collection and treatment facility for respective animal types.

Source: *2019 Refinement, Vol.4. Ch.10, Table 10.22*

5.3.2.2.3 Activity Data

Activity data including livestock population by species and fractions of total annual nitrogen excretion used for direct N_2O emissions as presented in Section 5.3.1.2.3. were also used to calculate indirect N_2O emissions.

5.3.2.3 Uncertainty and Time-series Consistency

5.3.2.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

5.3.2.3.2 Time-series Consistency

Indirect N_2O emissions were estimated using methodology and emissions factors consistently from 1990 through 2022 to ensure time series consistency as were CH_4 and N_2O direct emissions as described in Section 5.3.1.3.

5.3.2.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

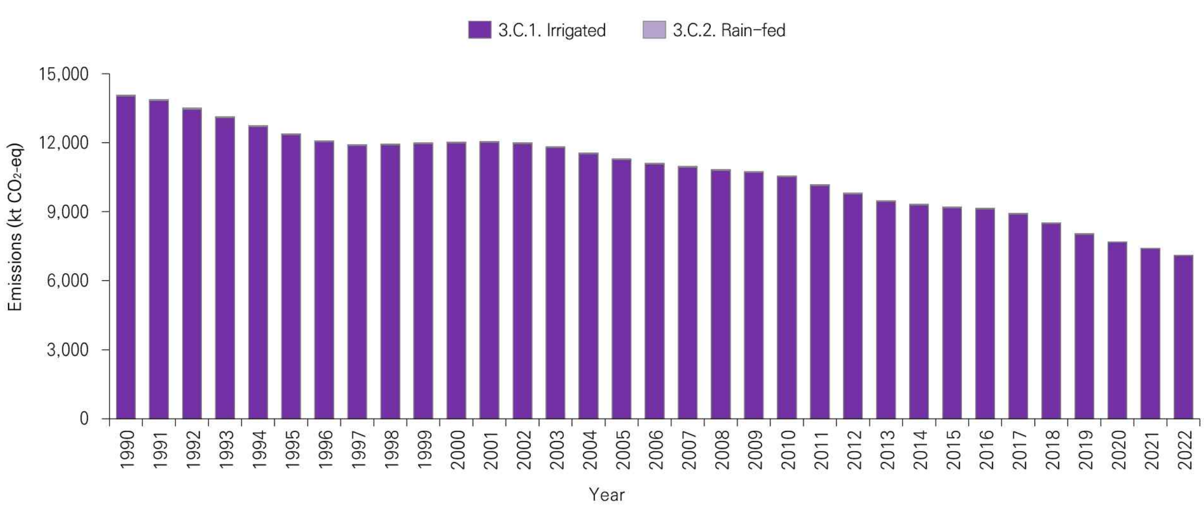
5.4 Rice Cultivation (3.C.)

Rice cultivation on flooded fields produces methane during the process of decomposition of organic matter in anaerobic conditions. In ROK, rice is grown on Irrigated (3.C.1.) and Rain−fed (3.C.2.) fields[19]. Irrigated field refers to fields that are flooded with water supplied throughout the rice growing season whereas rain−fed field refers to fields in which water supply solely depends on precipitation.

CH_4 emissions from rice cultivation are affected by soil (texture, organic matter, bulk density), climate (precipitation, temperature, solar radiation), fertilization and water management practices. Accordingly, emission factors and scaling factors that correspond to local circumstances such as ROK's unique soil type, climate and environmental variables as well as water regime and organic amendments.

In 2022, CH_4 emissions from rice cultivation were 7,112 kt CO_2−eq, representing a 49.5 percent decrease from 14,073 kt CO_2−eq in 1990 which was largely due to continued decrease in rice cultivation area and improved water management since 1990.

Almost all emissions in 2022 from rice cultivation were from irrigated fields, producing 7,098 kt CO_2−eq, contributing 99.8 percent of CH_4 emissions from rice cultivation while rain−fed emitted 14 kt CO_2−eq.



| Figure 5−5 | Trends in Rice Cultivation CH_4 Emissions (1990−2022)

19) No rice cultivation or emissions occur in deepwater rice fields in ROK.

| Table 5-24 | Emissions from Rice Cultivation

(Unit: kt CO_2-eq)

Sub-category	1990	2000	2010	2018	2021	2022
Irrigated	14,030	11,998	10,519	8,499	7,397	7,098
Rain-fed	43	37	32	25	16	14
Total	14,073	12,035	10,551	8,524	7,413	7,112

5.4.1 Irrigated (3.C.1.)

5.4.1.1 Category Description

2022	Gas	Methodology	Emission Factor	Activity Data
	CH_4	Tier 2	CS	Cultivation area (Rice, barley, wheat)

Water regimes of irrigated fields are divided into two categories : Continuously flooded (3.C.1.a.) and Intermittently flooded (3.C.1.b.). Continuously flooded fields refer to fields to which water is supplied throughout the rice growing season with end-season drainage for harvest while intermittently flooded fields represent fields that have at least one drainage period of more than three days during the cropping season. Depending on the number of aeration, intermittently flooded fields are divided into either single aeration and multiple aeration.[20] In ROK, single aeration is subdivided into single aeration period of less than 1 week, and that of 1-2 weeks to enhance the accuracy of emissions from this reporting subcategory.

In 2022, emissions from irrigated fields were 7,098 kt CO_2-eq, representing a 4.0 percent decrease from 2021. Intermittently flooded fields produced 5,805 kt CO_2-eq while continuously flooded emitted 1,294 kt CO_2-eq, accounting for 81.8 percent and 18.2 percent of total emissions from irrigated fields respectively.

| Table 5-25 | CH_4 Emissions from Irrigated Field

(Unit: kt CO_2-eq)

Water Regime		1990	2000	2010	2018	2021	2022
Continuously flooded		2,614	2,273	2,002	1,705	1,387	1,294
Intermittently flooded	Subtotal	11,416	9,725	8,517	6,794	6,010	5,805
	Intermittently flooded : single aeration ▶ For less than 1 week ▶ For 1-2 weeks	9,189	7,828	6,855	4,697	3,681	3,472
	Intermittently flooded : multiple aeration	2,227	1,897	1,661	2,097	2,329	2,332
Total		14,030	11,998	10,519	8,499	7,397	7,098

20) *2006 IPCC Guidelines, Vol.4, Ch.5, Table 5.12*

5.4.1.2 Methodology

5.4.1.2.1 Method

CH_4 emissions from both irrigated and rain-fed fields were estimated in accordance with the *2006 IPCC Guidelines*. Emissions are calculated by multiplying the rice cultivation area by CH_4 emission factor and the number of cultivation days. Since CH_4 emissions vary depending on water regimes before and during the cultivation period as well as organic amendments, country-specific factors including rice cultivated area per water regimes and adjusted emission factors were used.

CH_4 emissions from rice cultivation

$$CH_{4_{Rice}} = \sum_{i,j,k} (EF_{i,j,k} \times t_{i,j,k} \times A_{i,j,k} \times 10^{-6})$$

$CH_{4\ Rice}$	:	annual CH_4 emissions from rice cultivation [Gg CH_4/yr]
$EF_{i,j,k}$	:	a daily emission factor for i, j, and k conditions [kg CH_4/ha/day]
$t_{i,j,k}$	:	cultivation period of rice for i, j, and k conditions [day]
$A_{i,j,k}$	:	annual harvested area of rice for i, j, and k conditions [ha/yr]
i, j, k	:	represent different ecosystems, water regimes, type and amount of organic amendments, and other conditions under which CH_4 emissions from rice may vary

Source: *2006 IPCC Guidelines, Vol.4, Ch.5, Equation 5.1*

5.4.1.2.2 Emission Factor

CH_4 emission factors for both irrigated and rain-fed fields were estimated reflecting water regimes and organic amendments in accordance with the method presented in the *2006 IPCC Guidelines*. Country-specific factors were used to calculate CH_4 emission factors for irrigated field.

Adjusted daily emission factor

$$EF_i = EF_c \times SF_w \times SF_p \times SF_o \times SF_{s,r}$$

EF_i	:	adjusted daily emission factor for a particular harvested area [kt CH_4/yr]
EF_c	:	baseline emission factor for continuously flooded fields without organic amendments [kg CH_4/ha/day]
SF_w	:	scaling factor to account for the differences in water regime during the cultivation period
SF_p	:	scaling factor to account for the differences in water regime in the pre-season before the cultivation period
SF_o	:	scaling factor varies for both type and amount of organic amendment applied
$SF_{s,r}$	:	scaling factor for soil type or rice cultivar, if available[21]

Source: *2006 IPCC Guidelines, Vol.4, Ch.5, Equation 5.2*

21) Scaling factor for soil type or rice cultivar ($SF_{S,R}$) is not available in ROK due to lack of data.

| Table 5-26 | Adjusted Daily Emission Factor (EF_i) for Irrigated Fields

Water Regime						EF$_i$ without organic amendments (Equation = $EF_c \times SF_w \times SF_p$)	EF$_i$ with organic amendments (Equation = $EF_c \times SF_w \times SF_p \times SF_o$)	
			Water regime *before* cultivation (SF_p)		Water regime *during* cultivation (SF_w)	No organic amendment (EF_c)	Straw (rice, barley) (SF_o)	Green manure (SF_o)
						2.32	2.5	1.045
Continuously flooded			Non-flooded <180 days	1	1	2.32[1]	5.80[2]	2.42
			Non-flooded >180 days	0.8		1.86	4.64	1.94
			Flooded >30 days	1.09		2.53	6.32	2.64
Intermittently flooded	Intermittently flooded : single aeration	Aeration <1 week	Non-flooded <180 days	1	0.83	1.93	4.81	2.01
			Non-flooded >180 days	0.8		1.54	3.85	1.61
			Flooded >30 days	1.09		2.10	5.25	2.19
		Aeration 1-2 weeks	Non-flooded <180 days	1	0.66	1.53	3.83	1.60
			Non-flooded >180 days	0.8		1.22	3.06	1.28
			Flooded >30 days	1.09		1.67	4.17	1.74
	Intermittently flooded : multiple aeration	Intermittently flooded >2 weeks	Non-flooded <180 days	1	0.49	1.14	2.84	1.19
			Non-flooded >180 days	0.8		0.91	2.274	0.95
			Flooded >30 days	1.09		1.24	3.10	1.29

Note: 1) Adjusted daily emission factor (EF_i) for continuously flooded of which the field is non-flooded in pre-season for less than 180 days with no organic amendment is 2.32. (For EF_i, EF_c(2.32) is multiplied by SF_w(1) and SF_p(1).)

2) Adjusted daily emission factor (EF_i) for continuously flooded of which the field is non-flooded in pre-season for less than 180 days with organic amendment (rice and/or barley straw) is 5.80. (For EF_i, EF_c(2.32) is multiplied by SF_w(1), SF_p(1) and SF_o(2.5).)

Country-specific factors used to calculate CH_4 emission factors taking into account water regimes and organic amendments in irrigated field are as follows.

○ Baseline emission factor for continuously flooded fields without organic amendment (EF_c)

Country-specific emission factor was developed for a baseline emission factor for continuously flooded fields without organic amendment as shown in Table 5-27.

| Table 5-27 | Baseline Emission Factor for Continuously Flooded Fields without Organic Amendment (EF_c)

Emission Factor (EF_c)	EF Source
2.32 kg CH_4/ha/day	CS[1] (Developed in 2014)

Note: 1) Baseline emission factors are developed based on data on changes in CH_4 emissions from continuously flooded fields to which the recommended amount of chemical fertilizer was applied over a span of three years in four cities of *Daegu*, *Gwangju*, *Hwaseong* and *Jinju*. (Source: National Institute of Agricultural Sciences, 2013)

○ Scaling factor per water regimes before and during the rice cultivation period

As CH_4 emissions vary depending on water regimes before and during the rice cultivation period, country-specific factors (SF_p, SF_w) were developed to reflect differences in management practices. For pre-season, scaling factors were developed for each category of (i) non-flooded for less than 180 days, (ii) non-flooded for over 180 days, and (iii) flooded for over 30 days. For each category of growing season, country-specific factors are available for (i) continuously flooded, (ii) single aeration for less than 1 week, (iii) single aeration for 1-2 weeks, and (iv) multiple aeration.

| Table 5-28 | Scaling Factors per Water Regimes Before and During Rice Cultivation Period (SF_p, SF_w)

Water Regime			Scaling Factor	SF Source
Before cultivation (SF_p)	Non-flooded<180 days		1.00	CS[1]
	Non-flooded>180 days		0.80	
	Flooded>30 days		1.09	
During cultivation (SF_w)	Continuously flooded		1.00	CS[2]
	Intermittently flooded	Single aeration	0.83 (For less than 1 week)	
			0.66 (For 1-2 weeks)	
		Multiple aeration	0.49 (For over 2 weeks)	

Note: 1) Using the results of a regression analysis on changes in CH_4 emissions depending on water practices in the 2010 to 2012 period, scaling factors were developed in 2014 based on the ratio of CH_4 emissions from fields that were non-flooded for less than 180 days before growing season to (i) that from fields that were non-flooded for more than 180 days, and (ii) that from fields that were flooded for more than 30 days before growing season.

2) Using the results of a regression analysis on changes in CH_4 emissions depending on water practices in the 2010 to 2012 period, scaling factors were developed in 2014 based on the ratio of CH_4 emissions from continuously flooded during growing season to that from intermittently flooded fields depending on the number of aeration days.

Source: *2013 Country-Specific Emission Factors*, Greenhouse Gas Inventory and Research Center of Korea (GIR)

○ Scaling factor for organic amendments

Organic matters used as amendments in ROK include straw (rice, barley) and green manure. Accordingly, scaling factors (SF_o) for each type of organic matter were developed. As the likely level of other types of organic amendments applied such as compost and farm yard manure was insignificant based on expert judgment, relevant activity data were not considered.

| Table 5-29 | Scaling Factor for Organic Amendments (SF_o)

Organic Matter	Amount applied	Scaling Factor (SF_o)	SF Source
Straw (Rice, barley)	6 Mg/ha	2.5	CS[1)]
Green manure	0.0685 Mg/ha	1.045	

Note: 1) Country-specific scaling factors for straw and green manure were developed in 2014.

5.4.1.2.3 Activity Data

Cultivation area of paddy rice used as activity data for irrigated field was categorized by water regimes before and during cultivation period. It was again subcategorized by types of organic matter such as rice and barley straw and green manure applied to the field. Cultivation area of other cereal crops was included in the cultivation area of paddy rice due to double cropping of rice and barley in ROK.

| Table 5-30 | Irrigated Rice Field Area per Water Regime and Organic Amendments

(Unit: 1000 ha)

Organic Amendments	Water Regime	Before cultivation	1990	2000	2010	2018	2021	2022
With organic amendments	Continuously flooded	Non-flooded<180 days	74.6	66.2	59.6	47.3	34.8	29.3
		Non-flooded>180 days	2.9	2.6	2.3	0.1	0.2	0.2
		Flooded>30 days	8.0	7.1	6.4	11.0	8.5	8.7
	Intermittently flooded : single aeration ▶ For less than 1 week ▶ For 1-2 weeks	Non-flooded<180 days	375.7	324.1	289.3	188.6	135.8	115.4
		Non-flooded>180 days	14.6	12.6	11.2	0.5	0.8	0.6
		Flooded>30 days	40.5	35.0	31.2	43.4	33.1	34.4
	Intermittently flooded : multiple aeration	Non-flooded<180 days	132.5	114.3	102.1	121.1	121.2	109.3
		Non-flooded>180 days	5.1	4.4	4.0	0.3	0.7	0.6
		Flooded>30 days	14.3	12.3	11.0	26.9	29.6	33.0
Without organic amendments	Continuously flooded	Non-flooded<180 days	71.7	58.8	48.5	36.3	37.4	37.4
		Non-flooded>180 days	2.8	2.3	1.9	0.1	0.2	0.2

Organic Amendments	Water Regime	Before cultivation	1990	2000	2010	2018	2021	2022
		Flooded>30 days	7.7	6.3	5.2	8.5	9.2	11.5
	Intermittently flooded : single aeration ▶ For less than 1 week ▶ For 1–2 weeks	Non–flooded<180 days	331.3	271.9	224.2	138.3	137.5	138.3
		Non–flooded>180 days	12.8	10.5	8.7	0.4	0.8	0.8
		Flooded>30 days	35.7	29.3	24.2	31.8	34.0	42.5
	Intermittently flooded : multiple aeration	Non–flooded<180 days	116.9	95.9	79.1	88.7	122.9	132.7
		Non–flooded>180 days	4.5	3.7	3.1	0.2	0.7	0.7
		Flooded>30 days	12.6	10.4	8.5	19.7	30.5	41.4
Total			1,264.3	1,067.9	920.5	763.3	737.7	737.1

The total area of irrigated rice paddy field in 2022 was 737,100 hectares. The area with single aeration was 332,000 hectares, representing 45 percent of the total irrigated field area while multiple aeration area was 317,700 hectares and continuously flooded area of 87,400 hectares which accounted for 43.1 percent and 11.9 percent respectively.

Irrigated rice field area can also be divided by areas with and without organic amendments. The area without organic amendments was 405,600 hectares while that with amendments was 331,500 hectares, accounting for 55 percent and 45 percent respectively.

| Table 5-31 | Irrigated Rice Field Area per Type of Organic Amendments (2022)

(Unit: 1000 ha)

Water Regime				Without organic amendment (SF_p)	With organic amendment (SF_o)		Total	
During cultivation			Before cultivation		Straw (Rice, barley)	Green manure		
Continuously flooded			Non-flooded <180 days	37.4	28.2	1.2	67.9	87.4
			Non-flooded >180 days	0.2	0.2	0.01	0.4	
			Flooded>30 days	11.5	8.4	0.3	20.3	
Intermittently flooded	Intermittently flooded : single aeration	Aeration for less than 1 week	Non-flooded <180 days	29.6	23.4	0.9	53.9	332.0
			Non-flooded >180 days	0.2	0.1	0.005	0.3	
			Flooded>30 days	9.3	7.1	0.3	16.7	
		Aeration for 1-2 weeks	Non-flooded <180 days	108.7	87.8	3.3	199.9	
			Non-flooded >180 days	0.6	0.5	0.02	1.1	
			Flooded>30 days	33.2	26.0	1.0	60.2	
	Intermittently flooded : multiple aeration	Aeration for over 2 weeks	Non-flooded <180 days	132.7	105.2	4.1	241.9	317.7
			Non-flooded >180 days	0.7	0.6	0.02	1.3	
			Flooded>30 days	41.4	31.8	1.2	74.4	
Total				405.6	331.5		737.1	

Note: The average value of rice cultivation area over a span of three years (Inventory year *t*, *t*-1, *t*-2) were used as activity data.

Statistics and methodology used to disaggregate and calculate the irrigated rice field area are as follows.

○ Cultivation area

Cultivation area of paddy rice was based on data from the *Agricultural Area Statistics*.

○ Fraction of rice cultivation area per water regimes before and during rice cultivation

Data on rice cultivation area fractions before cultivation from 1990 to 2022 were based on *Annual Agriculture, Forestry and Fisheries Survey*. Since the survey has been conducted since 2011, a surrogate data method was applied for 1990 through 2009 using data from 2011 in accordance with the *2006 IPCC Guidelines*.

Data on fractions of rice cultivation area per water regime during cultivation were based on *Census of Agriculture, Forestry and Fisheries* for the year 2010, and on *Annual Agriculture, Forestry and Fisheries Survey* from 2011 onward. Since data on rice cultivation area during cultivation have been collected since 2010, a surrogate data method was applied for the 1990 through 2009 time series using data for 2010 based on expert judgment. For the cultivation area in 2015 and 2020, data were obtained by interpolation.[22]

| Table 5-32 | Rice Cultivation Area per Water Management Practice

(Unit: %)

Water Regime			1990	2000	2010	2018	2021	2022
Before cultivation	Non-flooded<180 days		87.22	87.22	87.22	84.18	77.21	71.76
	Non-flooded>180 days		3.38	3.38	3.38	0.13	0.47	0.35
	Flooded>30 days		9.41	9.41	9.41	15.69	22.32	27.89
During cultivation	Continuously flooded		13.67	13.67	13.67	12.66	12.06	11.71
	Intermittently flooded	Single aeration (<1 week)	19.80	19.80	19.80	9.50	9.48	10.48
		Single aeration (1-2 weeks)	43.38	43.38	43.38	38.70	36.21	31.92
		Multiple aeration (2-3 weeks)	22.29	22.29	22.29	38.41	41.72	45.49
	Drought-prone[1]		0.85	0.85	0.85	0.73	0.53	0.40

Note: 1) Refers to cultivation area of Rain-fed (3.C.2.) paddy fields

○ Fraction of rice cultivation area with and without organic amendments (Rice straw)

Data on fractions of rice cultivation area with and without rice straw as organic amendment were based on *Annual Agriculture, Forestry and Fisheries Survey*. Since data on cultivation area involving organic amendments have been available since 2017, linear interpolation method was used to determine values for the 1991 through 2016 time series using data for 1990 and 2017. For 2020, the fraction was determined by interpolation.

| Table 5-33 | Cultivation Area with and without Rice Straw as Organic Amendment

(Unit: %)

Organic Amendment (Rice straw)	1990[1]	2000	2010	2018	2021	2022
With amendment	50.00	52.23	54.47	55.62	43.95	36.78
Without amendment	50.00	47.77	45.53	44.38	56.05	63.22

Note: 1) A fraction of the area with rice straw to the area without rice straw in 1990 were based on expert judgment.

22) *Annual Agriculture, Forestry and Fisheries Survey* (KOSTAT) is not conducted in the years in which *Census of Agriculture, Forestry and Fisheries* (KOSTAT) is conducted. Since the *Census* is conducted every five years and does not collect some data (e.g. rice cultivation area per water regime during the growing season) which are covered in the *Annual Survey*, cultivation areas in 2015 and 2020, in which the *Census* was conducted, were estimated by interpolation. The *Census* collected respective data in 2010 but not in 2015 and 2020.

- Fraction of rice cultivation area with organic amendments (Barley straw)

Fraction of rice cultivation area with barley straw as organic amendments was calculated based on *Annual Agriculture, Forestry and Fisheries Survey*. Since data on cultivation area involving organic amendments have been available since 2017, a surrogate data method was used for 1990 through 2016 using data for 2017 based on expert judgment. For 2020, the fraction was determined by interpolation.

| Table 5-34 | Cultivation Area with Barley Straw as Organic Amendment

(Unit: %)

Organic Amendment (Barley straw)	1990	2000	2010	2018	2021	2022
With amendment	47.19	47.19	47.19	46.03	64.02	68.63

- Fraction of rice cultivation area with organic amendments (Green manure)

Data on cultivation area with green manure as organic amendment were based on *Annual Agriculture, Forestry and Fisheries Survey*. Since such data were collected since 2010, a surrogate data method was used for the 1990 through 2009 period using data for 2010 based on expert judgment. For 2015 and 2020, the fraction was determined by interpolation.

| Table 5-35 | Cultivation Area with Green Manure as Organic Amendment

(Unit: %)

Organic Amendment (Green manure)	1990	2000	2010	2018	2021	2022
With amendment	1.93	1.93	1.93	1.70	1.71	1.71

| Table 5-36 | Activity Data Source for Rice Cultivation

Period	Activity Data	Name of Statistics	Published by	Gas
1990-2022	Cultivation area of paddy rice	*Agricultural Area Statistics*	Statistics Korea (KOSTAT)	CH_4
	Rice cultivation area fractions before and during cultivation, rice cultivation area fractions with and without organic amendments	*Annual Agriculture, Forestry and Fisheries Survey*		
2010	Rice cultivation area fractions during cultivation	*Census of Agriculture, Forestry and Fisheries*		

5.4.1.3 Uncertainty and Time-series Consistency

5.4.1.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

5.4.1.3.2 Time-series Consistency

CH_4 emissions from irrigated fields were estimated using methodology and emissions factors consistently from 1990 through 2022 to ensure time series consistency. Data on rice cultivation area for the 1990 through 2022 time series were from *Agricultural Area Statistics*. For disaggregated data on water regimes and organic amendments, activity data including country-specific parameters were based on *Annual Agriculture, Forestry and Fisheries Survey* and *Census of Agriculture, Forestry and Fisheries*. To maintain time-series consistency, a surrogate data method and interpolation were applied.

5.4.1.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

5.4.2 Rain-fed (3.C.2.)

5.4.2.1 Category Description

2022	Gas	Methodology	Emission Factor	Activity Data
	CH_4	Tier 1, 2	CS, D	Cultivation area (Rice, barley, wheat)

Rain-fed field refers to fields in which water supply solely depends on precipitation which is divided into two sub-categories : Flood-prone (3.C.2.a.)[23] and Drought-prone (3.C.2.b.). As drought occurs during every cropping season in ROK, emissions from rain-fed field were reported under the drought-prone.

In 2022, emissions of 14 kt of CO_2-eq were produced from rain-fed fields, representing a 14.3 percent decrease from 2021 and a 67.9 percent decrease from 1990.

| Table 5-37 | Emissions from Rain-fed Fields

(Unit: kt CO_2-eq)

Field Type	1990	2000	2010	2018	2021	2022
Rain-fed	43	37	32	25	16	14

23) Rice cultivation that relies on rainfall for water for which the field is flood prone (3.C.2.a.) is not practiced in ROK.

5.4.2.2 Methodology

5.4.2.2.1 Method

CH_4 emissions from rain-fed fields were estimated using the Tier 1 method in accordance with the *2006 IPCC Guidelines* following the same method used to calculate emissions from irrigated fields as described in Section 5.4.1.2.1.

5.4.2.2.2 Emission Factor

CH_4 emission factors for rain-fed fields were calculated reflecting water regimes and organic amendments in accordance with the method presented in the *2006 IPCC Guidelines*. Country-specific factors were used for scaling factors per water regimes *before* cultivation and for organic amendments to calculate CH_4 emission factors while IPCC default values were used for scaling factors per water regime *during* cultivation period.

| Table 5-38 | Daily CH_4 Emission Factor (EF_i) in Rain-fed Field

Water Regime				Without Organic Matter Amendment Emission Factor(EF_i) ($EF_i = EF_c \times SF_w \times SF_p$)	With Organic Matter Amendment Emission Factor(EF_i) ($EF_i = EF_c \times SF_w \times SF_p \times SF_o$)	
During cultivation	Before cultivation	Water regimes *before* cultivation (SF_p)	Water regimes *during* cultivation (SF_w)	No organic amendments (EF_c)	Straw (Rice, barley) (SF_o)	Green manure (SF_o)
				2.32	2.5	1.045
Drought-prone	Non-flooded<180 days	1	0.25 1)	0.58 2)	1.45 3)	0.61
	Non-flooded>180 days	0.8		0.46	1.16	0.48
	Flooded>30 days	1.09		0.63	1.58	0.66

Note: 1) *2006 IPCC Guidelines, Vol.4, Ch.5, Table 5.12*

2) EF_i for drought-prone of which the field is non-flooded in pre-season for less than 180 days with no organic amendment is 0.53. (To obtain EF_i, EF_c(2.32) is multiplied by SF_w(0.25) and SF_p(1).)

3) EF_i for drought-prone of which the field is non-flooded in pre-season for less than 180 days with organic amendment (rice, barley straw) is 1.45. (To obtain EF_i, EF_c(2.32) is multiplied by SF_w(0.25), SF_p(1) and SF_o(2.5).

5.4.2.2.3 Activity Data

Activity data used for rain-fed field emissions were the same as for irrigated field as described in Section 5.4.1.2.3. The water regime for the majority of the rain-fed field area was non−flooded for less than 180 days before cultivation, and areas with and without organic amendments accounted for 45.7 percent and 54.3 percent respectively.

| Table 5−39 | Rain−fed Area per Water Regime and Organic Amendments

(Unit: 1000 ha)

Organic Amendment	Before cultivation water regime	1990	2000	2010	2018	2021	2022
With organic amendments (SF_o)	Non−flooded<180 days	5.1	4.4	3.9	2.8	1.7	1.3
	Non−flooded>180	0.2	0.2	0.2	0.01	0.01	0.01
	Flooded>30 days	0.5	0.5	0.4	0.7	0.4	0.4
Without organic amendments (SF_p)	Non−flooded<180 days	4.5	3.7	3.0	2.1	1.7	1.5
	Non−flooded>180 days	0.2	0.1	0.1	0.01	0.01	0.01
	Flooded>30 days	0.5	0.4	0.3	0.5	0.4	0.5
Total		10.9	9.2	7.9	6.1	4.2	3.7

| Table 5−40 | Rain−fed Area per Type of Organic Amendment (2022)

(Unit: 1000 ha)

Field Type	Before cultivation water regime	Without organic amendments	With organic amendments		Total
			Straw (Rice, barley)	Green manure	
Rain−fed	Non−flooded<180 days	1.5	1.3	0.05	2.8
	Non−flooded>180 days	0.01	0.01	0.0003	0.02
	Flooded>30 days	0.5	0.4	0.01	0.9
Total		2.0	1.6	0.1	3.7

5.4.2.3 Uncertainty and Time−series Consistency

5.4.2.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

5.4.2.3.2 Time−series Consistency

CH_4 emissions from rain−fed fields were estimated using methodology and emissions factors consistently from 1990 through 2022. Activity data including country−specific parameters were based on *Annual Agriculture, Forestry and Fisheries Survey and Census of Agriculture, Forestry and Fisheries*. To maintain time−series consistency, a surrogate data method and interpolation were applied.

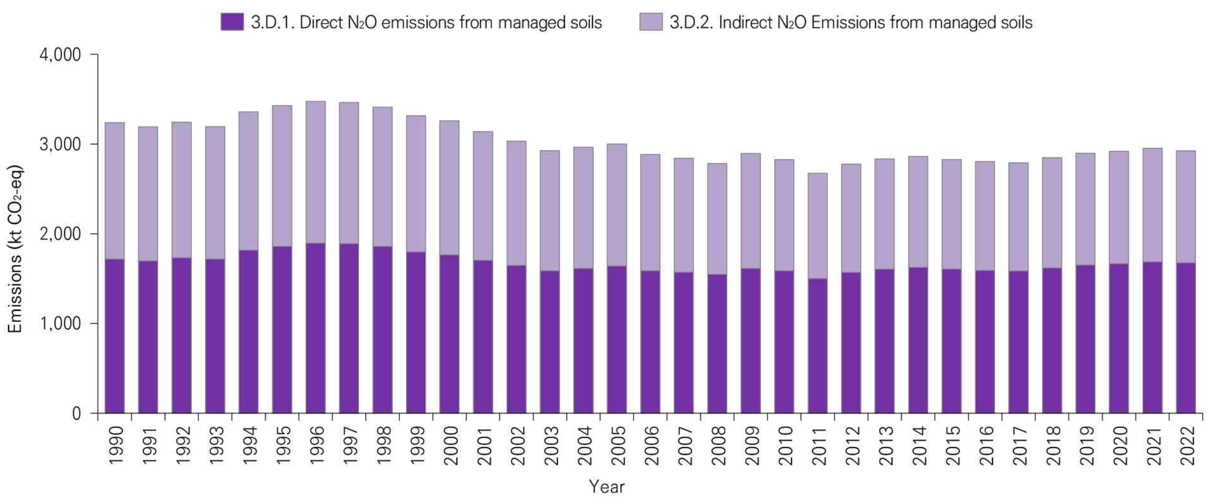
5.4.2.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

5.5 Agricultural Soils (3.D.)

Nitrous oxide (N_2O) emissions from agricultural soils are divided into two sub-categories: Direct N_2O emissions from managed soils (3.D.1.) where nitrogen applied to the soil is directly emitted at the same location without being moved elsewhere; and Indirect N_2O emissions from managed soils (3.D.2.). Direct N_2O emissions are produced when mineral nitrogen in soils is converted to N_2O and emitted at the site of agricultural activities whereas indirect emissions of N_2O are emitted by either atmospheric deposition or leaching and runoff into groundwater and surface water.

In 2022, N_2O emissions from agricultural soil management were 2,924 kt CO_2-eq which include direct N_2O emissions of 1,677 kt CO_2-eq and indirect N_2O emissions of 1,248 kt CO_2-eq, representing 57.3 percent and 42.7 percent respectively.



| Figure 5-6 | Trends in Emissions from Agricultural Soils (1990-2022)

| Table 5-41 | N_2O Emissions from Agricultural Soils

(Unit: kt CO_2-eq)

Sub-category	1990	2000	2010	2018	2021	2022
Direct N_2O emissions	1,719	1,767	1,588	1,621	1,689	1,677
Indirect N_2O emissions	1,520	1,493	1,239	1,228	1,263	1,248
Total	3,239	3,260	2,827	2,849	2,953	2,924

5.5.1 Direct N_2O emissions from managed soils (3.D.1.)

5.5.1.1 Category Description

	Gas	Methodology	Emission Factor	Activity Data
2022	N_2O	Tier 2	CS, D	Nitrogen input (Organic and inorganic fertilizers, crop residues)

Sources of nitrogen input that led to direct emissions include Inorganic nitrogen (N) fertilizers (3.D.1.a.) such as synthetic fertilizers, and Organic nitrogen (N) fertilizers (3.D.1.b.) such as animal manure. Mineral nitrogen is also made by retention of Crop residues (3.D.1.d.). Residues that are not returned to the soil or used as animal feed are burnt of which emissions are reported under Field burning of agricultural residues (3.F.).[24)]

In 2022, direct N_2O emissions were 1,677 kt CO_2−eq which represented a decrease of 0.7 percent from 2021. Organic N fertilizers contributed the largest share of total direct N_2O emissions in agricultural soils of 62.0 percent with 1,039 kt CO_2−eq followed by inorganic N fertilizers of 510 kt CO_2−eq and crop residues of 128 kt CO_2−eq, representing 30.4 percent and 7.6 percent respectively.

| Table 5−42 | Direct N_2O Emissions from Managed Soils

(Unit: kt CO_2−eq)

Sub−category	1990	2000	2010	2018	2021	2022
Inorganic N fertilizers	1,035	891	532	504	527	510
Organic N fertilizers	554	741	918	988	1,024	1,039
Crop residues	130	134	138	129	138	128
Total	1,719	1,767	1,588	1,621	1,689	1,677

5.5.1.2 Methodology

5.5.1.2.1 Method

Direct N_2O emissions from managed soils were calculated in accordance with the *2006 IPCC guidelines* using the Tier 2 method by multiplying the amount of nitrogen applied to agricultural soils by either IPCC default emission factors or country−specific

24) Emissions from Urine and dung deposited by grazing animals (3.D.1.c.) were included in Animal manure applied to soils (3.D.1.b.i.). Emissions from subcategories of Mineralization/immobilization associated with loss/gain of soil organic matter (3.D.1.e.) and Cultivation of organic soils (3.D.1.f.) were not estimated as there is no relevant data on 3.D.1.e. and no organic soils in ROK.

values. Emissions were estimated per source of nitrogen input which includes inorganic N fertilizers, organic N fertilizers and crop residue as suggested by the *2006 IPCC Guidelines*.

Direct N_2O emissions from managed soils		
$$N_2O_{Direct} - N = \sum_i (F_{SN} + F_{ON})_i \times EF_{1i} + (F_{CR} + F_{SOM}) \times EF_1 + N_2O\text{-}N_{OS} + N_2O - N_{PRP}$$		
$N_2O_{Direct}-N$	:	annual direct N_2O emissions from agricultural soils [kg N_2O/yr]
N_2O-N_{OS}	:	annual direct N_2O-N emissions from managed organic soils [kg N_2O-N/yr][25]
N_2O-N_{PRP}	:	annual direct N_2O-N emissions from urine and dung inputs to grazed soils [kg N_2O-N/yr][26]
44/28	:	N_2O conversion factor [kg N_2O-N/yr]
F_{SN}	:	annual amount of synthetic fertiliser N applied to soils [kg N/yr]
F_{ON}	:	annual amount of animal manure, compost, sewage sludge and other organic N additions applied to soils [kg N/yr]
F_{CR}	:	annual amount of N in crop residues (above-ground and below-ground), including N-fixing crops, and from forage/pasture renewal, returned to soil [kg N/yr]
F_{SOM}	:	annual amount of N in mineral soils that is mineralised, in association with loss of soil C from soil organic matter as a result of changes to land use or management [kg N/yr][27]
EF_{1i}	:	emission factor for N_2O emissions from crop i [kg N_2O-N/kg N input]
EF_1	:	emission factor for N_2O emissions from N inputs [kg N_2O-N/kg N input]

Source: *2006 IPCC Guidelines, Vol.4, Ch.11, Equation 11.2.*

5.5.1.2.2 Emission Factor

1) Inorganic N fertilizers (3.D.1.a.)

N_2O emission factors for inorganic nitrogen fertilizers are distinguished based on characteristics of crops to which inorganic nitrogen is applied. For paddy rice, a default emission factor provided by *the 2006 IPCC guidelines* was used while emissions from upland crops were calculated using country-specific emission factors.

25) Direct N_2O-N emissions(N_2O-N_{OS}) from annually managed organic soils were not estimated as the area of organic soil in ROK is 409 ha, accounting for 0.004 percent of the total land area with no available activity data.

26) Direct N_2O-N emissions(N_2O-NP_{RP}) from manure inputs to grazed soils were included in Animal manure applied to soils (3.D.1.b.i.).

27) Annual amount of N in mineral soils that is mineralised in association with loss of soil C from soil organic matter as a result of changes to land use or management(F_{SOM}) was not estimated due to lack of data.

| Table 5-43 | Crop-specific N_2O Emission Factors(EF_{1i}) for Managed Soils

(Unit: kg N_2O-N/kg N)

Crop Type(i)		Emission Factor	EF Source
Rice (EF_{1FR})		0.0030	*2006 IPCC Guidelines*
Upland Crops	Pepper	0.0086	CS (Developed in 2014)
	Soybean	0.0119	
	Potato	0.0049	
	Spring cabbage	0.0056	
	Autumn cabbage	0.0058	
	Other upland crops	0.00596	

Source: *2006 IPCC Guidelines, Vol.4, Ch.11, Table 11.1.*

2) Organic N fertilizer (3.D.1.b.)

For direct N_2O emissions from nitrogen mineralized from organic fertilizers and soil carbon losses, default emission factors from the *2006 IPCC Guidelines* were used.

| Table 5-44 | Direct N_2O Emission Factors per Source of Nitrogen Input Source

(Unit: kg N_2O-N/kg N)

Nitrogen Source	Emission Factor	EF Source
Nitrogen from organic amendments (EF_{1i})	0.01	*2006 IPCC Guidelines*
Nitrogen mineralized from loss of soil organic carbon (EF_1)		

Source: *2006 IPCC Guidelines, Vol.4, Ch.11, Table 11.1.*

3) Crop residues (3.D.1.d.)

N_2O emission factor used for crop residues was the same for inorganic nitrogen fertilizer (3.D.1.a.).

5.5.1.2.3 Activity Data

1) Inorganic N fertilizer (3.D.1.a.)

To estimate emissions from inorganic fertilizers, data on the amount applied per crop are required. National statistics provide the total amount of fertilizer (nitrogen fertilizers) applied to agricultural soils, nitrogen content in fertilizers, and fertilizer consumption per unit area by crop which were used to calculate the amount of inorganic nitrogen inputs by crop. As data on inorganic fertilizers used for some crops of which cultivated area is insignificant are not available, nitrogen inputs were calculated based on the area of cultivation.[28] There were also some crops of which inorganic fertilizer consumption was calculated by multiplying the cultivated area by recommended quantity of inorganic fertilizers per unit area per crop presented in *Fertilizer Application Guidelines*. Annual nitrogen inputs from inorganic fertilizers per crop were calculated as shown in Table 5-45.

| Table 5-45 | Annual Nitrogen Input from Inorganic Fertilizers (2022)

Parameter		Unit	Paddy rice	Upland Crops					
				Red pepper	Soybean	Potato	Spring cabbage	Autumn cabbage	Other[1]
Cultivated Area (A)		kha	726.7	33.5	75.7	18.6	9.9	14.0	NA
Nitrogen Fertilizer	Amount applied per unit area (B)	kg/10a	2.56	190	31	137	320	320	
	Nitrogen content (C)	NA	0.47	NA					
Compound Fertilizer	Amount applied per unit area (D)	kg/10a	53.41						
	Nitrogen content (E)	NA	0.2						
Estimated annual nitrogen input from inorganic fertilizers[2] • Paddy rice =(A×B×C)+(A×D×E)×10 • Upland crops=(A×B)×10 • Other=Total - Rice - Upland crops (chili pepper, soybean, potato and cabbages)		kt	86.3	6.4	2.4	2.5	3.2	4.5	122.6
Total nitrogen input from inorganic fertilizers		kt	227.8						

Note: 1) Upland crops of which country-specific N_2O emission factors are not available are categorized as 'Other'. Inorganic fertilizer consumption for 'other' category was estimated by deducting nitrogen input of five varieties of upland crop from total nitrogen input.

2) The average of nitrogen input over a span of three years (Inventory year *t*, *t*-1, *t*-2) were used as activity data.

28) Activity data on inorganic fertilizer consumption per crop are disaggregated based on crops of which the quantity of inorganic fertilizer is provided in the 5th Edition of the *Fertilizer Application Guidelines* which include pepper, soybean, potato and cabbages. For all other crop varieties, fertilizer input was estimated based on the remaining amount of the total fertilizer consumption.

| Table 5-46 | Nitrogen Input from Inorganic Fertilizers per Crop

(Unit: kt)

Crop Type		1990	2000	2010	2018	2021	2022
Paddy	Rice	200.3	176.4	116.7	93.4	86.9	85.8
Upland Crops	Pepper	15.1	14.6	9.8	6.5	6.9	6.8
	Soybean	6.1	3.5	2.6	1.9	2.1	2.1
	Potato	3.2	3.5	2.8	2.8	3.0	2.7
	Spring cabbage	6.4	8.7	5.1	3.4	3.3	3.3
	Autumn cabbage	6.4	4.7	4.6	4.1	4.1	4.4
	Other	267.3	226.7	124.7	133.5	144.9	138.5
	Subtotal (Upland crops)	304.5	261.7	149.6	152.2	164.4	157.9
Total		504.8	438.1	264.4	245.6	251.2	243.6

Note: The average of nitrogen input over a span of three years (Inventory year t, $t-1$, $t-2$) were used as activity data.

| Table 5-47 | Activity Data Source for Nitrogen Input from Inorganic Fertilizers

Period	Activity Data	Name of Statistics	Published by
1988-2022	Cultivated area per crop variety	*Agricultural Area Statistics*	Statistics Korea (KOSTAT)
1988-2022	Fertilizer[1)] input per unit area	*Agricultural and Livestock Production Cost Survey*	Statistics Korea (KOSTAT)
	Nitrogen fertilizer consumption	*Statistical Yearbook of Agriculture, Food and Rural Affairs*	Ministry of Agriculture, Food and Rural Affairs (MAFRA)
	Nitrogen content of fertilizer[1)]	*Fertilizer Yearbook*	Korea Fertilizer Industry Association (KFA)

Note: 1) Synthetic nitrogen fertilizers and compound fertilizers

2) Organic N fertilizer (3.D.1.b.)

In ROK, animal manure (F_{AM}) is the only source of nitrogen input for organic nitrogen fertilizer (F_{ON})[29)]. The amount of nitrogen applied to managed soils from animal manure was calculated by deducting the fraction of nitrogen loss in the manure management system ($Frac_{LossMS}$) from nitrogen content in animal manure which was obtained by multiplying the number of animals per livestock species by nitrogen input from manure of respective species.

29) Emissions from sources including sewage sludge applied to soils (3.D.1.b.ii.) and other organic fertilizers applied to soils (3.D.1.b.iii.) were not estimated due to lack of activity data.

Nitrogen from organic N fertilizer applied to soils (F_{ON})		
$$F_{ON} = F_{AM} + F_{SEW} + F_{COMP} + F_{OOA}$$ $$F_{AM} = N_{MMS\,Avb} \times [1 - (Frac_{FEED} + Frac_{FUEL} + Frac_{CNST})]$$ $$N_{MMS\,Avb} = \sum_{s}\left\{\sum_{(T)}\left[(N_{(T)} \times Nex_{(T)} \times MS_{(T,S)}) \times \left(1 - \frac{Frac_{LossMS}}{100}\right)\right] + [N_{(T)} \times MS_{(T,S)} \times N_{beddingMS}]\right\}$$		
F_{ON}	:	total annual amount of organic N fertiliser applied to soils other than by grazing animals [kg N/yr]
F_{AM}	:	annual amount of animal manure N applied to soils [kg N/yr]
F_{SEW}	:	annual amount of total sewage N that is applied to soils [kg N/yr] (coordinate with waste sector to ensure sewage N is not double-counted)
F_{COMP}	:	annual amount of total compost N applied to soils [kg N/yr] (coordinate with waste sector to ensure sewage N is not double-counted)
F_{OOA}	:	annual amount of other organic amendments used as fertiliser (rendering waste, guano, brewery waste, etc)[kg N/yr]
$N_{MMS\ Avb}$[1]	:	amount of managed manure nitrogen available for application to managed soils or for feed, fuel, or construction purposes [kg N/yr]
$Frac_{FEED}$	:	fraction of managed manure used for feed
$Frac_{FUEL}$	:	fraction of managed manure used for fuel
$Frac_{CNST}$	:	fraction of managed manure used for construction
$N_{(T)}$	:	number of head of livestock species/category T in the country [head]
$Nex_{(T)}$	:	annual average N excretion per head of species/category *T* in the country [kg N/head/yr]
$MS_{(T,S)}$	:	fraction of total annual nitrogen excretion for each livestock species / category *T* that is managed in manure management system S in the country
$Frac_{LossMS}$	:	amount of managed manure nitrogen for livestock category *T* that is lost in the manure management system *S* [%]
$N_{beddingMS}$	:	amount of nitrogen from bedding [kg N/animal/yr]
S	:	manure management system
T	:	species/category of livestock

Note: 1) *2006 IPCC Guidelines, Vol.4, Ch.10, Equation 10.34*
Source: *2006 IPCC Guidelines, Vol.4, Ch.11, Equation 11.3, Equation 11.4*

| Table 5-48 | Nitrogen Input from Livestock Manure

(Unit: kt)

Animal Type	1990	2000	2010	2018	2021	2022
Subtotal (Cattle)	82.7	90.2	109.1	112.1	123.0	126.0
Dairy cows	42.7	46.2	37.2	34.7	34.3	33.4
Subtotal (Non-dairy cattle)	40.0	44.0	72.0	77.4	88.7	92.6
Hanwoo (Korean native cattle)	35.0	38.0	67.3	73.0	83.6	87.5
Beef cattle	5.0	5.9	4.7	4.4	5.1	5.0
Subtotal (Swine)	30.1	53.8	63.6	73.3	72.3	71.7
Swine (Market)	21.2	40.6	49.7	58.3	57.8	57.4
Swine (Breeding)	8.9	13.3	13.9	15.0	14.6	14.3
Subtotal (Poultry)	18.4	28.9	44.3	49.0	47.7	49.0
Layer hens	10.5	13.2	16.6	19.0	18.1	19.2
Broiler	7.6	13.9	22.6	26.5	26.9	26.8
Duck	0.2	1.8	5.0	3.6	2.6	3.1
Sheep	0.010	0.003	0.013	0.007	0.007	0.007
Goats	0.4	1.3	0.6	1.1	1.3	1.2
Horses	0.1	0.3	1.0	0.9	0.9	0.9
Deer	1.1	3.6	1.8	0.7	0.6	0.6
Total	133.0	178.0	220.5	237.2	245.8	249.4

Note: The average of nitrogen input over a span of three years (Inventory year *t*, *t*-1, *t*-2) were used as activity data.

| Table 5-49 | Nitrogen Loss per Livestock Species in Manure Treatment System ($Frac_{LossMS}$)

(Unit : %)

Animal Type		Manure Management System			
		Solid storage	Composting-in-vessel	Poultry manure with/without litter	Aerobic treatment
Cattle	Dairy cattle	40.0	40.0	NA	40.0
	Hanwoo (Korean native cattle)	50.0	50.0		50.0
	Beef cattle				
Swine	Market		48.0		48.0
	Breeding				
Poultry	Layer hens	NA	55.0		
	Broiler		50.0		
	Duck				
Sheep		15.0	NA[1]		
Goat					
Horses					
Deer					

Note: 1) All manure from sheep, goat, horse and deer were considered to be entirely composted by solid storage as there is no collection and treatment facility for respective animal types.

3) Crop residues (3.D.1.d.)

Following *the 2006 IPCC Guidelines,* the amount of nitrogen from crop residues returned to soils (F_{CR}) was calculated using the crop cultivation area as shown in Table 5-50. Residues of which nitrogen content were calculated were distinguished into above-ground and below-ground residues per crop variety.

N from crop residues returned to soils (F_{CR})

$$F_{CR} = \sum_T \left\{ \begin{array}{l} AG_{DM(T)} \times (Area_{(T)} - Area\,burnt_{(T)} \times CF) \times Frac_{Renew(T)} \times \\ [N_{AG(T)} \times (1 - Frac_{Remove(T)}) + R_{BG-BIO(T)} \times N_{BG(T)}] \end{array} \right\}$$

F_{CR}	:	annual amount of N in crop residues returned to soils annually
$AG_{DM(T)}$	:	above-ground residue building weight by crop T [Mg/ha]
$Area_{(T)}$	:	total annual area harvested of crop T
$Area\ burnt_{(T)}$	:	annual area of crop T burnt
CF	:	combustion factor
$Frac_{Renew(T)}$	:	fraction of total area under crop T that is renewed annually[30)]
N_{AG}	:	N content of above-ground residues for crop T
$Frac_{Remove}$	:	fraction of above-ground residues of crop T removed annually for purposes such as feed, bedding and construction[31)]
R_{BG-BIO}	:	ratio of aboveground biomass to below-ground biomass by crop
$N_{BG(T)}$	:	N content of below-ground residues for crop T
T	:	crop or forage type

Source: *2006 IPCC Guidelines, Vol.4, Ch.11, Equation 11.7A*

30) There is no activity data available on the total area of renewed crops ($Frac_{Renew(T)}$).

31) There is no activity data available on the above-ground residues of removed crops for purposes of feed, bedding and construction ($Frac_{Remove}$).

| Table 5-50 | Nitrogen Input from Crop Residues Returned to Soils (F_{CR})

(Unit: kt)

Crop Type	1990	2000	2010	2018	2021	2022
Rice	47.1	42.1	38.4	33.2	28.1	26.6
Barley	4.5	1.8	1.2	0.8	1.1	0.9
Wheat	0.01	0.03	0.2	0.2	0.1	0.2
Potato	0.9	1.1	0.9	0.9	1.0	0.9
Sweet potato	0.9	0.6	0.6	0.7	0.8	0.8
Maize	1.0	0.7	0.7	0.7	0.8	0.8
Pepper	0.9	1.6	1.4	1.0	1.1	1.1
Garlic	6.5	7.9	5.8	5.3	6.3	5.6
Onion	8.8	15.9	22.5	23.6	28.0	25.2
Sesame	0.3	0.2	0.1	0.1	0.1	0.1
Bean	2.3	1.2	1.1	0.8	1.0	1.2
Total	73.3	73.1	73.0	67.4	68.5	63.4

- Parameters used to estimate the annual amount of nitrogen in crop residues returned to soils (F_{CR})

For dry matter fraction of harvested product (*DRY*) and nitrogen content of above-ground and below-ground residues (N_{AG}, N_{BG}), default values from the *2006 IPCC Guidelines* were used. Ratios of crop residue dry matter returned to soils were obtained by using national data from *Annual Agriculture, Forestry and Fisheries Survey*. As such data have been collected since 2017, the 2017 values were applied for the 1990 through 2016 time series.

| Table 5-51 | Crop Residue Dry Matter Burnt and Returned to Soils (DRY)

(Unit: %)

Category	Crop Type	1990	2000	2010	2018	2021	2022
Residue dry matter burnt	Paddy rice	0.03	0.03	0.03	0.07	0.02	NO
	Barley	17.68	17.68	17.68	13.90	8.15	8.88
	Wheat[1)]	43.90	43.90	43.90	43.90	43.90	43.90
	Potato	7.56	7.56	7.56	4.94	2.74	1.42
	Sweet potato	8.45	8.45	8.45	4.70	4.07	5.80
	Maize[2)]	NE	NE	NE	NE	NE	NE
	Pepper	52.20	52.20	52.20	53.46	42.37	35.39
	Garlic	14.96	14.96	14.96	15.25	16.00	10.17
	Onion	9.99	9.99	9.99	10.90	7.39	5.36
	Sesame	50.79	50.79	50.79	50.03	44.20	40.81
	Pulses (Soybean)	40.16	40.16	40.16	42.69	29.61	20.99
Residue dry matter returned	Paddy rice	50.00	52.23	54.47	55.62	43.95	36.78
	Barley	47.19	47.19	47.19	46.03	64.02	68.63
	Wheat[1)]	39.04	39.04	39.04	39.04	39.04	39.04
	Potato	77.17	77.17	77.17	79.72	84.53	93.11
	Sweet potato	68.73	68.73	68.73	87.12	90.14	89.98
	Maize[2)]	100.00	100.00	100.00	100.00	100.00	100.00
	Pepper	41.09	41.09	41.09	40.09	52.86	60.03
	Garlic	74.03	74.03	74.03	77.88	74.98	74.47
	Onion	81.10	81.10	81.10	84.61	88.00	87.85
	Sesame	40.61	40.61	40.61	45.04	51.81	55.09
	Pulses (Soybean)	49.38	49.38	49.38	49.67	64.00	72.69

Note: 1) As wheat was not included in the *Annual Agriculture, Forestry and Fisheries Survey*, the *2010 Census of Agriculture, Forestry and Fisheries* was used to apply the fraction of wheat burning and that of wheat residue return in 2010 were applied for the entire time series based on expert judgment.

2) Maize was assumed to be fully returned to agricultural soils with no residues being burnt based on expert judgment.

| Table 5-52 | Parameters for Estimation of Nitrogen Added to Soils from Crop Residues

Crop Type	Dry Matter Fraction (DRY)	Above-Ground Residue Dry Matter ($AG_{DM(T)}$) ($AG_{DM(T)}$= $Crop_{(T)}$ * Slope + Intercept)		N Content of Above-Ground Residues (N_{AG})	Below-Ground to Above-Ground Biomass Ratio (R_{BG-BIO})	N Content of Below-Ground Residues (N_{BG})
		Slope	Intercept			
Rice	0.89	0.95	2.46	0.007	0.16	0.009
Barley	0.89	0.98	0.59	0.007	0.22	0.014
Wheat	0.89	1.51	0.52	0.006	0.24	0.009
Potato	0.22	0.1	1.06	0.019	0.2	0.014
Sweet potato	0.22	0.1	1.06	0.019	0.2	0.014
Maize	0.87	1.03	0.61	0.006	0.22	0.007
Pepper[1)]	0.87	1.03	0.61	0.006	0.22	0.007
Garlic	0.94	1.07	1.54	0.016	0.2	0.014
Sesame	0.9	0.36	0.68	0.010	0.19	0.01
Onion	0.94	1.07	1.54	0.016	0.2	0.014
Soybean	0.91	1.13	0.85	0.008	0.19	0.008

Note: 1) A default value for maize was used for pepper based on expert judgment as no default factor is provided in the *2006 IPCC Guidelines*.

Source: *2006 IPCC Guidelines, Vol.4, Ch.11, Table 11.2*

5.5.1.3 Uncertainty and Time-series Consistency

5.5.1.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

5.5.1.3.2 Time-series Consistency

Direct N_2O emissions from managed soils were estimated using methodology and emission factors consistently from 1990 through 2022 to ensure time series consistency. Data used for the cultivation area and production per crop type and livestock population were from *Livestock Statistics* while data on fractions of total annual nitrogen excretion as well as fractions of dry matter burnt and of returned to soils of crop residues were from *Annual Agriculture, Forestry and Fisheries Survey*.

5.5.1.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

5.5.2 Indirect N_2O Emissions from Managed Soils (3.D.2.)

5.5.2.1 Category Description

	Gas	Methodology	Emission Factor	Activity Data
2022	N_2O	Tier 1, 2	CS, D	Nitrogen input (Organic and inorganic fertilizer, crop residues)

Indirect emissions of N_2O are emitted from either Atmospheric deposition (3.D.2.a.) or Leaching and runoff (3.D.2.b.) into groundwater and surface water. According to the *2006 IPCC Guidelines*, emissions reported under atmospheric deposition are produced by volatilization of nitrogen as NH_3 and NO_x in the atmosphere or upon deposition whereas emissions that occur through leaching and runoff involve hydrological processes of nitrogen transported and subsequently converted to N_2O.

In 2022, indirect emissions of N_2O were 1,248 kt CO_2−eq which represented a decrease of 17.9 percent compared to 1990 levels. Emissions from leaching and run−off in 2022 contributed 75.2 percent of total indirect N_2O emissions in agricultural soils with 938 kt CO_2−eq while emissions through atmospheric deposition were 309 kt CO_2−eq, accounting for 24.8 percent.

| Table 5−53 | Indirect N_2O Emissions from Managed Soils

(Unit: kt CO_2−eq)

Sub−category	1990	2000	2010	2018	2021	2022
Atmospheric deposition	321	331	295	300	309	309
Nitrogen leaching and run−off	1,199	1,162	944	928	954	938
Total	**1,520**	**1,493**	**1,239**	**1,228**	**1,263**	**1,248**

5.5.2.2 Methodology

5.5.2.2.1 Method

1) Atmospheric deposition (3.D.2.a.)

Following the method in the *2006 IPCC Guidelines*, indirect N_2O emissions from atmospheric deposition were estimated by multiplying nitrogen from organic and inorganic fertilizer by fraction of volatilized nitrogen, and by N_2O emission factor.

Indirect N_2O emissions from atmospheric deposition

$$N_2O_{(ATD)} = [(F_{SN} \times Frac_{GASF}) + ((F_{ON} + F_{PRP}) \times Frac_{GASM})] \times EF_4 \times 44/28$$

$N_2O_{(ATD)}$	: annual amount of N_2O Emissions from atmospheric deposition [kg N_2O/yr]
F_{SN}	: annual amount of synthetic fertiliser N applied to soils [kg N/yr]
$Frac_{GASF}$	: fraction of synthetic fertiliser N that volatilises as NH_3 and NO_x [kg N v/kg N applied]
F_{ON}	: annual amount of managed animal manure, compost, sewage sludge and other organic N additions applied to soils [kg N/yr]
F_{PRP}	: annual amount of urine and dung N deposited by grazing animals on pasture, range and paddock [kg N/yr][32]
$Frac_{GASM}$	: fraction of applied organic N fertiliser materials (F_{ON}) and of urine and dung N deposited by grazing animals (F_{PRP}) that volatilises as NH_3, and NO_x [kg N volatilised/(kg N applied or deposited)]
EF_4	: emission factor for N_2O emissions from atmospheric deposition of N on soils and water surfaces [kg N−N_2O/(kg NH_3−N + NO_x−N volatilised)]
44/28	: N_2O conversion factor

Source: *2006 IPCC Guidelines, Vol.4, Ch.11, Equation 11.9*

2) Nitrogen leaching and run−off (3.D.2.b.)

In accordance with the method in the *2006 IPCC Guidelines,* emissions from nitrogen leaching and run−off were estimated by multiplying the annual amount of organic and inorganic fertilizer by fraction of nitrogen in managed soils that was lost through leaching and runoff ($Frac_{LEACH-(H)}$), and by N_2O emission factor.

32) No activity data is available for the annual amount of urine and dung nitrogen deposited by grazing animals on pasture, range and paddock in which leaching and runoff occurs (F_{PRP}).

Indirect N_2O emissions from nitrogen leaching and run-off

$$N_2O_{(L)} = [(F_{SN} + F_{ON} + F_{PRP} + F_{CR} + F_{SOM}) \times Frac_{\leq\ LEACH-(H)}] \times EF_5 \times 44/28$$

$N_2O_{(L)}$	annual amount of N_2O emissions due to nitrogen leaching and run-off [kg N_2O/yr]
F_{SN}	annual amount of synthetic fertiliser N applied to soils in regions where leaching/runoff occurs [kg N/yr]
F_{ON}	annual amount of managed animal manure, compost, sewage sludge and other organic N additions applied to soils in regions where leaching/runoff occurs [kg N/yr]
F_{PRP}	annual amount of urine and dung N deposited by grazing animals in regions where leaching/runoff occurs [kg N/yr][33]
F_{CR}	amount of N in crop residues (above- and below-ground), including N-fixing crops, and from forage/pasture renewal, returned to soils annually in regions where leaching/runoff occurs [kg N/yr]
$Frac_{SOM}$	annual mineralized nitrogen due to soil carbon loss from land use and management changes in agricultural lands with irrigation water infiltration or surface run-off [kg N/yr][34]
$Frac_{LEACH-(H)}$	fraction of all N added to/mineralised in managed soils in regions where leaching/runoff occurs that is lost through leaching and runoff, [kg N/kg N additions]
EF_5	emission factor for N_2O emissions from N leaching and runoff [kg N_2O-N/kg N leached and runoff]
44/28	N_2O conversion factor

Source: *2006 IPCC Guidelines, Vol.4, Ch.11, Equation 11.10*

5.5.2.2.2 Emission Factor

For atmospheric deposition (EF_4), an IPCC default emission factor was used while the emissions from leaching and run-off (EF_5) were estimated using country-specific emission factor. The IPCC default values were assigned for parameters including $Frac_{GASF}$, $Frac_{GASM}$ and $Frac_{LEACH-(H)}$.

| Table 5-54 | Indirect N_2O Emission Factors for Managed Soils

Source	Emission Factor	EF Source
Atmospheric deposition (EF_4)	0.010 kg N_2O-N/kg NH_3-N and NO_x-N[1)]	*2006 IPCC Guidelines*
Nitrogen leaching and run-off (EF_5)	0.0135 kg N_2O-N/kg N[2)]	CS (Developed in 2015)

Note: 1) Fraction of NH_3 and NO_x volatilized into the atmosphere and converted to N_2O
2) Fraction of NH_3 and NO_X leached into water systems and converted to N_2O

Source: *2006 IPCC Guidelines, Vol.4, Ch.11, Table 11.3*

33) No activity data is available for the annual amount of urine and dung nitrogen deposited by grazing animals on pasture, range and paddock in which leaching/runoff occurs(F_{PRP}).

34) No activity data is available for nitrogen mineralized due to loss of soil organic carbon from land-use and management changes(F_{SOM}).

| Table 5-55 | Parameters for Indirect N_2O Emissions

Parameter	Default Value	Parameter Source
Inorganic N fertilizer ($Frac_{GASF}$)	0.10 kg NH_3-N/kg + NO_x-N/kg N	*2006 IPCC Guidelines*
Organic N fertilizer ($Frac_{GASM}$)	0.20 kg NH_3-N/kg + NO_x-N/kg N	
Run-off or leaching into surface or groundwater ($Frac_{LEACH-(H)}$)	0.30 kg N/kg N	

Source: *2006 IPCC Guidelines, Vol.4, Ch.11, Table 11.3*

5.5.2.2.3 Activity Data

Activity data used for indirect N_2O emissions were obtained following the same procedures as for direct N_2O emissions as described in Section 5.5.1.2.3.

5.5.2.3 Uncertainty and Time-series Consistency

5.5.2.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

5.5.2.3.2 Time-series Consistency

Indirect N_2O emissions from managed soils were estimated using methodology and emission factors consistently from 1990 through 2022 to ensure time series consistency. Data used for the cultivation area and production per crop type and livestock population were from *Livestock Statistics* while data on fractions of total annual nitrogen excretion as well as fractions of dry matter burnt and of returned to soils of crop residues were from *Annual Agriculture, Forestry and Fisheries Survey*.

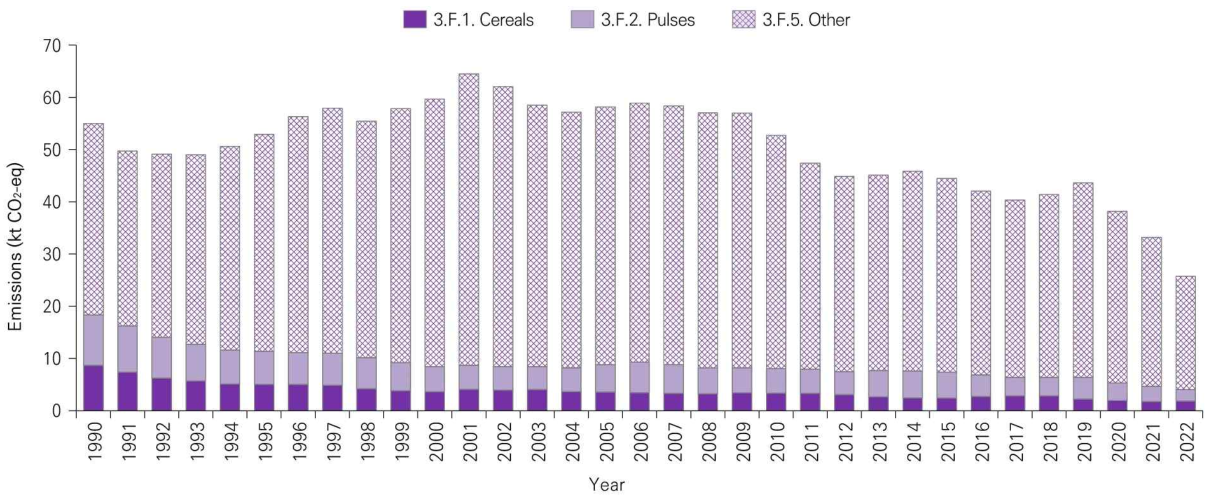
5.5.2.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

5.6 Field Burning of Agricultural Residues (3.F.)

Field burning of crop residues is a net source of CH_4 and N_2O.[35] The primary crops in ROK from which emissions were reported were segregated into : Cereal (3.F.1.) which include wheat, barley and paddy rice; Pulses (3.F.2.); and Other (3.F.5.) which includes pepper, garlic, sesame and onion.[36]

In 2022, emissions from field burning of agricultural residues were 26 kt CO_2-eq with cereal and pulses producing 1.8 kt CO_2-eq and 2 kt CO_2-eq respectively which accounted for 7.1 percent and 8.4 percent. The remaining crops other than cereal and pulses were the biggest source of emissions as it emitted 22 kt CO_2-eq, contributing 84.4 percent. Pepper accounted for the majority of total emissions from crop residue burning as it represented 64.9 percent, followed by garlic of 9.1 percent, sesame of 7.6 percent and onion of 2.8 percent.



| Figure 5-7 | Trends in Emissions from Field Burning of Agricultural Residues (1990-2022)

| Table 5-56 | Emissions from Field Burning of Agricultural Residues

(Unit: kt CO_2-eq)

Crop Type	1990	2000	2010	2018	2021	2022
Cereal	9	4	3	3	1.8	1.8
Pulses	10	5	5	3	3	2
Other	37	51	45	35	29	22
Total	55	60	53	41	33	26

35) According to the *2006 IPCC Guidelines*, CO_2 emissions from field burning of crop residues are not subject to reporting as the carbon released as CO_2 during the combustion process is assumed to be reabsorbed by the crop during the next growing season.

36) Tubers and roots (3.F.3.) as well as leafy vegetables do not create residues for burning, and thus emissions do not occur. Sugar cane (3.F.4.) does not grow in ROK.

5.6.1 Cereal (3.F.1.)

5.6.1.1 Category Description

	Gas	Method	Emission Factor	Activity Data
2022	CH_4, N_2O	Tier 1	D	Crop production of wheat, barley and paddy rice

In 2022, emissions from cereal which include wheat, barley and paddy rice were 1.8 kt CO_2-eq, representing a 4.7 percent increase from 2021, and accounted for 7.1 percent of the total emissions from field burning of agricultural residues.

Wheat and barley were two largest sources of emissions from cereal, producing 1.1 kt CO_2-eq and 0.7 kt CO_2-eq which contribute 60.7 percent and 39.3 percent respectively.

| Table 5-57 | Emissions from Cereal

(Unit: kt CO_2-eq)

Cereal Type	1990	2000	2010	2018	2021	2022
Wheat	0.1	0.2	1.0	1.5	0.8	1.1
Barley	8.4	3.3	2.3	1.1	0.8	0.7
Paddy rice	0.2	0.2	0.1	0.3	0.1	NO
Total	8.7	3.6	3.4	2.9	1.8	1.8

5.6.1.2 Methodology

5.6.1.2.1 Method

CH_4 and N_2O emissions from field burning of agricultural residues were estimated by multiplying annual production of crop by the amount of residue produced per unit of crop production, dry matter fraction, proportion of dry matter burnt, combustion factor, and CH_4 and N_2O emission factors. The value for area burnt multiplied by mass of fuel for combustion ($A \times M_B$) as indicated in the equation from the *2006 IPCC Guidelines* was calculated using crop production multiplied by the amount of residue per unit of production, dry matter fraction and proportion of dry matter burnt.

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Emissions from field burning of agricultural residues

$$L_{fire} = A \times M_B \times CF \times G_{EF} \times 10^{-6}$$

L_{fire}	:	amount of emissions from fire
A	:	area burnt [ha]
M_B	:	mass of fuel available for combustion [t/ha]
C_f	:	combustion factor
G_{ef}	:	CH_4/N_2O emission factors [g/kg d.m. burnt]

Source: *2006 IPCC Guidelines, Vol.4, Ch.2, Equation 2.27*

5.6.1.2.2 Emission Factor

CH_4 and N_2O emission factors used were default values provided in *the 2006 IPCC Guidelines*.

| Table 5-58 | Emission Factor for Field Burning of Agricultural Residues

(Unit: g/kg dry matter burnt)

Gas	Emission Factor	EF Source
CH_4	2.7	*2006 IPCC Guidelines*
N_2O	0.07	

Source: *2006 IPCC Guidelines, Vol.4, Ch.2, Table 2.5*

5.6.1.2.3 Activity Data

Activity data required for emissions from field burning of crop residues include the area burnt and mass of fuel (crop residues) available for combustion. As such data are not available in ROK, the respective value was calculated by using annual production of crop, the amount of residue per unit of crop production, dry matter fraction and proportion of dry matter burnt.

Area burnt and mass of fuel (residue) for combustion

$$A \times M_B = AP_C \times RCR \times DMF \times P_{DM}$$

A	:	area burnt [ha]
M_B	:	mass of fuel available for combustion [t/ha]
AP_C		annual production of crop
RCR		residue:crop ratio (the amount of residue produced per unit of crop production)
DMF		dry matter fraction
P_{DM}		proportion of dry matter burnt

Source: *Country-specific methodology*

Data used for estimating CH_4 and N_2O emissions include annual production of paddy rice, wheat and barley from the *Crop Production Statistics* while the ratio of residue and crop for each crop type were based on domestic research.[37] Dry matter fraction per crop and combustion factors for rice and wheat were based on the 2006 IPCC default values. For barley, the 1996 IPCC default value of combustion factor was applied as the *2006 IPCC Guidelines* do not provide the respective value.

| Table 5-59 | Activity Data Source for Field Burning of Agricultural Residues

Period	Activity Data	Name of Statistics	Published by
1990-2022	Annual production of paddy rice, wheat and barley, pulses and other crops	*Crop Production Statistics*	Statistics Korea (KOSTAT)

| Table 5-60 | Annual Production of Cereal

(Unit: kt)

Cereal	1990	2000	2010	2018	2021	2022
Rice	5,846.8	5,188.6	4,668.5	4,011.2	3,710.1	3,716
Barley	497.8	193.4	133.3	83.8	107.9	85.0
Wheat	1.5	4.2	22.8	34.0	19.4	26.0

Note: Annual production used as activity data is the value for the average production of three latest years of the inventory year t (t, t-1, t-2). (Source: *Crop Production Statistics*, KOSTAT)

| Table 5-61 | Parameters for Estimating Emissions from Field Burning of Residues : Cereal

Cereal Type	Residue:Crop Ratio[1)]	Dry Matter Fraction[2)]	Fraction of Dry Matter Burnt[3),4)]					Combustion Factor[5),6)]
			1990-2017	2018	2020	2021	2022	
Rice	1.56	0.89	0.03	0.07	0.02	0.02	NO	0.8
Barley	1.27	0.89	17.68	13.9	8.98	8.15	8.88	0.9
Wheat	1.3	0.89	43.9					0.9

Note: 1) *Study on Carbon Sinks in the Agricultural Sector under the UNFCCC*, National Institute of Agricultural Sciences (NAS) (2008)

2) *2006 IPCC Guidelines, Vol.4, Ch.11, Table 11.2*

3) (Wheat) *2010 Census of Agriculture, Forestry and Fisheries*, KOSTAT

4) (Barley) *2017-2021 Agriculture, Forestry and Fisheries Survey*, KOSTAT

5) (Rice, wheat) *2006 IPCC Guidelines, Vol.4, Ch.2, Table 2.6*

6) (Barley) *1996 Revised IPCC Guidelines, Vol 3, Reference Manual Ch.4, p.4.83*

37) *Study on Carbon Sinks in the Agricultural Sector under the UNFCCC*, National Institute of Agricultural Sciences (NAS) (2008)

5.6.1.3 Uncertainty and Time-series Consistency

5.6.1.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

5.6.1.3.2 Time-series Consistency

CH_4 and N_2O emissions from field burning of residues of cereal were estimated using methodology and emission factors consistently from 1990 through 2022 to ensure time series consistency.

5.6.1.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

5.6.2 Pulses (3.F.2.)

5.6.2.1 Category Description

2022	Gas	Methodology	Emission Factor	Activity Data
	CH_4, N_2O	Tier 1	D	Crop production of pulses

In 2022, emissions from pulses were 2 kt CO_2-eq which represented a decrease of 24.2 percent from 2021, accounting for 8.4 percent of total emissions from field burning of agricultural residues.

| Table 5-62 | Emissions from Pulses

(Unit: kt CO_2-eq)

Crop Type	1990	2000	2010	2018	2021	2022
Pulses	10	5	5	3	3	2

5.6.2.2 Methodology

5.6.2.2.1 Method

Method used for pulses was the same as for cereal as described in Section 5.6.1.2.1.

5.6.2.2.2 Emission Factor

Emission factors used for pulses were the same as for cereals as described in Section 5.6.1.2.2.

5.2.2.2.3 Activity Data

Data used for estimating emissions from pulses include annual production of pulses from the *Crop Production Statistics* while the ratio of residue and crop was based on domestic research.[38] Dry matter fraction was based on the 2006 IPCC default values whereas the 1996 IPCC default value of combustion factor was applied as the *2006 IPCC Guidelines* do not provide the respective value for pulses.

| Table 5-63 | Annual Production of Pulses

(Unit: kt)

Crop Type	1990	2000	2010	2018	2021	2022
Pulses	292.1	145.9	140.4	99.3	117.3	125.5

Note: Annual production used as activity data is the value for the average production of three latest years of the inventory year t (t, $t-1$, $t-2$). (Source: *Crop Production Statistics*, KOSTAT)

| Table 5-64 | Parameters for Estimating Emissions from Field Burning of Residues : Pulses

Crop Type	Residue:Crop Ratio[1)]	Dry Matter Fraction[2)]	Proportion of Dry Matter Burnt[3)]					Combustion Factor[4)]
			1990-2017	2018	2020	2021	2022	
Pulses	1.07	0.91	40.16	42.69	37.23	29.61	20.99	0.9

Note: 1) *Study on Carbon Sinks in the Agricultural Sector under the UNFCCC*, National Institute of Agricultural Sciences (NAS) (2008)

2) *2006 IPCC Guidelines, Vol.4, Ch.11, Table 11.2*

3) *2017-2022 Agriculture, Forestry and Fisheries Survey*, KOSTAT

4) *1996 Revised IPCC Guidelines, Vol 3, Reference Manual Ch.4, 4.83*

5.6.2.3 Uncertainty and Time-series Consistency

5.6.2.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

5.6.2.3.2 Time-series Consistency

CH_4 and N_2O emissions from field burning of residues of pulses were estimated using methodology and emission factors consistently from 1990 through 2022 to ensure time series consistency.

38) *Study on Carbon Sinks in the Agricultural Sector under the UNFCCC*, National Institute of Agricultural Sciences (NAS) (2008)

5.6.2.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

5.6.3 Other (3.F.5.)

5.6.3.1 Category Description

	Gas	Methodology	Emission Factor	Activity Data
2022	CH_4, N_2O	Tier 1	D	Crop production of pepper, garlic, sesame, onion

In 2022, emissions from other category comprising pepper, garlic, sesame and onion were 22 kt CO_2-eq, representing a 23.9 percent decrease from 2021, and contributed 84.4 percent of total emissions from field burning of crop residues.

Pepper accounted for the majority of emissions from other crops as it emitted 17 kt CO_2-eq representing 77 percent, followed by garlic of 10.6 percent with 2 kt CO_2-eq, sesame of 9.2 percent with 2 kt CO_2-eq and onion of 3.2 percent with 0.7 kt CO_2-eq.

| Table 5-65 | Emissions from Other : Pepper, Garlic, Sesame and Onion

(Unit: kt CO_2-eq)

Crop Type	1990	2000	2010	2018	2021	2022
Pepper	21	38	36	27	21	17
Garlic	4	5	4	3	4	2
Sesame	11	7	4	3	2	2
Onion	0.5	0.9	1.3	1.5	1.1	0.7
Total	37	51	45	35	29	22

5.6.3.2 Methodology

5.6.3.2.1 Method

Method used for other crops was the same as for cereals as described in Section 5.6.1.2.1.

5.6.3.2.2 Emission Factor

Emission factors used for other crops were the same as for cereals as described in Section 5.6.1.2.2.

5.6.3.2.3 Activity Data

Data used for estimating emissions from other crops include annual production of pepper, garlic, sesame and onion from the *Crop Production Statistics* while the ratio of residue and crop was based on domestic research[39]. Dry matter fraction was based on the 2006 IPCC default values whereas the 1996 IPCC default value of combustion factor was applied as the *2006 IPCC Guidelines* do not provide the respective value for crops under this subcategory.

| Table 5-66 | Annual Production of Other Crops

(Unit: kt)

Crop Type	1990	2000	2010	2018	2021	2022
Pepper	205.6	372.0	348.9	254.0	252.9	239.9
Garlic	359.0	450.7	334.8	3.3.6	353.2	314.9
Sesame	43.4	27.8	15.0	13.5	10.0	9.5
Onion	497.3	895.2	1,273.0	1,321.4	1,446.5	1,313.5

Note: Annual production used as activity data is the value for the average production of three latest years of the inventory year (*t*, *t*−1, *t*−2). (Source: *Crop Production Statistics*, KOSTAT)

| Table 5-67 | Parameters for Estimating Emissions from Field Burning of Residues : Other

Crop Type	Residue: Crop Ratio[1)]	Dry Matter Fraction[2)]	Proportion of Dry Matter Burnt(%)[3)]					Combustion Factor[4)]
			1990-2017	2018	2020	2021	2022	
Pepper	2.67	0.87	52.2	53.46	49.99	42.37	35.39	0.9
Garlic	0.92	0.94	14.96	15.25	15.2	16	10.17	0.9
Sesame	6.6	0.9	50.79	50.03	52.08	44.20	40.81	0.9
Onion	0.13	0.94	9.99	10.9	6.76	7.39	5.36	0.9

Note: 1) *Study on Carbon Sinks in the Agricultural Sector under the UNFCCC*, National Institute of Agricultural Sciences (NAS) (2008)
2) *2006 IPCC Guidelines, Vol.4, Ch.11, Table 11.2*
3) *2017-2022 Agriculture, Forestry and Fisheries Survey*, KOSTAT
4) *1996 Revised IPCC Guidelines, Vol 3, Reference Manual Ch.4, 4.83*

5.6.3.3 Uncertainty and Time-series Consistency

5.6.3.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

5.6.3.3.2 Time-series Consistency

CH_4 and N_2O emissions from field burning of residues of other crops were estimated

39) *Study on Carbon Sinks in the Agricultural Sector under the UNFCCC*, National Institute of Agricultural Sciences (NAS) (2008)

using methodology and emission factors consistently from 1990 through 2022 to ensure time series consistency.

5.6.3.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

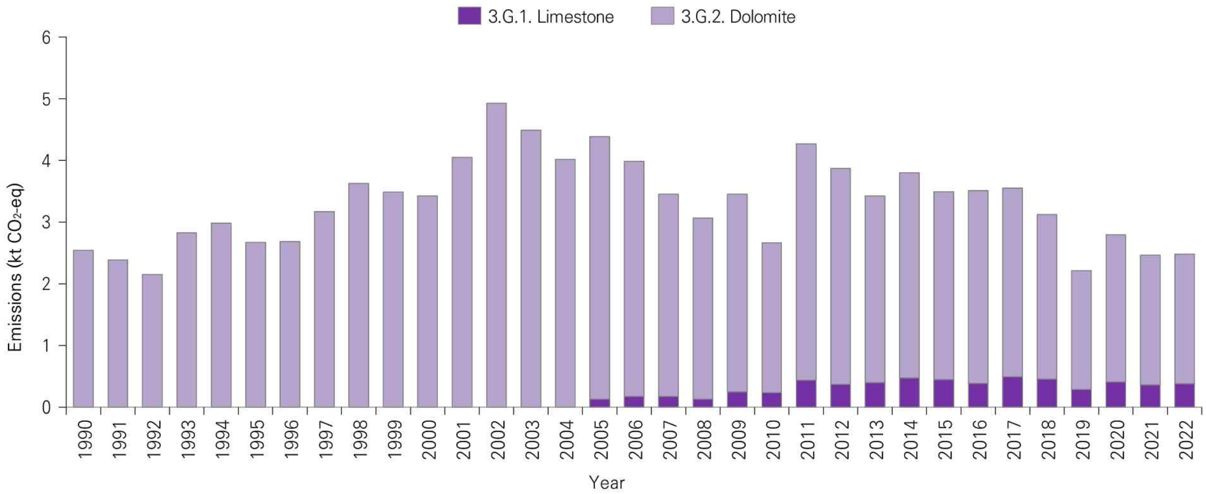
5.7 Liming (3.G.)

5.7.1 Category Description

	Gas	Methodology	Emission Factor	Activity Data
2022	CO_2	Tier 2	CS	Annual supply of carbonate lime

Liming (3.G.) is a source of carbon dioxide (CO_2) which is produced when compounds of limestone and dolomite containing carbonates are applied to soil for the purpose of reducing soil acidity and improving plant growth in agricultural lands. Emissions from liming are reported under either Limestone (3.G.1.) or Dolomite (3.G.2.).

In 2022, emissions from liming were 2.5 kt CO_2−eq, representing a 0.7 percent increase from 2021, and contributed 0.01 percent of the total sectoral emissions. Dolomite emitted 2.1 kt CO_2−eq while limestone produced 0.4 kt CO_2−eq, accounting for 84.7 percent and 15.3 percent respectively.



| Figure 5-8 | Trends in Emissions from Liming (1990-2022)

| Table 5-68 | Emissions from Liming

(Unit: kt CO_2-eq)

Source	1990	2000	2010	2018	2021	2022,
Limestone	NE[1)]	NE	0.2	0.5	0.4	0.4
Dolomite	2.5	3.4	2.4	2.7	2.1	2.1
Total	2.5	3.4	2.7	3.1	2.5	2.5

Note: 1) Data on limestone as a raw material have been collected since 2005. Prior to 2005, the amount of lime fertilizer using limestone was insignificant.

5.7.2 Methodology

5.7.2.1 Method

Emissions from liming were estimated by multiplying the annual amount of limestone and dolomite applied by emission factors using the Tier 2 methodology in accordance with the *2006 IPCC Guidelines*.

Annual CO_2 emissions from lime application

$$E_{CO_2-C} = (M_{Limestone} \times EF_{Limestone}) + (M_{Dolomite} \times EF_{Dolomite})$$

E_{CO_2-C}	:	annual C emissions from lime application [t C/yr]
M	:	annual amount of calcic limestone ($CaCO_3$) or dolomite ($CaMG(CO_3)_2$) [t]
EF	:	emission factor, tonne of C (Limestone, Dolomite) [kg CO_2/kg]

Source: *2006 IPCC Guidelines, Vol.4, Ch.11, Equation 11.12*

5.7.2.2 Emission Factor

Emissions from both limestone and dolomite were calculated using country-specific emission factors.

| Table 5-69 | Emission Factor for Liming

(Unit: kg CO_2/kg Limestone, Dolomite)

Source	Emission Factor	EF Source
Limestone	0.0086	CS[1)]
Dolomite	0.0157	

Note: 1) Developed in 2018 based on data on changes in CO_2 emissions from pepper fields to which the recommended quantity of fertilizer was applied during the growing season over a span of three years. (Source: National Institute of Agricultural Sciences, 2013)

5.7.2.3 Activity Data

Data used to calculate emissions from liming include the annual supply of limestone and dolomite consumed for lime fertilizer production from 1990 through 2022 which were derived from the *Statistical Yearbook of Fertilizer Use*.

| Table 5-70 | Annual Supply of Carbonate Limes

(Unit: kt)

Amount	1990	2000	2010	2018	2021	2022
Limestone	NE[1)]	NE	27.0	53.0	42.0	44.1
Dolomite	162.0	218.0	155.0	170.0	134.0	134.0
Total	**162.0**	**218.0**	**182.0**	**223.0**	**176.0**	**178.1**

Note: 1) Data on limestone as a raw material have been collected since 2005. Prior to 2005, the amount of lime fertilizer using limestone was insignificant.

5.7.3 Uncertainty and Time-series Consistency

5.7.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

5.7.3.2 Time-series Consistency

CO_2 emissions from liming were estimated using methodology and emission factors consistently from 1990 through 2022 to ensure time series consistency.

5.7.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC* Guidelines (see Section 1.5).

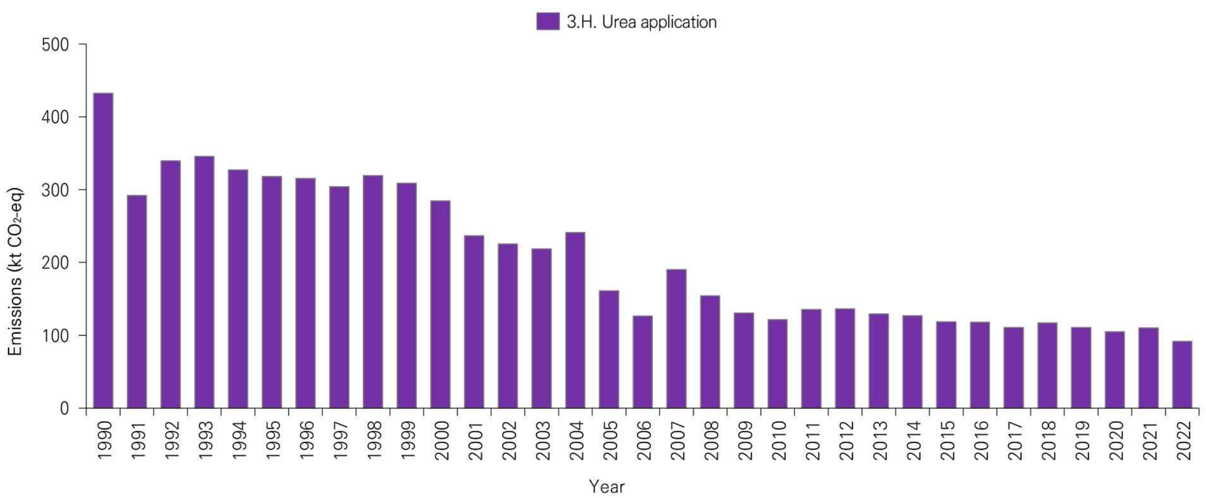
5.8 Urea Application (3.H.)

5.8.1 Category Description

2022	Gas	Methodology	Emission Factor	Activity Data
	CO_2	Tier 1	D	Annual supply of urea

Urea is applied to agricultural soils as a fertilizer which leads to CO_2 emissions during the process of its conversion into ammonium (NH_4^+), hydroxyl ion (OH^-) and bicarbonate (HCO_3^-) in the presence of water and urease enzymes. Bicarbonate is then evolves into water and CO_2 which is released into the atmosphere.

In 2022, emissions from the use of urea were 92 kt CO_2-eq, representing a decrease of 16.7 percent and 78.8 percent from 2021 and 1990 respectively. This subcategory accounted for 0.4 percent of the total sectoral emissions.



| Figure 5-9 | Trends in Urea Application CO_2 Emissions (1990-2022)

| Table 5-71 | Emissions from Urea Application

(Unit: kt CO_2-eq)

Sub-category	1990	2000	2010	2018	2021	2022
Urea application	432	285	122	117	110	92

5.8.2 Methodology

5.8.2.1 Method

Emissions from urea application were estimated by multiplying the amount of urea fertilization by the emission factor, following the Tier 1 methodology of the *2006 IPCC Guidelines*.

Annual CO_2 emissions from urea application

$$E_{CO_2-C} = M \times EF$$

E_{CO_2-C} : annual C emissions from urea application [t C/yr]

M : annual amount of urea fertilisation [t]

EF : emission factor, tonne of C [t C/ton of urea]

Source: *2006 IPCC Guidelines, Vol.4, Ch.11, Equation 11.13*

5.8.2.2 Emission Factor

The default emission factor provided in the *2006 IPCC Guidelines* was used.

| Table 5-72 | Emission Factor for Urea Application

(Unit: t C/ton of Urea)

Source	Emission Factor	EF Source
Urea application	0.2	*2006 IPCC Guidelines*

Source: *2006 IPCC Guidelines, Vol.4, Ch.11, 11.34*

5.8.2.3 Activity Data

Activity data for urea application which include the annual supply of urea applied in cropland and grassland from *Statistical Yearbook of Fertilizer Use* have been used since 2021. For the 1990 to 2020 period, data were derived from *Fertilizer Yearbook*.

| Table 5-73 | Activity Data Source for Urea Application

Period	Activity Data	Name of Statistics	Published by
1990-2020	Annual supply of urea	*Fertilizer Yearbook*	Korea Fertilizer Industry Association (KFA)
2021-2022		*Statistical Yearbook of Fertilizer Use*	National Agricultural Cooperative Federation (NACF)

| Table 5-74 | Annual Amount of Urea Fertilization

(Unit: kt)

Amount	1990		2000		2010		2018		2021	2022
Urea fertilization	589.8		388.4		165.8		159.6		150	125

5.8.3 Uncertainty and Time-series Consistency

5.8.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

5.8.3.2 Time-series Consistency

CO_2 emissions from urea application were estimated using methodology and emission factors consistently since 1990. Activity data for the 1990 through 2020 time series were derived from *Fertilizer Yearbook* which has not been released since 2021. From 2021 onward, data on the annual urea supply from the *Fertilizer Use Statistical Yearbook of Fertilizer Use* were used. To maintain time-series consistency, the approach of tracking changes in activity data and emissions across the time series was used.

5.8.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

SECTION

06 Land Use, Land-Use Change and Forestry

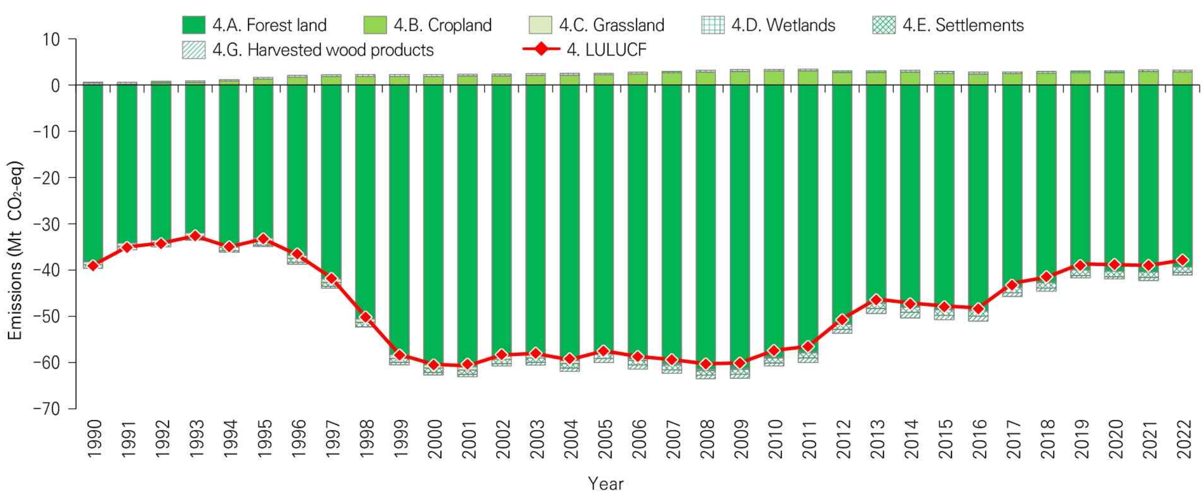
6 Land Use, Land-Use Change and Forestry

6.1 Overview

6.1.1 Category Description

In the Land Use, Land-Use Change and Forestry (LULUCF) sector, the entire land[1] of ROK is categorized by land use type into Forest land (4.A.), Cropland (4.B.), Grassland (4.C.), Wetlands (4.D.), Settlements (4.E.), and Other land (4.F.). Carbon stock changes in carbon pools which include biomass, soils and dead organic matter are influenced by land-use and management activities. The storage of carbon in wood products and its subsequent release as CO_2 are reported under Harvested Wood Products (4.G.).

In 2022, the LULUCF showed net removals of 37.8 Mt CO_2-eq, a decrease of 1.1 Mt CO_2-eq compared to 39.0 Mt CO_2-eq in 1990. Forest land was the biggest contributor to CO_2 removals with 39.3 Mt CO_2-eq followed by settlements removing 1.2 Mt CO_2-eq and 0.5 Mt CO_2-eq from harvested wood products (HWP). In contrast, emissions from LULUCF in 2022 were from cropland, wetlands and grassland emitting 2.9 Mt CO_2-eq, 0.4 Mt CO_2-eq, and 0.001 Mt CO_2-eq respectively.



| Figure 6-1 | Trends in Emissions and Removals from LULUCF Sector (1990-2022)

1) In accordance with the *2006 IPCC Guidelines,* all emissions by sources and removals by sinks from managed lands are reported. In ROK, the entire land is subject to government policies, monitoring and management, and thus the entire territory of ROK is classified as 'Managed Land'.

| Table 6-1 | Emissions and Removals from LULUCF Sector (1990-2022)

(Unit: Mt CO_2-eq)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
4.A. Forest land	−38.2	−34.2	−33.5	−32.0	−34.4	−33.1	−36.8	−41.9	−50.6	−58.3	−60.5
4.B. Cropland	0.1	0.3	0.4	0.6	0.8	1.3	1.7	1.9	1.9	1.9	1.9
4.C. Grassland	−0.7	−0.7	−0.7	−0.7	−0.7	−0.7	−0.7	−0.7	−0.7	−0.7	−0.7
4.D. Wetlands	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4
4.E. Settlements	−0.7	−0.8	−0.8	−0.8	−0.8	−0.8	−0.9	−0.9	−0.9	−0.9	−0.9
4.G. Harvested Wood Products (HWP)	0.2	0.04	0.03	−0.1	−0.3	−0.3	−0.4	−0.4	−0.1	−0.5	−0.5
Total	−39.0	−35.0	−34.2	−32.6	−35.0	−33.3	−36.7	−41.7	−50.1	−58.3	−60.4
Source	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
4.A. Forest land	−60.9	−58.6	−58.4	−59.6	−57.6	−59.2	−60.3	−61.5	−61.2	−58.8	−57.7
4.B. Cropland	2.0	2.0	2.1	2.1	2.2	2.4	2.6	2.8	2.9	3.0	3.1
4.C. Grassland	−0.7	−0.7	−0.7	−0.6	−0.5	−0.4	−0.3	−0.3	−0.2	−0.2	−0.2
4.D. Wetlands	0.4	0.4	0.4	0.4	0.3	0.4	0.4	0.4	0.4	0.4	0.4
4.E. Settlements	−0.9	−0.9	−0.9	−1.0	−1.0	−1.0	−1.0	−1.0	−1.1	−1.1	−1.1
4.G. Harvested Wood Products (HWP)	−0.5	−0.5	−0.6	−0.8	−0.9	−0.9	−0.8	−0.7	−0.9	−0.6	−1.0
Total	−60.7	−58.4	−58.1	−59.4	−57.5	−58.7	−59.4	−60.3	−60.1	−57.4	−56.5
Source	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
4.A. Forest land	−51.6	−47.0	−47.9	−48.5	−48.7	−43.7	−42.6	−39.9	−40.2	−40.4	−39.3
4.B. Cropland	2.7	2.7	2.8	2.5	2.4	2.5	2.6	2.6	2.7	2.9	2.9
4.C. Grassland	−0.2	−0.2	−0.2	−0.1	−0.1	−0.1	−0.04	−0.02	−0.02	−0.01	0.001
4.D. Wetlands	0.4	0.4	0.4	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4
4.E. Settlements	−1.1	−1.1	−1.1	−1.2	−1.2	−1.2	−1.2	−1.2	−1.2	−1.2	−1.2
4.G. Harvested Wood Products (HWP)	−0.8	−1.1	−1.2	−1.0	−1.0	−0.8	−0.7	−0.5	−0.5	−0.7	−0.5
Total	−50.6	−46.3	−47.1	−47.8	−48.2	−42.8	−41.6	−38.7	−38.8	−39.0	−37.8

Note: Emissions in positive values (+) and removals in negative values (−)

6.1.2 Definitions of Land-Use and Representation of the Land Base

6.1.2.1 Definition of Land-Use in ROK

In accordance with the *2006 IPCC Guidelines*, all lands in ROK are classified into six main land-use categories: forest land, cropland, grassland, wetlands, settlements and other land. Definitions for each category are as follows.

The definition of **Forest land** is based on the *National Forest Inventory* (Korea Forest Service) definition of forest which meets the criteria of the Food and Agriculture Organization of the United Nations (FAO) for forest. Forest land in ROK is subdivided into stocked forest land and unstocked forest land. Stocked forest land consists of coniferous forests, broadleaf forests, mixed forests, and bamboo forests while unstocked forest land includes all forest land that is not classified as stocked land that are temporarily unstocked resulting from human intervention or natural causes which are expected to regenerate such as unstocked forests land due to clear-cutting, and forest roads.

| Table 6-2 | Definition of Forest Land

Category	Minimum Area (ha)	Minimum Tree Height (m)	Minimum Canopy Cover (%)	Minimum Width (m)	Data Source
ROK	0.5	5	10	30	Korea Forest Service (KFS), 2022[1)]
UNFCCC	0.05-1	2-5	10-30	-	UNFCCC, 2002[2)]
FAO	0.5	5	10	20	FAO, 2012[3)]

Note: 1) *Guidelines for the 8th National Forest Inventory and Field Survey of Forest Health*, KFS (2022)
2) UNFCCC/CP/2001/13/Add.1, UNFCCC (2002)
3) *Forest Resources Assessment Working Paper 180 - FRA 2015 Terms and Definitions*, FAO (2012)

| Table 6-3 | Definition of Stocked Forest Land and Uunstocked Forest Land

Category	Definition
Stocked forest land	• Stocked forest land: Forest area of over 10 percent canopy cover with trees that can reach at least 5 metres in height. Stocked forest land is classified into four types as follows: ▶ Coniferous Forest: Forest with more than 75 percent canopy cover or tree density of coniferous trees ▶ Broadleaf Forest: Forest with more than 75 percent canopy cover or tree density of broadleaf trees ▶ Mixed Forest: Forest with 25 to 75 percent canopy cover or tree density of both coniferous and broadleaf trees ▶ Bamboo Forest: Forest with more than 75 percent tree density of bamboos
Unstocked forest land	• All forest land that is not classified as stocked forest land. Unstocked forest land is classified into two types as follows: ▶ Temporarily unstocked land: Unstocked area of less than 10 percent canopy cover due to clear-cutting as part a forest management practice or natural disasters that is expected to be forested ▶ Other unstocked land: Unstocked area of less than 10 percent canopy cover which is not subject to forest management

Cropland is defined in the *2006 IPCC Guidelines* as arable and tillable land for all annual and perennial crops. In the *Agricultural Area Statistics*, cropland includes paddy fields, upland crop fields and orchards.

Grassland is defined in the *2006 IPCC Guidelines* as pasture or hayfields which corresponds to pasture in the *Cadastral Statistics*.

Wetlands are categorized into flooded land and coastal wetlands. Flooded land is defined in the *2006 IPCC Guidelines* as any land that is covered or saturated by water for all or part of the year which correspond to drainage, reservoirs and fish farms in the *Cadastral Statistics*. Coastal wetlands are defined in accordance with the *2013 IPCC Supplement : Wetlands* as lands that consist of saturated organic and mineral soils covered for all or part of the year by tidal freshwater, brackish or saline water and are vegetated by vascular plants. The boundary of coastal wetlands extends to the landward extent of tidal inundation and seaward to the maximum depth of vascular plant vegetations[2)]. In ROK, coastal wetlands correspond to seagrass meadows and tidal marshes as specified in *Korea Blue Carbon Inventory System (K-BIS)*.

Settlements are defined in the *2006 IPCC Guidelines* as all developed land used for residential purpose and socio-economic activities which correspond to the lands for residential, commercial, and transportation infrastructure, and for public use such as parks, gardens and sports facilities, and for social and cultural purposes, as specified in the

2) *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands, Ch.4*

Cadastral Statistics.

The *2006 IPCC Guidelines* classify all land areas that do not fall into any of the other five land-use categories above as **Other land** which includes bare soil, rock and ice.

| Table 6-4 | Land Area Classification and Criteria (2022)

IPCC Land Sector	Domestic Land Use Criteria	Domestic Criteria for Land Area	Statistical Data
All Land	-	• The entire land area	*Cadastral Statistics (Ministry of Land, Infrastructure and Transport, MOLIT)*
Forest land	Coniferous Forest	• Coniferous forest area	*Statistical Yearbook of Forestry (Korea Forest Service, KFS)*
	Broadleaf Forest	• Broadleaf forest area	
	Mixed Forest	• Mixed forest area	
	Bamboo Forest	• Bamboo forest area	
	Unstocked Land	• Area of all forest land that is not classified as stocked land	
Cropland	Paddy Field	• Area of paddy fields	*Agricultural Area Statistics (Statistics Korea, KOSTAT)*
	Upland Crop Field	• Area of upland crop fields	
	Orchard	• Area of orchards	
Grassland	Pasture	• Area of pasture	*Cadastral Statistics (MOLIT)*
Wetlands	Flooded Land	• Area of drainage, reservoir and fish farms	
	Coastal Wetlands	• Area of seagrass meadows and tidal marshes as classified in K-BIS	*National Blue Carbon Inventory System (K-BIS) (Ministry of Oceans and Fisheries, MOF)*
Settlements	Land Categories	• Area of lands that fall into land categories including lands for spring water, salt farm, building site, factory, school, parking lot, gas station, warehouse, road, railroad, embankment, water supply, park, sports facility, amusement park, religion, cultural heritage, cemetery, and other multi-purpose land	*Cadastral Statistics (MOLIT)*
Other Land	-	• Remaining Land Area excluding the sum of Forest Land, Cropland, Grassland, Wetlands, and Settlements Area from the Total National Land Area	

Note: The area of coastal wetlands is not included in the total land area.

6.1.2.2 Land-Use Conversion Matrix

ROK has been reporting greenhouse gas emissions and removals from the LULUCF sector using Approach 1 of the *2006 IPCC Guidelines.* Research is currently underway to move to

Approach 2 or 3 and develop a land–use conversion matrix. ROK is continuously working with domestic experts and stakeholders to utilize the best available method including the land–use matrix for the LULUCF sector and enhance the national inventory.

6.1.3 Land Use Data Sources

Data for land–use categories and areas in ROK were from the *Statistical Yearbook of Forestry* (KFS), *Basic Forest Statistics* (KFS), *Agricultural Area Statistics* (KOSTAT), *Cadastral Statistics* (MOLIT), and K–BIS (MOF).

Statistics used for forest land include *Basic Forest Statistics* (KFS), *National Forest Inventory* (KFS), *and Statistical Yearbook of Forestry* (KFS). *Basic Forest Statistics* and *National Forest Inventory* are KOSTAT–approved statistics published every five years which include data on forest area and growing stock volume. The *Statistical Yearbook of Forestry* is published annually and includes statistics related to forests and forestry.

| Table 6–5 | Statistics and Data Source for Forest Land

Name of Statistics	*Basic Forest Statistics*	*Statistical Yearbook of Forestry*	*National Forest Inventory*
Purpose	To collect data on the current status of forest resources and provide data for policy–making processes	To provide comprehensive statistics on forests and forestry	To identify changes in forest resources
Publication	Every 5 years	Every year	Every 5 years
Survey Method	Administrative data, spatial information and field survey	Compilation of administrative and management data	Field surveys at sample plots
Key Items	Area of forest, growing stock volume	Includes data from *Basic Forest Statistics*, forest economy	Growing stock volume, biomass, soils

Statistical Yearbook of Forestry

The *Statistical Yearbook of Forestry*, published annually by KFS, collects data on forest area, growing stock volume and forestry–related information. It also includes survey results on forest services and forest health as well as data covered in the *Basic Forest Statistics* (KFS) which is published every five years.

Basic Forest Statistics

The *Basic Forest Statistics*, published every five years by KFS, provides fundamental data on the current status of forest resources. It collects data on forest area and growing stocks by forest type, age class and ownership at the local government level in ROK.

The forest area by forest type and age class is calculated by using the area ratio of each forest type and age class and the total forest area at the local government level. The growing stocks is obtained by using the growing stocks per hectare for each forest type and age class which is derived from the *National Forest Inventory.*

The forest cover map which is used for the *Basic Forest Statistics* provides information on the boundaries between forest and non−forest land, forest types such as coniferous forest, broadleaf forest, mixed forest, and classification of forest age classes (stand age), tree size, canopy density, species composition, and dominant tree height (stand height). National Institute of Forest Science (NIFoS) used to create and interpret an aerial orthoimage to produce the forest cover map until such aerial orthoimage were provided by MOLIT from 2006. Until 2011, the forest cover map was produced at a scale of 1 : 25,000 which was enhanced to 1 : 5,000 from 2012 onward.

National Forest Inventory

The survey for *National Forest Inventory* is conducted every five years to collect data on all lands that fall into forest land since 2006. A systematic sampling method has been applied where samples are selected at regular intervals of 4 km across the entire land in ROK. The survey collects data on carbon content in carbon pools to calculate growing stock volume and carbon stocks from 4,000 sample plots in the forest land. Using a weighted moving average method and data collected for the past five years, the survey is conducted on 70 items including the growing stock volume per hectare, biomass and carbon stocks. Based on the result of the survey, the *National Forest Inventory* is prepared. It is one of data sources used to produce the *Basic Forest Statistics*.

Agricultural Area Statistics

Data for cropland are from the *Agricultural Area Statistics* which consists of the *Arable Land Area Survey* and the *Crop Cultivation Area Survey.* It aims to provide data for securing and utilizing land resources for agricultural production, and establishing plans for stabilization of agricultural supply and demand, and implementing agricultural policies. The *Agricultural Area Statistics* are published annually by KOSTAT.

Cadastral Statistics

Data for grassland, flooded land as well as settlements are from *Cadastral Statistics* which are based on the cadastral registry[3] in which all lands in ROK are registered and classified by administrative divisions (e.g. city, province, district and county), ownership (e.g. private, state-owned, province-owned, municipal-owned, corporate, non-corporate and other), and 28 land categories. The *Cadastral Statistics* are released annually by MOLIT.

National Blue Carbon Inventory System (K-BIS)

Data for coastal wetlands are from the *National Blue Carbon Inventory System* which was developed in 2022 after five years of research and development, and has been providing information on domestic coastal wetlands. MOF annually collects data on domestic tidal marsh and seagrass meadows through the national blue carbon monitoring project to provide the wetlands area by region and wetlands maps through its system. Data on the area of tidal marsh from 1990 onward has been available through analysis of *Landsat Satellite Imagery* developed by National Aeronautics and Space Administration (NASA) and the United States Geological Survey (USGS) while the area of seagrass meadows is obtained through analysis of Sentinel-2 satellite imagery operated by the European Space Agency (ESA) from 2016 onward. The areas of tidal marsh and seagrass meadows per year are used as activity data for coastal wetlands in the Land Use, Land Use Change, and Forestry (LULUCF) sector of national inventory.

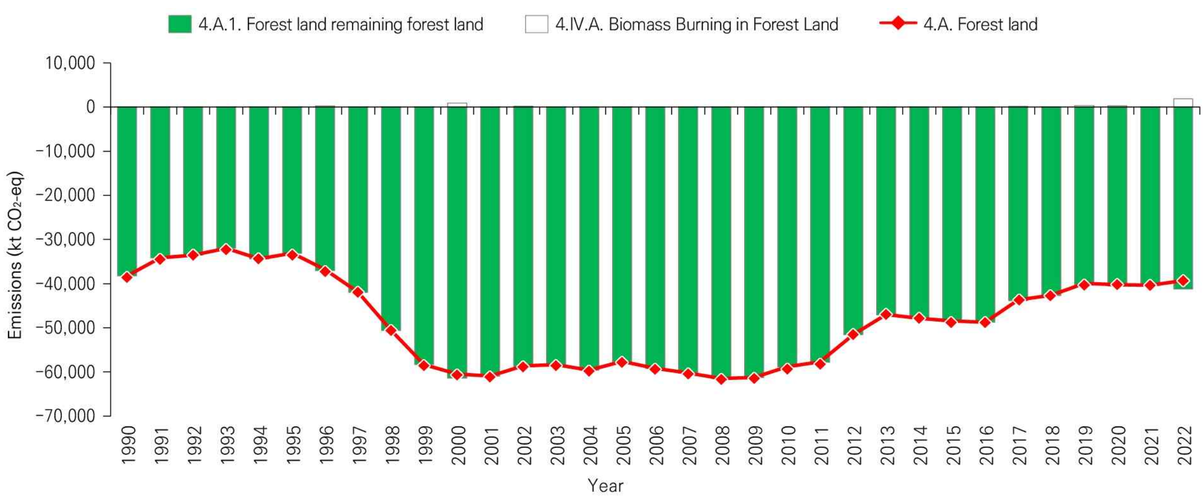
3) It refers to the national registry for management of land-related information such as land ownership, area and location.

6.2 Forest Land (4.A.)

Under the Forest land (4.A.) category, greenhouse gas removals through the process in which carbon is removed from the atmosphere and stored in living biomass as well as emissions through biogeochemical processes in forests such as wildfires are estimated.

As part of efforts to implement active fire protection and prevention of pest outbreaks for sustainable management of forests, the ROK government enacted the *Forestry Act*[4] in 1961 of which *Article 2* defines forest land as the land that is covered with trees and bamboos, and where trees and bamboos have been temporarily lost. The *Act* mandates to establish a *Forest Management Plan* for all forest lands, and includes regulations for forest management practices such as licensing system for logging *(Article 9)*, prevention of deforestation *(Article 49)*, wildfire prevention *(Article 50)*, and pest control and prevention *(Article 51)*. Based on the Act, projects for erosion control, watershed rehabilitation and forest conservation have been implemented through public−private cooperation[5].

In 2022, forest lands were estimated to result in net removal of 39,327 kt CO_2−eq, representing an increase of 1,101 kt CO_2−eq from 1990. Since 1995, net removals in forest land increased and peaked in 2000s until it started to decrease from 2010.



| Figure 6−2 | Trends in Forest Land Emissions and Removals (1990−2022)

4) Renamed as the *Act on the Creation and Management of Forest Resources*

5) *The 8th National Forest Inventory,* KFS (2021)

| Table 6-6 | Emissions and Removals from Forest Land

(Unit: kt CO_2-eq)

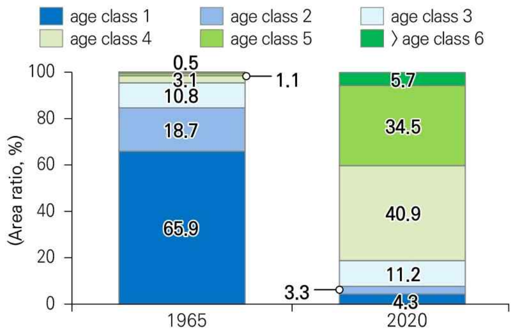
(Sub)Category	1990	2000	2010	2018	2021	2022
4.A. Forest land	-38,226	-60,489	-58,836	-42,626	-40,385	-39,327
4.A.1. Forest land remaining forest land	-38,227	-61,380	-58,843	-42,691	-40,389	-41,207
4.A.2. Land converted to forest land[1)]	IE	IE	IE	IE	IE	IE
4.IV.A. Biomass burning in forest land	0.2	891	7	65	4	1,880

Note: 1) According to the *2006 IPCC Guidelines*, emissions and removals from Land converted to forest land (4.A.2.) are included in Forest land remaining forest land (4.A.1.) if activity data on the area of land converted to forest land are not available.

The decrease in net removals in forest land since 2008 is attributed to reductions in the annual net forest increment and forest area. The annual net increment represents the growing stock volume within a forest over a given year and CO_2 removal is estimated based on such annual net increment as described in Section 6.2.1.2.1. In other words, the greater the annual net increment compared to the previous year, the higher the net carbon uptake.

Due to forest aging and declining the biomass growth rate of trees, the annual net increment decreased which led to the reduction of net removals in forest land. The area of young forests aged less than 30 years which have faster growth rates were approximately 5,676 kha, accounting for 88 percent of the total forest area in 1990 which decreased to 19 percent as of 2020.

Forest area was 6,291 kha in 2022, representing a decrease of 185 kha compared to 1990. This reduction appears to have contributed to the decline in net removals in forest land. In 2022, the large-scale wildfire caused an increase in greenhouse gas emissions which further influenced the decrease in net removals in the respective year.



| Figure 6-3 | Change in the Proportion of Forest Land by Age Class (1965 and 2020)[6]

| Table 6-7 | Change in the Proportion of Forest Land by Age Class[13]

(Unit: kha, %)

Age Class \ Year	1965	1974	1992	2010	2020
Total Forest Land Area (kha)	6,614	6,641	6,464	6,369	6,298
Age Class 1 (1 to 10) (%)	65.9	53.3	16.6	2.6	4.3
Age Class 2 (11 to 20) (%)	18.7	32.2	40.6	7.6	3.3
Age Class 3 (21 to 30) (%)	10.8	8.9	32.4	22.7	11.2
Age Class 4 (31 to 40) (%)	3.1	3.6	7.5	36.7	40.9
Age Class 5 (41 to 50) (%)	1.1	1.1	2.2	22.5	34.5
Age Class 6 and above (over 51) (%)	0.5	0.9	0.7	8.0	5.7

Note: Age classes are reported in 10-year intervals, starting from 1-10 years.

6.2.1 Forest Land Remaining Forest Land (4.A.1.)

6.2.1.1 Category Description

2022	Gas	Methodology	Emission Factor	Activity Data	Carbon Pool
	CO_2	Tier 2	CS	Area and growing stock volume of forest land by forest type	Living biomass (above-ground, below-ground)

Under the reporting category of Forest land remaining forest land (4.A.1.), CO_2 removals based on the carbon stocks that increases along with the growth of standing trees are estimated. Biomass carbon stocks are estimated for stocked forests land which includes coniferous forests, broadleaf forests, mixed forests and bamboo forests. In ROK, the area of bamboo forests accounted for 0.34 percent of stocked forest land with no available activity data. As it was considered the likely level of associated emissions was insignificant, emissions from bamboo forests were not estimated.

Changes in carbon stocks in forest land remaining forest land were estimated to result in net removal of 41,207 kt CO_2-eq, representing an increase of 2,980 kt CO_2-eq from 1990. CO_2 removals have been decreasing since 2008 due to declines in annual net increment and forest area, and fluctuated between 40,261 kt CO_2-eq and 41,207 kt CO_2-eq in the 2019 to 2022 time series.

6) National Institute of Forest Science (NIFoS) (2021)

| Table 6-8 | Emissions and Removals of Forest Land Remaining Forest Land

(Unit: kt CO_2-eq)

Forest Type[1]	1990	2000	2010	2018	2021	2022
Coniferous Forest	−17,610	−25,906	−30,476	−25,952	−24,701	−24,669
Broadleaf Forest	−20,616	−35,475	−28,097	−16,738	−15,688	−16,538
Mixed Forest	IE	IE	IE	IE	IE	IE
Other (Unstocked and bamboo forest)[2]	NE	NE	NE	NE	NE	NE
Total	**−38,227**	**−61,380**	**−58,843**	**−42,691**	**−40,389**	**−41,207**

Note: 1) Removals of forest land were reported separately under coniferous forest and broadleaf forest. Mixed forest, in domestic statistics, was assumed to be consisted of coniferous and broadleaf trees by 50 percent each based on growing stock volume of each forest type based on expert judgment. Therefore removals of mixed forest were included in coniferous and broadleaf forest proportionally.

2) As unstocked land does not sequester carbon, emissions from unstocked forest were reported as "NA" (Not Applicable) while that from bamboo forest were not estimated as the bamboo forest accounted for 0.34 percent of stocked forest land with no available activity data. It was considered the likely level of associated emissions was insignificant.

6.2.1.2 Methodology

6.2.1.2.1 Method

Biomass carbon stocks of forest land remaining forest land were estimated using the Stock-Difference Method[7] at Tier 2 in accordance with the *2006 IPCC Guidelines*. The respective method involves estimating the carbon stocks by multiplying the growing stock volume by forest type of the inventory year by basic wood densities (D), biomass expansion factor (BEF), ratio of below-ground biomass to above-ground biomass (R) and carbon fraction of dry matter (CF). Emissions and removals are obtained from the difference in carbon stock estimates from previous year of the inventory year.

7) The stock-difference method is used to obtain the annual carbon stock change for the inventory year by determining the carbon stocks at two points in time and calculating the difference between the two carbon stock estimates. It is a data-intensive method and thus used in Tier 2 approach.

Annual change in carbon stocks in biomass in land remaining in the same land−use category (Stock−Difference Method)	
$$\triangle C_B = \frac{C_{t2} - C_{t1}}{t_2 - t_1}$$	
$\triangle C_B$	: annual change in carbon stocks in biomass (the sum of above−ground and below−ground biomass terms in Equation 2.3) in land remaining in the same category (e.g. forest land remaining forest land), [t C/yr]
C_{t2}	: total carbon in biomass at time t2 [t C]
C_{t1}	: total carbon in biomass at time t1 [t C]
$$C = \sum_{i,j}[A_{i,j} \times V_{i,j} \times BCEFs_{i,j}] \times (1 + R_{i,j}) \times CF_{i,j}$$	
C	: total carbon in biomass for time t1 to t2
$A \times V$	: growing stock volume [m^3] = area of land remaining in the same land−use category(A) [ha] × merchantable growing stock volume per hectare(V) [m^3/ha]
$BCEFs$	$BCEFs$ = BEFs × D : biomass conversion and expansion factor for expansion of merchantable growing stock volume to above−ground biomass [t d.m./m^3]
R	: ratio of below−ground biomass to above−ground biomass
CF	: carbon fraction of dry matter [t C/t d.m.]
i	: ecological zone/forest type i (*i = 1 to n*)
j	: climate domain j (*j = 1 to m*)

Source: *2006 IPCC Guidelines, Vol.4, Ch.2, Equation 2.8*

6.2.1.2.2 Emission and Removal Factor

For forest land remaining forest land, country−specific removal factors for wood density, biomass expansion factors and the ratio of below− to above−ground biomass by forest type were derived by applying removal factors of each tree species weighted by the growing stock volume of the respective species (see Table 6−9).

The default values from the *2006 IPCC Guidelines* were used for carbon fraction of dry matter (CF). Corresponding to the climate zone of ROK, the values for conifers (0.51) and broad−leaved (0.48) of temperate and boreal climate domain were used.

| Table 6-9 | Removal Factor for Forest Biomass

Removal Factor	Value		Source
Basic Wood Density (D)	Conifers	0.46	CS
	Broad-leaved	0.68	
Biomass Expansion Factor (BEF)	Conifers	1.43	
	Broad-leaved	1.51	
Biomass Conversion and Expansion Factor (BCEF)	= Basic Wood Density (D) × Biomass Expansion Factor (BEF)		
Ratio of below-ground biomass to above-ground biomass (R)	Conifers	0.27	
	Broad-leaved	0.36	
Carbon Fraction (CF)	Conifers	0.51	*2006 IPCC Guidelines*
	Broad-leaved	0.48	

Source: *2006 IPCC Guidelines, Vol.4, Ch.4, Table 4.3*

BOX 1. Forest Land : Country-Specific (CS) Removal Factors

Korea Forest Service (KFS) and National Institute of Forest Science (NIFoS) developed national removal factors in 2014, 2017, and 2018 for national greenhouse gas inventory. Wood density, biomass expansion factor and ratio of below- to above-ground biomass were developed based on the weighted growing stock volume of 20 dominant species of conifers and broadleaf trees in ROK.

Category	Tree Species	Basic Wood Density (D)		Biomass Expansion Factor (BEF)		Ratio of Below- to Above-ground Biomass (R)		Carbon Conversion Factor (CF)
		CS	Uncertainty	CS	Uncertainty	CS	Uncertainty	
Coniferous Forest	• Conifers[1]	0.46	-	1.43	-	0.27	-	0.51
	• Pinus densiflora (Gangwon Province pine) • Pinus densiflora (Central Korean pine) • Pinus rigida • Pinus thunbergii • Pinus koraiensis • Cryptomeria japonica • Chamaecyparis obtusa	0.35 - 0.50	3.50 - 11.90	1.31 - 1.74	5.97 - 11.62	0.20 - 0.36	8.16 - 32.69	
Broadleaf Forest	• Broadleaf [1]	0.68	-	1.51	-	0.36	-	0.48
	• Quercus variabilis • Quercus mongolica • Quercus acutissima • Quecus aliena • Quercus acuta • Evergreen broadleaf species	0.36 - 0.83	1.66 - 17.30	1.17 - 2.63	2.20 - 16.03	0.19 - 0.50	11.80 - 27.43	

Note: 1) Factors for conifers and broadleaf trees were derived from factors of each forest type using country-specific removal factors developed for each tree species.

6.2.1.2.3 Activity Data

Activity data for forest land remaining forest land were from *Basic Forest Statistics* and *Statistical Yearbook of Forestry* which include the area of forest land as well as growing stock volume by forest type and age class. When estimating removals, growing stock volume of coniferous and broadleaf forests available in respective statistics were used while that of mixed forests were allocated to coniferous and broadleaf forests by 50 percent each based on expert judgment.

The total volume of growing stock in 2022 was 1,062 million ㎥, a 2.2 percent increase from 2021. Coniferous forest increased by 2.7 percent while broadleaf forest and mixed forest increased by 1.3 percent and 2.1 percent.

| Table 6-10 | Activity Data Source for Forest Land Remaining Forest Land

Period	Activity Data	Name of Statistics	Published by
1990-2022	Area and growing stock volume of forest land by forest type	*National Forest Inventory*	Korea Forest Service (KFS)
		Basic Forest Statistics	
		Statistical Yearbook of Forestry	

| Table 6-11 | Growing Stock Volume by Forest Type

(Unit: Thousand ㎥)

Forest Type	1990	2000	2010	2018	2021	2022
Coniferous Forest	122,009	202,924	330,561	431,432	470,452	483,288
Broadleaf Forest	61,923	130,339	223,830	271,375	281,837	285,611
Mixed Forest	69,828	130,491	213,752	270,247	287,414	293,324
Other (Unstocked and bamboo forest)	NE	NE	NE	NE	NE	NE
Total	253,760	463,755	768,143	973,055	1,039,702	1,062,222

Note: The average volume of growing stock over a span of three years (Inventory year *N*, *N*-1, *N*-2) was used as activity data.

| Table 6-12 | Forest Land Area by Forest Type

(Unit: kha)

Forest Type		1990	2000	2010	2018	2021	2022
Coniferous Forest		3,079	2,711	2,581	2,321	2,321	2,308
Broadleaf Forest		1,389	1,666	1,719	2,018	2,015	2,000
Mixed Forest		1,810	1,885	1,865	1,693	1,643	1,658
Other	Bamboo Forest	8	6	7	20	20	20
	Unstocked Land[1)]	190	154	197	254	295	305
Total		6,476	6,422	6,369	6,306	6,294	6,291

Note: 1) In accordance with the FAO definition of forest land, unstocked land where trees have been removed but is expected to recover as forest land falls under forest land.

6.2.1.3 Uncertainty and Time-series Consistency

6.2.1.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

6.2.1.3.1 Time-series Consistency

CO_2 removals of forest land remaining forest land were estimated using methodology, activity data and emission factors consistently from 1990 through 2022 to ensure time series consistency.

6.2.1.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

6.2.2 Land converted to forest land (4.A.2.)

In accordance with Approach 1 as presented in the *2006 IPCC Guidelines*, land converted to forest land was included in Forest land remaining forest land (4.A.1.).

6.2.3 Biomass burning in forest land (4.IV.A.)

6.2.3.1 Category Description

2022	Gas	Methodology	Emission Factor	Activity Data	Carbon Pool
	CO_2, CH_4, N_2O	Tier 1	D	Volume of trees damaged	Living biomass (above-ground)

Biomass burning in forest land (4.IV.A.) are reported under the categories of Controlled burning (4.IV.A.1.a.) and Wildfires (4.IV.A.1.b.). Only direct emissions of CO_2, CH4, and N_2O caused by wildfires were reported[8] as controlled burning does not occur in ROK.

8) According to the *2006 IPCC Guidelines*, CO_2 emissions from biomass burning in forest land remaining forest land are reported in the year of the fire since they are generally not synchronous with rates of CO_2 uptake with losses representing several years of growth and carbon accumulation.

Emissions from wildfires in coniferous and broadleaf forests of stocked land were estimated, and emissions from mixed forest were allocated to coniferous and broadleaf forest by 50 percent each which was the same approach as used for Forest land remaining forest land (4.A.1.).

In 2022, biomass burning in forest land caused emissions of 1,880 kt CO_2-eq. Over the past decade from 2013 to 2022, an average number of 537 wildfires occurred annually, affecting approximately 3,560 ha of forest area. The number of wildfires per year and the forest land area burnt have fluctuated for the past five years[9]. In 2022, an increase in both the number of wildfires and the area burnt was observed.

| Table 6-13 | Emissions and Removals from Biomass Burning in Forest Land

(Unit: kt CO_2-eq)

Source	1990	2000	2010	2018	2021	2022
Biomass burning in forest land	0.2	891	7	65	4	1,880

6.2.3.2 Methodology

6.2.3.2.1. Method

Emission of CO_2, CH_4, and N_2O from biomass burning in forest land were calculated using the Tier 1 methodology presented in the *2006 IPCC Guidelines.*

Estimation of greenhouse gas emissions from fire

$$L_{fire} = A \times M_B \times C_f \times G_{ef} \times 10^{-3}$$

L_{fire}	:	amount of greenhouse gas emissions from fire, [tonnes of each greenhouse gas]
A	:	area burnt [ha]
M_B	:	mass of fuel available for combustion [t d.m./ha]
$A \times l$	:	volume of trees damaged(V) [m3] × basic wood density(D) [t d.m./m3] × biomass expansion factor (BEFs)
C_f	:	combustion factor
G_{ef}	:	emission factor [g/kg d.m.]

Sources: *2006 IPCC Guidelines, Vol.4, Ch.2, Equation 2.27*

9) 2018: 496 wildfires (area burnt: 894 ha); 2019: 653 wildfires (area burnt: 3,255 ha); 2020: 620 wildfires (area burnt: 2,920 ha); 2021: 349 wildfires (area burnt: 766 ha); 2022: 756 wildfires (area burnt: 24,797 ha)

6.2.3.2.2 Emission Factor

Emission factors used to estimate CO_2, CH_4, and N_2O emissions from biomass burning in forest land were based on the default values provided in the *2006 IPCC Guidelines.*

| Table 6-14 | Combustion and Emission Factor for Biomass Burning in Forest Land

Combustion and Emission Factor	Value		Source
Combustion Factor (C_f)	0.45 (All "other" temperate forests)		*2006 IPCC Guidelines*
Emission Factor (G_{ef}) (extra tropical forest)	CO_2	1,569	
	CH_4	4.7	
	N_2O	0.26	

Source: *2006 IPCC Guidelines, Vol.4, Ch.2, Table 2.5*

6.2.3.2.3 Activity Data

Activity data for biomass burning in forest land include the mass of fuel available for combustion (M_B) which was calculated using the volume of trees damaged by wildfires reported in the *Statistical Yearbook of Forestry* (KFS) to which the proportion of growing stock volume by forest type as well as the basic wood density and biomass expansion factors by forest type were applied as shown in Table 6-9.

| Table 6-15 | Activity Data Source for Emissions from Biomass Burning in Forest Land

Period	Activity Data	Name of Statistics	Published by
1990-2022	Volume of trees damaged	*Statistical Yearbook of Forestry*	Korea Forest Service (KFS)

| Table 6-16 | Activity Data for Emissions from Biomass Burning in Forest Land

(Unit: m^3)

Activity Data	1990	2000	2010	2018	2021	2022
Volume of trees damaged	323	1,373,302	11,168	100,710	5,641	2,925,560

6.2.3.3 Uncertainty and Time-series Consistency

6.2.3.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

6.2.3.3.2 Time-series Consistency

Emissions from biomass burning in forest land were estimated using methodology, activity data and emission factors consistently from 1990 through 2022 to ensure time series consistency.

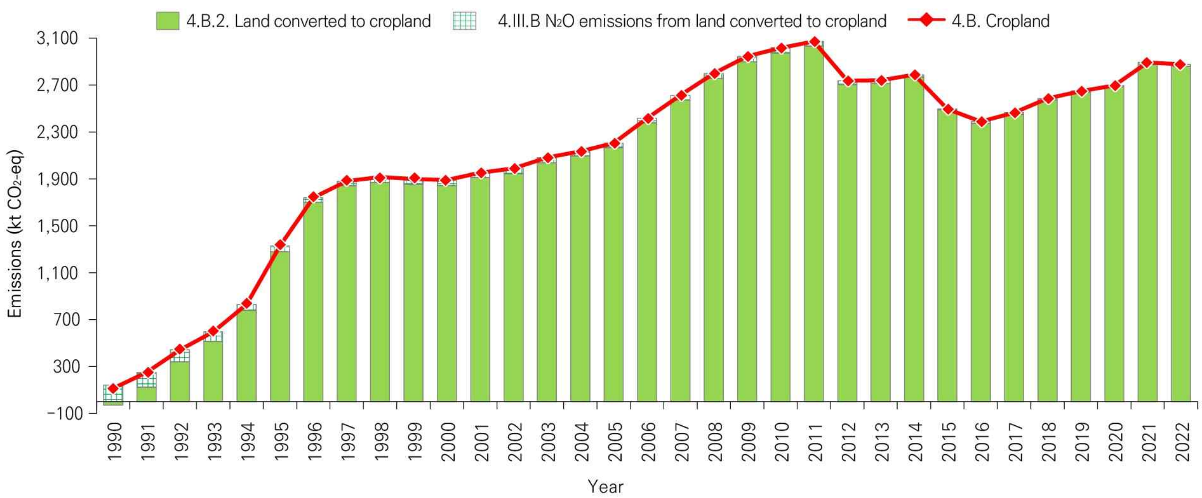
6.2.3.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

6.3 Cropland (4.B.)

Cropland (4.B.) includes rice fields, arable and tillable land used for cultivation of annual and perennial crops. Under this reporting category, CO_2 emissions and removals from soils are estimated based on changes in land conversion, land use, and management regimes such as organic matter application and tillage[10]. The land with high carbon content in soils that is converted to cropland releases carbon into the atmosphere as an emission source whereas the land with sparse vegetation or frequently tilled that is converted to cropland increases carbon in soils and thus is accounted for as a carbon sink.

In 2022, emissions from cropland were 2,876 kt CO_2−eq, an increase of 2,763 kt CO_2−eq from 1990.



| Figure 6−4 | Trends in Cropland Emissions and Removal (1990−2022)

| Table 6−17 | Emissions and Removals from Cropland

(Unit: kt CO_2−eq)

Source	1990	2000	2010	2018	2021	2022
4.B. Total Cropland	113	1,889	3,017	2,585	2,893	2,876
4.B.1. Cropland remaining cropland[1)]	NE	NE	NE	NE	NE	NE
4.B.2. Land converted to cropland[2)]	−30	1,843	2,972	2,570	2,874	2,859
4.Ⅲ.B. N_2O Emissions from land converted to cropland	143	46	45	15	19	17

Note: 1) Emissions and removals from soil carbon changes in cropland remaining cropland were not estimated due to lack of activity data

2) Using the IPCC Approach 1 method, soil carbon changes were estimated based on the net change of cropland including the area of Land converted to cropland.

10) Emissions and removals from biomass and dead organic matter in cropland were not estimated due to lack of activity data.

6.3.1 Cropland Remaining Cropland (4.B.1.)

Emissions from cropland remaining cropland were not estimated due to lack of data.

6.3.2 Land Converted to Cropland (4.B.2.)

6.3.2.1 Category Description

2022	Gas	Methodology	Emission Factor	Activity Data	Carbon Pool
	CO_2	Tier 1	D, CS	Area of cropland	Soil carbon

To estimate emissions and removals from soil carbon in Land converted to cropland (4.B.2.), the land that was converted to cropland in the past 20 years was classified as the land subject to this reporting subcategory which was then divided by soil type including mineral and organic soils and by management regimes such as application of organic matter and tillage. Only emissions and removals from mineral soils were reported[11]. As land cover change matrix is currently not available in ROK, emissions from the cropland converted to other land were included in this subcategory.

Emissions from land converted to cropland were 2,859 kt CO_2−eq. In 1990, it was a carbon sink with removal of 30 kt CO_2−eq. From 1991 onward, emissions occurred.

| Table 6−18 | Emissions and Removals from Land Converted to Cropland

(Unit: kt CO_2−eq)

Category	1990	2000	2010	2018	2021	2022
Land converted to cropland	−30	1,843	2,972	2,570	2,874	2,859

6.3.2.2 Methodology

6.3.2.2.1 Method

Soil carbon stock changes for land converted to cropland were estimated using the Formulation A of Equation 2.25 from the *2006 IPCC Guidelines.*

11) Emissions and removals from organic soil were not estimated as the area of organic soil is 409 ha, accounting for 0.004 percent of the total land area with no available activity data.

Annual change in carbon stocks in soils

$$\Delta C_{Soils} = \Delta C_{Mineral} - L_{Organic} + \Delta C_{Inorganic}$$

ΔC_{Soils}	: annual change in carbon stocks in soils [t C/yr]
$\Delta C_{Mineral}$	: annual change in organic carbon stocks in mineral soils [t C/yr]
$L_{Organic}$	: annual loss of carbon from drained organic soils [t C/yr]
$\Delta C_{Inorganic}$	: annual change in inorganic carbon stocks from soils [t C/yr] (assumed to be 0 unless using a Tier 3 approach)

Source: *2006 IPCC Guidelines, Vol.4, Ch.2, Equation 2.24*

Annual change in organic carbon stocks in mineral soils (Formulation A)

$$\Delta C_{Mineral} = \frac{(SOC_0 - SOC_{(0-T)})}{D}$$

$$SOC = \sum_{c,s,i} (SOC_{REF_{c,s,i}} \cdot F_{LU_{c,s,i}} \cdot F_{MG_{c,s,i}} \cdot F_{I_{c,s,i}} \cdot A_{c,s,i})$$

※ D is replaced by T if T is ≥ 20 years.

$\Delta C_{Mineral}$	: annual change in carbon stocks in mineral soils [t C/yr]
SOC_0	: soil organic carbon stock in the last year of an inventory time period [t C]
$SOC_{(0-T)}$	: soil organic carbon stock at the beginning of the inventory time period [t C]
T	: number of years over a single inventory time period [yr]
D	: time dependence of stock change factors which is the default time period for transition between equilibrium SOC values [yr]
c	: c represents the climate zones, *s* the soil types, and *i* the set of cropland management
SOC_{REF}	: the reference carbon stock [t C/ha]
F_{LU}	: stock change factor for land-use systems or sub-system for a particular land-use
F_{MG}	: stock change factor for management regime
F_I	: stock change factor for input of organic matter
A	: land area of the stratum being estimated [ha]

Source : *2006 IPCC Guidelines. Vol.4, Ch.2, Box 2.1, Formulation A*

6.3.2.2.2 Emission and Removal Factor

For land converted to cropland, country-specific values of the reference carbon stocks (SOC_{REF}) were developed and used for the entire time series under the assumption that it remained unchanged throughout the respective period.

According to the climate data from Korea Meteorological Administration, the climate zone of ROK is warm temperate moist. As domestic soil includes HAC (High Activity Clay), LAC (Low Activity Clay), sandy and volcanic ash soil, the cropland area of the whole country was classified into four categories of respective soil types[12]. Soil organic carbon stocks (SOC) were calculated using the area of cropland by soil type to which reference carbon stocks (SOC_{REF}) and stock change factors (F_{LU}, F_{MG}, F_I) were applied.

| Table 6-19 | Proportion of Cropland Area by Soil Type

(Unit: %)

Soil Type	HAC Soils	LAC Soils	Sandy Soils	Volcanic Ash
Rice paddy	89.55	3.92	2.33	4.21
Upland field	89.41	4.89	2.33	3.37
Orchards	81.89	4.82	3.17	10.12

Source: *Taxonomical Classification of Korea Soils*, Rural Development Administration (RDA) (2014)

| Table 6-20 | Reference Carbon Stocks (SOC_{REF}) and Soil Organic Carbon Stocks (SOC)

(Unit: t C/ha, Soil Depth 0-30cm)

Soil Organic Carbon		HAC Soils	LAC Soils	Sandy Soils	Volcanic Ash	Source
SOC_{REF}		39	34	24	127	CS[1]
SOC by Cropland Type	Paddy Field	42.90	37.40	26.40	139.70	
	Upland Field	26.91	23.46	16.56	87.63	
	Orchard	44.85	39.10	27.60	146.05	

Note: 1) Developed by the National Institute of Agricultural Sciences using soil series which is a category of the national soil classification system of soil taxonomy developed by the U.S. Department of Agriculture to distinguish between different soil properties and the sampling analysis for soil organic carbon content

For stock change factors including F_{LU}, F_{MG} and F_I, default values from the *2006 IPCC Guidelines* that were considered to represent the cropland soil and climate regime in ROK were used as shown in Table 6-21.

| Table 6-21 | Stock Change Factors by Management Regime

Stock Change Factor	Level	Temperature Regime	Moisture Regime	IPCC Default	Source
Land-use(F_{LU})	Long-term Cultivated (Upland Field)	Temperate	Wet	0.69	*2006 IPCC Guidelines*
	Long-term Cultivated (Orchard)	Temperate	Wet	1.0	
	Paddy Field Rice Cultivation (Paddy Field)	Temperate/ Tropical	Dry/Wet	1.1	
Tillage (F_{MG})	Full (Paddy Field, Upland Field)	Temperate	Dry/Wet	1.0	
	No-till (Orchard)	Temperate	Wet	1.15	
Organic Material Application (F_I)	Medium (Paddy Field, Upland Field, Orchard)	Temperate	Dry/Wet	1.0	

Source : *2006 IPCC Guidelines. Vol.4, Ch.5, Table 5.5*

12) *Taxonomical Classification of Korea Soils*, Rural Development Administration (RDA) (2014)

6.3.2.2.3 Activity Data

Activity data for land converted to cropland include the area of land for cultivation of paddy rice and upland crops, orchards (open−field, greenhouse farming), mulberry fields, other tree farms and other crop cultivation. Since national data on the area of orchards in controlled environment have been collected from 2000, respective data for the 1993 to 1999 time period were interpolated from the values for the 1987 to 1992 period presented in a research paper[13].

The proportions of areas that fall into soil categories of HAC soils, LAC soils, sandy soils and volcanic ash soils were obtained using *Taxonomical Classification of Korea Soils* and applied to the area of croplands provided in *Agricultural Area Statistics* to disaggregate the area by soil type. Based on the proportions for each soil type, the cropland area in year *N* was compared with that in year *N*−20. If the cropland area in year *N* was larger, the difference value was included in Land converted to cropland (4.B.2.); if smaller, it was still included in Land converted to cropland (4.B.2.).

| Table 6−22 | Activity Data Source for Land Converted to Cropland

Period	Activity Data	Name of Statistics	Published by
1970−2022	Area of cropland	*Agricultural Area Statistics*	Statistics Korea (KOSTAT)
1987−1992	Area of orchards in controlled environment	*Research on Development of Fruit Farming*	Rural Development Administration (RDA)
1970−2022	Proportion of areas by soil type	*Taxonomical Classification of Korea Soils*	

| Table 6−23 | Activity Data for Land Converted to Cropland

(Unit: kha)

Activity Data	1990	2000	2010	2018	2021	2022
Area of land converted to cropland (A)	213	62	60	20	38	28
Area of cropland converted to other land (B)	354	369	453	334	368	362
Net change area in cropland (A−B)	−142	−307	−394	−314	−329	−334

6.3.2.3 Uncertainty and Time−series Consistency

6.3.2.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

13) *Research on Development of Fruit Farming*, RDA (1992)

6.3.2.3.2 Time-series Consistency

Emissions from land converted to cropland were estimated using methodology, activity data and emission factors consistently from 1990 through 2022 to ensure time series consistency.

6.3.2.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

6.3.2.5 Planned Improvement

A research is underway to develop the land cover change matrix which will be used for future inventories to reflect land-use conversions more accurately and enhance national statistics of the LULUCF sector.

6.3.3 N_2O Emissions from Land Converted to Cropland (4.III.B.)

6.3.3.1 Category Description

2022	Gas	Methodology	Emission Factor	Activity Data	Carbon Pool
	N_2O	Tier 1	D, CS	Area of cropland	Soil carbon

In the land converted to cropland, mineralization of soil organic matter occurs during which ammonium and nitrate are converted into N_2O by microbial activity, resulting in releasing N_2O for several years after the conversion.

In 2022, N_2O emissions from land converted to cropland were 17 kt CO_2-eq, a decrease of 126 kt CO_2-eq from 1990.

| Table 6-24 | Emissions from Land Converted to Cropland

(Unit: kt CO_2-eq)

Sub-category	1990	2000	2010	2018	2021	2022
N_2O Emissions from Land Converted to Cropland	143	46	45	15	19	17

6. Land Use, Land-Use Change and Forestry

6.3.3.2 Methodology

6.3.3.2.1 Method

N_2O emissions from land converted to cropland were calculated using the methodology presented in the *GPG-LULUCF Guidelines.*

N_2O Emissions as a result of the disturbance associated with land-use conversion of forest land, grassland, or other land to cropland

$$N_2O_{conv} = EF_1 \times N_{net-min} \times 44/28 \times 10^{-6}$$
$$N_{net-min} = \triangle C_{LCMineral} \times 1/C{:}N\ ratio$$

N_2O_{conv}	N_2O emissions as a result of the disturbance associated with land-use conversion of forest land, grassland, or other land to cropland [Gg N_2O/yr]
EF_1	IPCC default emission factor to calculate emissions from agricultural land caused by added N (2006 IPCC D-EF Value of 0.01 kg N_2O-N/kg N)
$N_{net-min}$	annual N released by net soil organic matter mineralisation as a result of the disturbances [kg N/yr]
$\triangle C_{LCMineral}$	annual change in carbon stocks in mineral soils in land converted to cropland [kg C/yr]
C:N ratio	the ratio by mass of C to N in the soil organic matter (SOM) [kg C/kg N]
44/28	N_2O conversion factor

Source: *GPG-LULUCF, Equation 3.3.14, 3.3.15*

6.3.3.2.2 Emission and Removal Factor

For N_2O emissions from land converted to cropland, the default value of 0.01 kg N_2O-N/kg N presented in the *2006 IPCC Guidelines* as well as the default value of 15 for carbon-to-nitrogen ratio of organic matter in soils were used.

6.3.3.2.3 Activity Data

For N_2O emissions from land converted to cropland, the same activity data as for Land Converted to Cropland (4.B.2.) were used.

6.3.3.3 Uncertainty and Time-series Consistency

6.3.3.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

6.3.3.3.2 Time-series Consistency

N_2O emissions from land converted to cropland were estimated using methodology, activity data and emission factors consistently from 1990 through 2022 to ensure time series consistency.

6.3.3.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

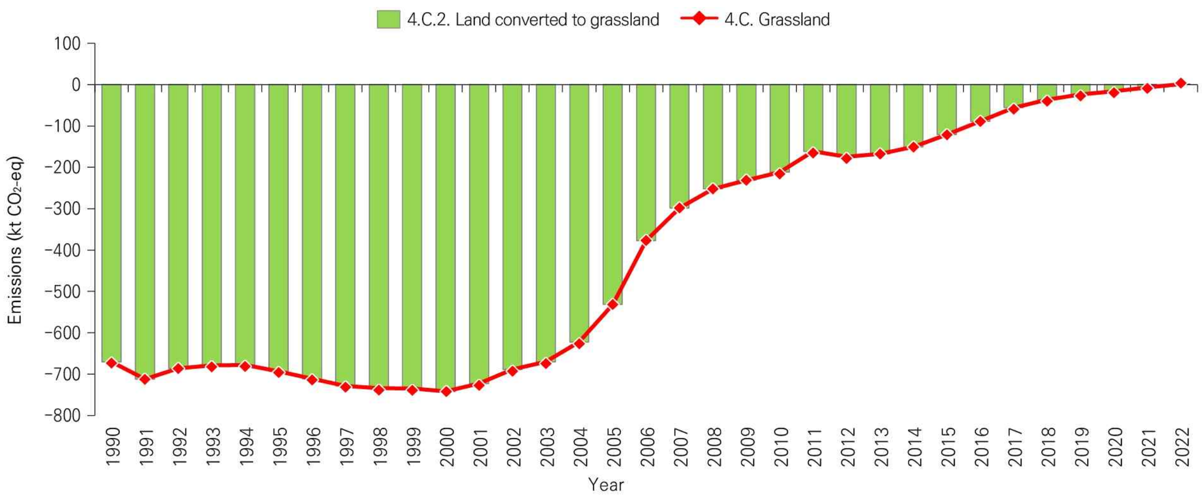
6.3.3.5 Improvement Plan

Emissions and removals from cropland were estimated using stock change factors (F_{LU}, F_{MG}, F_I) of the same values every year with the assumption that there was no change in land-use, input of organic matter or tillage practices due to lack of land-use matrix and historical archive on agricultural management practices. A key improvement is to develop a land-use matrix and collect activity data for Approach 2 and 3 to enhance the accuracy of soil carbon estimates in cropland. This category of cropland will also be extended to include emissions and removals from biomass to provide a complete inventory for this category.

6.4 Grassland (4.C.)

Grassland refers to rangelands, savannahs, pastures and hay land that have vegetation dominated by perennial grasses where grazing is the predominant land use. Under this reporting category, emissions and removals from soils are estimated which are determined by land conversion, land use and management variables such as organic matter application and irrigation[14]. The land with high carbon content in soils that is converted to grassland releases carbon into the atmosphere as an emission source whereas the land with sparse vegetation or frequently tilled that is converted to grassland increases carbon in soils and thus is accounted for as a carbon sink.

In 2022, emissions from grassland were 1 kt CO_2−eq which were the first emissions from this category followed by decreasing removals since 2000. The grassland area which steadily increased from 1970 until it started to decrease since 2013 was 55,977 ha in 2022.



| Figure 6−5 | Trends in Emissions and Removals from Grassland (1990−2022)

| Table 6−25 | Emissions and Removals from Grassland

(Unit: kt CO_2−eq)

(Sub)Category	1990	2000	2010	2018	2021	2022
4.C. Grassland	−670	−742	−212	−36	−7	1
4.C.1. Grassland remaining grassland[1)]	NE	NE	NE	NE	NE	NE
4.C.2. Land converted to grassland[2)]	−670	−742	−212	−36	−7	1

Note: 1) Emissions and removals from soil carbon changes in grassland remaining grassland were not estimated due to lack of activity data

2) Using the IPCC Approach 1 method, soil carbon changes were estimated based on the net change of grassland including the area of Grassland converted to other land.

14) Emissions and removals from biomass and dead organic matter in grassland were not estimated due to lack of activity data.

6.4.1 Grassland Remaining Grassland (4.C.1.)

Emissions and removals from grassland remaining grassland were not estimated due to insufficient statistics and research data required to apply the Tier 1 methodology of the *2006 IPCC Guidelines.*

6.4.2 Land Converted to Grassland (4.C.2.)

6.4.2.1 Category Description

2022	Gas	Methodology	Emission Factor	Activity Data	Carbon Pool
	CO_2	Tier 1	D, CS	Area of grassland	Soil carbon

To estimate emissions and removals from soil carbon in Land converted to grassland (4.C.2.), the land that was converted to grassland in the past 20 years was classified as the land subject to this reporting subcategory which was then divided by soil type including mineral and organic soils and by management regimes including application of organic matter and tillage. Only emissions and removals from mineral soils were reported[15)]. As land cover change matrix is currently not available in ROK, emissions from the grassland converted to other land were included in this subcategory.

Emissions from soils in the land converted to grassland were 1 kt CO_2-eq in 2022. In 1990, the area was estimated to be a net sink with removals of 670 kt CO_2-eq, but the removals gradually declined over time, eventually shifting to net emissions by 2022.

| Table 6-26 | Emissions and Removals from Land Converted to Grassland

(Unit: kt CO_2-eq)

Category	1990	2000	2010	2018	2021	2022
Soil Carbon	-670	-742	-212	-36	-7	1

6.4.2.2 Methodology

6.4.2.2.1 Method

Soil carbon stock changes for land converted to grassland were estimated using the Formulation A of Equation 2.25 from the *2006 IPCC Guidelines.*

15) *Taxonomical Classification of Korea Soils*, RDA (2014)

Annual change in carbon stocks in soils	
	$$\Delta C_{Soils} = \Delta C_{Mineral} - L_{Organic} + \Delta C_{Inorganic}$$
$\triangle C_{Soils}$	: annual change in carbon stocks in soils [t C/yr]
$\triangle C_{Mineral}$	: annual change in organic carbon stocks in mineral soils [t C/yr]
$L_{Organic}$	: annual loss of carbon from drained organic soils [t C/yr]
$\triangle C_{Inorganic}$	: annual change in inorganic carbon stocks from soils [t C/yr] (assumed to be 0 unless using a Tier 3 approach)

Source : *2006 IPCC Guidelines, Vol.4, Ch.2, Equation 2.24*

Annual change in organic carbon stocks in mineral soils (Formulation A)

$$\Delta C_{Mineral} = \frac{(SOC_0 - SOC_{(0-T)})}{D}$$

$$SOC = \sum_{c,s,i} (SOC_{REF_{c,s,i}} \cdot F_{LU_{c,s,i}} \cdot F_{MG_{c,s,i}} \cdot F_{I_{c,s,i}} \cdot A_{c,s,i})$$

※ D is replaced by T if T is ≥ 20 years

$\Delta C_{Mineral}$	: annual change in carbon stocks in mineral soils [t C/yr]
SOC_0	: soil organic carbon stock in the last year of an inventory time period, [t C]
$SOC_{(0-T)}$	: soil organic carbon stock at the beginning of the inventory time period [t C]
T	: number of years over a single inventory time period [yr]
D	: time dependence of stock change factors which is the default time period for transition between equilibrium SOC values [yr]
c	: represents the climate zones, s the soil types, and i the set of management systems that are present in a country.
SOC_{REF}	: the reference carbon stock [t C/ha]
F_{LU}	: stock change factor for land-use systems or sub-system for a particular land-use
F_{MG}	: stock change factor for management regime
F_I	: stock change factor for input of organic matter
A	: land area of the stratum being estimated [ha]

Source : *2006 IPCC Guidelines, Vol.4, Ch.2, Equation 2.25*

6.4.2.2.2 Emission and Removal Factor

The climate zone of ROK is warm temperate moist, and the grassland area of the whole country was classified into four categories of respective soil types following the classifications of grassland area by soil type suggested in *Taxonomical Classification of Korea Soils*. Soil organic carbon stocks (SOC) were calculated by applying the default value of 1.0 for stock change factors (F_{LU}, F_{MG}, F_I) from the *2003 IPCC GPG-LULUCF* as well as country-specific factors and soil organic carbon stocks (SOC_{REF}) per soil type to the area of grassland.

| Table 6-27 | Proportion of Grassland Area by Soil Type

(Unit: %)

Soil Type	HAC Soils	LAC Soils	Sandy Soils	Volcanic Ash
Grassland	71.96	4.14	5.45	18.45

Source: *Taxonomical Classification of Korea Soils*, RDA (2014)

| Table 6-28 | Soil Organic Carbon Stocks (SOC_{ref})

(Unit: t C /ha, Soil Depth 0-30cm)

Soil Type	Value	Climate	Source
HAC Soils[1]	88	Warm temperate, moist[3]	*2003 IPCC GPG-LULUCF*
LAC Soils[2]	63		
Sandy Soils	34		
Volcanic Ash	95	-	CS

Note: 1) HAC: over 0.3 of CEC/Clay content

2) LAC: less than 0.3 of CEC/Clay content

3) According to climate data from the KMA (1990-2010) and the classification of climate and humidity system in the *IPCC Guidelines,* ROK's climate falls into the category of warm temperate and wet with an annual average temperature of 13°C as well as the ratio of annual precipitation to evapotranspiration (MAP/PET) of 1.19.

For stock change factors of F_{LU}, F_{MG} and F_I, the default values from the *2006 IPCC Guidelines* that are classified by land use, tillage method and organic matter application. The land use or land-use change factor (F_{LU},) of which the default value is 1.0 for all grasslands and climate regimes was used. The grassland management regime factor (F_{MG}) of which the default value is 1.0 was used as domestic grasslands are continuously managed without degradation. The organic matter application factor (F_I) of which the default value is 1.0 was applied assuming that the reference quantity of organic matter was applied to domestic grassland.

| Table 6-29 | Stock Change Factors by Grassland Management

Category	Level	Moisture Regime	Default Factor
Land Use (F_{LU})	All	All	1.0
Management (F_{MG})	Nominally managed (non-degraded)	All	1.0
	Moderately degraded	Temperate/ Boreal	0.95
	Severely degraded	All	0.7
	Improved grassland	Temperate/ Boreal	1.14
Organic Matter Input (F_I) (applied only to improved grassland)	Medium	All	1.0
	High	All	1.11

Note: Default values used for ROK's domestic grassland in yellow shaded cells ( )
Source: *2006 IPCC Guidelines Vol.4, Ch.6, Table 6.2*

6.4.2.2.3 Activity Data

Activity data used for land converted to grassland was based on the area of pastures from the *Cadastral Statistics* from which area changes from 20 years prior to the inventory year was calculated. Data on grassland area for the 1970 to 1977 time series which were not available were extrapolated consistent with the *2006 IPCC Guidelines* to ensure completeness and time-series consistency.

| Table 6-30 | Activity Data Source for Land Converted to Grassland

Period	Activity Data	Name of Statistics	Published by
1970-2022	Area of pastures	*Cadastral Statistics*	Ministry of Land, Infrastructure, and Transport (MOLIT)
1970-2022	Proportions of area by soil type	*Taxonomical Classification of Korea Soils*	Rural Development Administration (RDA)

| Table 6-31 | Activity Data for Land Converted to Grassland

(Unit: kha)

Activity Data	1990	2000	2010	2018	2021	2022
Area of Land Converted to Grassland (A)	43	47	14	2	0.4	0
Area of grassland converted to other land (B)	0	0	0	0	0	0.08
Net change area in grassland (A-B)	43	47	14	2	0.4	-0.08

6.4.2.3 Uncertainty and Time-series Consistency

6.4.2.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

6.4.2.3.2 Time-series Consistency

CO_2 emissions from land converted to grassland were estimated using methodology, activity data and emission factors consistently from 1978 through 2022 to ensure time series consistency.

6.4.2.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

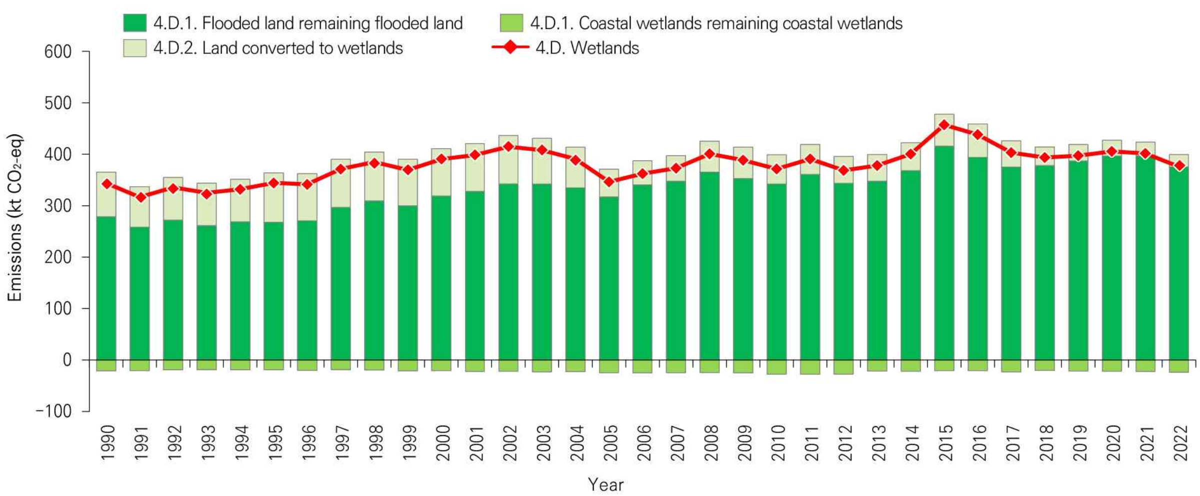
6.4.2.5 Planned Improvement

A research is underway to develop the land cover change matrix which will be used for future inventories to reflect land-use conversions more accurately and enhance national statistics of the LULUCF sector.

6.5 Wetlands (4.D.)

Wetlands (4.D.) refer to any land that is covered or saturated by water for all or part of the year as defined by the *2006 IPCC Guidelines* and the *2013 IPCC Supplement (Wetlands).* Under this reporting category, greenhouse gas emissions and removals from managed wetlands are estimated. In ROK, wetlands are categorized into flooded lands and coastal wetlands. Flooded land and coastal wetlands are managed at the national level under relevant legislation including the *Wetlands Conservation Act, Act on the Sustainable Management and Restoration of Tidal Flats (Gaetbeol) and Adjacent Areas Thereof,* and *Public Waters Management and Reclamation Act.* Emissions and removals from wetlands where the water table is artificially raised or drained were included in flooded land while those from human-induced activities such as rewetting, revegetation and creation of tidal marshes and seagrass meadows were reported under coastal wetlands.

In 2022, emissions from wetlands were 376 kt CO_2-eq, representing an increase of 31.7 kt CO_2-eq from 1990. Flooded lands emitted 399 kt CO_2-eq, representing an increase of 34.4 kt CO_2-eq from 1990 while removals from coastal wetlands were 24 kt CO_2-eq which was an increase of 2.7 kt CO_2-eq from 1990.



| Figure 6-6 | Trends in Wetlands Emissions and Removals (1990-2022)

| Table 6-32 | Emissions and Removals from Wetlands

(Unit: kt CO_2-eq)

(Sub)Category	1990	2000	2010	2018	2021	2022
4.D. Wetlands	**344**	**390**	**372**	**394**	**402**	**376**
4.D.1. Wetlands remaining wetlands	258	298	315	358	375	352
4(II).D.1.b. Flooded land remaining flooded land	279	319	342	378	397	376
4.D.1.c. Other wetlands remaining other wetlands	-21	-21	-28	-20	-22	-24
4.D.2. Land converted to wetlands	86	92	57	36	27	24
4.D.2.b. Land converted to flooded land	86	92	57	36	27	24

6.5.1 Wetlands remaining wetlands (4.D.1.)

	Gas	Method	Emission Factor	Activity Data	Carbon Pool
2022	(Flooded land) CH_4	Tier 1	D	Area of flooded land	Soil carbon
	(Coastal wetlands) CO_2	Tier 2	D, CS	Area of coastal wetlands	

6.5.1.1 Flooded Land Remaining Flooded Land (4.D.1.b.)

6.5.1.1.1 Category Description

Flooded land remaining flooded land (4.D.1.b.) includes rivers, dams, lakes and ponds that are managed by human activities such as the water table and vegetation. Accordingly, emissions from all areas falling into the category of flooded lands such as ditches, reservoirs and fish farms in the *Cadastral Statistics* were estimated. Only CH_4 emissions were reported following the methodological approach outlined in Appendices of the *2006 IPCC Guidelines* as no methodologies for CO_2 and N_2O emissions from flooded lands were suggested by the *2006 IPCC Guidelines*.

In accordance with the *2006 IPCC Guidelines,* CO_2, CH_4, and N_2O emissions resulting from peat extraction as well as from molecular diffusion across the air-water interface and bubble emissions from flooded land are reported under Peat extraction remaining peat extraction (4.D.1.a.). In ROK, peatlands do not exist and thus no emissions occur from this source.

Emissions from flooded land remaining flooded land were 376 kt CO_2-eq, a decrease of 96.8 kt CO_2-eq from 1990.

| Table 6-33 | Emissions and Removals from Flooded Land Remaining Flooded Land

(Unit: kt CO_2-eq)

Sub-category	1990	2000	2010	2018	2021	2022
Flooded Land Remaining Flooded Land	279	319	342	378	397	376

6.5.1.1.2 Methodology

1) Method

CH_4 emissions from molecular diffusion across the air-water interface gaseous diffusion due to the decomposition of soil organic matter in flooded land remaining flooded land were estimated in accordance with the *2006 IPCC Guidelines*.

The CH_4 emissions from flooded land were calculated by multiplying the number of freezing-free days (P) by the daily average diffusion emission and the flooded land area.

CH_4 emissions from flooded lands

$$CH_4 emissions_{WW\ flood} = P \times E(CH_4)_{diff} \times A_{flood,\ total\ surface} \times 10^{-6}$$

$CH_4 emissions_{WW\ flood}$	:	total CH_4 emissions from flooded land [Gg CH_4/yr]
P	:	ice-free period [day]
$A_{flood,\ total\ surface}$	:	total flooded surface area, including flooded land, lakes and rivers [ha]
$E(CH_4)_{diff}$	:	averaged daily diffusive emissions [kg CH_4/ha/day]

Source : *2006 IPCC Guidelines, Vol.4, Appendix 3, Equation 3A.1*

The ice-free period (P) was calculated by subtracting annual frost days from 365 days. The weighted average value was calculated using the ratio of wetlands area in six province s[16].

| Table 6-34 | Annual Ice-Free Period

(Unit: Day)

Activity Data	1990	2000	2010	2018	2021	2022
Annual Ice-Free Period (P)	275	268	263	283	295	279

16) Gyeonggi-do, Gangwon-do, Gyeongsang-do, Jeju-do, Chungcheong-do and Jella-do

2) Emission and Removal Factor

For the average diffusion emissions for flooded land remaining flooded land, the median value for climate zone of warm temperate and moist which is 0.15 kg CH_4/ha/day as provided in the *2006 IPCC Guidelines*[17] *was used.*

3) Activity Data

Activity data for flooded land remaining flooded land were based on the area of ditches, reservoirs and fish farms provided in the *Cadastral Statistics*.

In 2022, the area of flooded land remaining flooded land increased to 310,000 from 309,000 in 2021.

| Table 6-35 | Activity Data Source for Flooded Land Remaining Flooded Land

Period	Activity Data	Name of Statistics	Published by
1980-2022	Area of ditch, reservoir and fish farm	*Cadastral Statistics*	Ministry of Land, Infrastructure, and Transport (MOLIT)

| Table 6-36 | Activity Data for Flooded Land Remaining Flooded Land

(Unit: kha)

Activity Data	1990	2000	2010	2018	2021	2022
Area of flooded land for the previous 10 years	203	241	283	303	309	310

6.5.1.1.3 Uncertainty and Time-series Consistency

6.5.1.1.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

6.5.1.1.3.2 Time-series Consistency

Emissions from flooded land remaining flooded land were estimated using data on the area of ditches, reservoirs and fish farms from the *Cadastral Statistics*, and the number of frost days provided in the *Annual Climatological Report* for the 1980 to 2022 time series. Methodology and emission factors were used consistently for the entire time series to ensure time series consistency.

17) *2006 IPCC Guidelines, Vol.4, Appendix 3, Table 3A.2*

6.5.1.1.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

6.5.1.1.5 Improvement Plan

Under this subcategory, emissions from ditches, reservoirs and fish farms which were classified as flooded land remaining flooded land were estimated. ROK will explore the potential to disaggregate data into flooded lands to estimate CH_4 emissions from molecular diffusion across the air-water interface, and into non-flooded land to estimate emissions and removals from vegetation, soils and dead organic matter. This will improve the accuracy of the national inventory.

6.5.1.2 Other Wetlands Remaining Other Wetlands (4.D.1.c.)

6.5.1.2.1 Category Description

In accordance with the *2013 IPCC Supplement (Wetlands),* Other wetlands remaining other wetlands (4.D.1.c.) are categorized into organic and mineral soils within managed vegetated coastal wetlands which include tidal freshwater wetlands, brackish wetlands, saline wetlands, and wetlands vegetated with vascular plants. Vegetated coastal wetlands are further subdivided into categories such as mangrove forests, tidal marshes and seagrass meadows. As there is no mangrove forest in ROK, only removals from tidal marshes and seagrass meadows were estimated.

Coastal wetlands in ROK are nationally designated as protected areas which include tidal flats (*Gaetbeol*) control areas, marine protected areas and wetlands protection areas. In accordance with the *Act on the Sustainable Management and Restoration of Tidal Flats (Gaetbeol) and Adjacent Areas Thereof,* the *Conservation and Management of Marine Ecosystems Act,* and the *Wetlands Conservation Act*, biodiversity management measures such as removal of pollutants and invasive species as well as protection of habitats are in place along with prohibition of environmentally damaging activities.

Coastal wetlands that are managed and protected store organic carbon in soils over the long term through processes involving vegetation photosynthesis, anaerobic conditions in saturated lands, and capture of externally introduced organic carbon. Such CO_2 uptake in coastal wetlands was estimated.

Coastal wetlands may also be an emission source of CH_4 when drained soils are rewetted through reconnection of seawater as it shifts microbial decomposition from aerobic to anaerobic conditions. In accordance with the *2013 IPCC Supplement (Wetlands)*, an annual CH_4 emission rate is zero for rewetting that results in more than 18 ppt of salinities. With the assumption that tidal flats in ROK are outside the coastline and thus the salinity is over 18 ppt, CH_4 emissions from coastal wetlands were reported as 'Not Applicable (NA)'[18].

In 2022, CO_2 removals from coastal wetlands were 24 kt CO_2−eq, an increase of 3 kt CO_2−eq from 1990.

| Table 6−37 | Emissions and Removals from Coastal Wetlands

(Unit: kt CO_2−eq)

Source	1990	2000	2010	2018	2021	2022
Tidal marshes	−11	−11	−18	−10	−11	−12
Seagrass meadows	−10	−10	−10	−10	−11	−11
Total	−21	−21	−28	−20	−22	−24

6.5.1.2.2 Methodology

1) Method

○ Soil Carbon

CO_2 removals from coastal wetlands were estimated using the Tier 1 method for CO_2 emissions from rewetting, revegetation and creation of coastal wetlands presented in *2013 Supplement (Wetlands)* by multiplying the area of coastal areas influenced by management practices such as rewetting, revegetation and creation by CO_2 emission factor.

CO_2 emissions from rewetting, revegetation and creation of coastal wetlands

$$CO_{2\,SO-RE} = \sum_{V,S,C} (A_{RE} \times EF_{RE})_{V,S,C}$$

- $CO_{2\,SO-RE}$: CO_2 emissions associated with rewetting, revegetation and creation activities by vegetation type (v), soil type (s), and climate (c) [t C/yr]
- A_{RE} : area of soils that has been influenced by rewetting, revegetation and creation activities by vegetation type (v), soil type (s), and climate (c) [ha]
- EF_{RE} : CO_2 emission factor from aggregated mineral and organic soils that have been influenced by rewetting and revegetation activities by vegetation type (v), soil type (s), and climate (c) [t C/ha·yr]

Source : *2013 IPCC Supplement (Wetlands), Ch.4, Equation 4.7*

18) *2013 IPCC Supplement (Wetlands), Ch.4, p.4.33*

○ Non-CO_2 Emission

CH_4 emissions from rewetted and created tidal marshes were estimated using the area of tidal marshes around tidal flat based on the methodology and equation as provided in the *IPCC 2013 Supplement (Wetlands).*

CH₄ emissions from rewetted soils and created tidal marshes and mangroves		
	$$CH_{4-SO-REWET} = \Sigma_V (A_{REWET} \cdot EF_{REWET})_V$$	
$CH_{4-SO-REWET}$	:	CH_4 emissions associated with rewetted and created coastal wetlands by vegetation type (v) [kg CH_4 /yr]
A_{REWET}	:	area of soil that has been rewetted (including tidal marsh or mangrove wetland creation), by vegetation type (v) [ha]
EF_{REWET}	:	CH_4 emission factor from mineral and organic soils that have been rewetted by vegetation type (v)[kg CH_4 /ha·yr]

Source : *2013 IPCC Supplement (Wetlands), Ch.4, Equation 4.9*

2) Emission and Removal Factor

○ Soil Carbon

For tidal marshes, the default value of emission factor from the *2013 IPCC Supplement (Wetlands)* was used while a country-specific emission factor was developed for seagrass meadow.[19)]

| Table 6-38 | Annual Soil Carbon Emission Factor (EF_{RE}) for Rewetted Soils

Vegetation Type	Soil Carbon Default Emission Factor (tC/ha·yr)[1)]	Source
Tidal marsh	-0.91	*2013 IPCC Supplement (Wetlands)*[2)]
Seagrass meadow	-0.45	*CS*

Note: 1) Negative values indicate carbon removal (accumulation)
2) *2013 IPCC Supplement (Wetlands), Ch.4, Table 4.12*

○ Non-CO_2 Emission

According to the salinity-based definitions in the *2013 IPCC Supplement (Wetlands),* domestic tidal marshes which are located within tidal flat are categorized as seawater-saturated soils with over 18 ppt of salinity. Therefore, the default value of 0

19) To develop country-specific emission factor for seagrass meadow, soil samples were obtained through soil coring from five regions (*Geoje, Namhae, Jangheung, Samcheok, Gunsan*) in which major seagrass meadows of ROK are located to measure dry density, total organic carbon content and sedimentation rate which were used to calculate the annual soil carbon accumulation per unit area. The country-specific value falls within the range of 0.09-1.12 suggested in the *2013 Supplement* for seagrass meadow.

(zero) for CH_4 emission factor for rewetted land previously vegetated by tidal marshes was applied.

| Table 6-39 | Default CH_4 Emission Factor (EF_{RE}) for Rewetted Coastal Wetlands by Tidal Marshes

Vegetation Type	Salinity (ppt)	CH_4 Default Emission Factor ($kgCH_4$/ha·yr)	95% Confidence Interval	Source
Tidal freshwater and brackish marsh and mangrove	<18	193.7	99.8, 358	*IPCC 2013 Supplement (Wetlands)*
Tidal saline water marsh and mangrove	>18	0	-	

Note: Default values used for ROK's rewetted coastal wetlands in yellow shaded cells ( ).
Source: *2013 IPCC Supplement (Wetlands), Ch.4, Table 4.14*

3) Activity Data

Activity data for coastal wetlands, specifically tidal marshes and seagrass meadows, were from information provided by K-BIS. In 2022, the area of tidal marshes was 4 kha, representing a 9.6 percent increase from 2021 while that of seagrass meadows was 7 kha, a 3.6 percent increase.

| Table 6-40 | Activity Data Source for Coastal Wetlands

Period	Activity Data	Name of Statistics	Published by
1990-2022	Area of tidal marshes	*National Blue Carbon Inventory System (K-BIS)*	Ministry of Oceans and Fisheries (MOF)
2016-2022	Area of seagrass meadows		

Note: Data on the area of seagrass meadows was from Sentinel-2 satellite imagery which has been available from 2016. The area for the period from 1990 to 2015 was assumed be to the same as the area in 2016 based on expert judgment.

| Table 6-41 | Activity Data for Coastal Wetlands

(Unit: kha)

Area	1990	2000	2010	2018	2021	2022
Tidal marsh	3	3	5	3	3	4
Seagrass meadow	6	6	6	6	7	7
Total	9	9	11	9	10	11

BOX 2. Korea Blue Carbon Inventory System (K-BIS)

1. Overview

- To transparently provide data as well as data collection methods for coastal wetlands in the national greenhouse gas inventory, the Korean Marine Environment Management Corporation (KOEM) manages the system entrusted by the Ministry of Oceans and Fisheries (MOF).
- The system provides nationwide annual distribution area of tidal marshes and seagrass meadows as well as the result of a survey on the area of tidal flats which is conducted every five years by MOF.
- To ensure data transparency and reliability, the Standard Operating Procedures (SOP) were used for monitoring the status and trends of coastal wetlands.

2. Area of Tidal Marsh and Seagrass Meadow

- For tidal marshes, *Landsat* satellite imagery was used to produce various spectral indices and identify vegetation as well as water bodies. Conducting analysis on flooding frequency, the area of tidal marshes was calculated for the period from 1990.
- For seagrass meadows, *Sentinel-2* satellite imagery collected at the lowest possible coastal sea level was used. Identifying vegetation through the SVM (Support Vector Machine) method, the area of seagrass meadows is produced for the period from 2016.

6.5.1.2.3 Uncertainty and Time-series Consistency

6.5.1.2.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

6.5.1.2.3.2 Time-series Consistency

Emissions and removals from coastal wetlands were estimated consistently using methodology, emission factors and activity data from K-BIS which are the areas of tidal marshes and seagrass meadows obtained from satellite imagery for the entire time series. As data on seagrass meadows from Sentinel-2 satellite imagery have been available from 2016, the area of seagrass meadows for the 1990 to 2015 period was assumed to be the same as that in 2016 based on expert judgment.

6.5.1.2.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

6.5.1.2.5 Improvement Plan

ROK will continue its efforts to improve the time-series consistency of data on the area of seagrass meadows for the 1990 to 2015 period. Another planned improvement is to collect activity data following the methodology in the *2013 IPCC Supplement (Wetlands)* to estimate N_2O emissions from aquaculture which were not estimated in this inventory due to lack of data.

6.5.2 Land Converted to Wetlands (4.D.2.)

6.5.2.1 Category Description

2022	Gas	Methodology	Emission Factor	Activity Data	Carbon Pool
	CO_2	Tier 1	D	Area of flooded land	Soil carbon

Under the subcategory of Land converted to wetlands (4.D.2.), CO_2 emissions from the land of which the use was changed to flooded land in the past 10 years were reported[20]. The definition of flooded land is described in Section 6.5.1.1.1 (Flooded land remaining flooded land). N_2O emissions were not estimated due to the unavailability of a methodology in the *2006 IPCC Guidelines.* CH_4 emissions were included in Flooded land remaining flooded land (4.D.1.b.).

| Table 6-42 | Emissions and Removals from Land Converted to Wetlands

(Unit: kt CO_2-eq)

Sub-category	1990	2000	2010	2018	2021	2022
Land Converted to Wetlands	86	92	57	36	27	24

20) Peatland does not exist in ROK and thus emissions thereof do not occur.

6.5.2.2 Methodology

6.5.2.2.1 Method

CO_2 emissions from land converted to wetlands were calculated according to the methodological approach in the *2006 IPCC Guidelines,* by multiplying the number of days without ice cover during a year (P) by the averaged daily diffusive emissions ($E(CO_2)_{diff}$), the total flooded area (A), and the fraction of the total area converted to wetlands within the last 10 years relative to the total flooded area (f_A).

The ice-free period (P) was calculated by subtracting annual frost days from 365 days. The weighted average value was calculated using the ratio of wetlands by region.

CO₂ emissions from land converted to flooded land (Level 1)		
$$CO_2 emissions_{LW\ flood} = P \times E(CO_2)_{diff} \times A_{flood,\ total\ surface} \times f_A \times 10^{-6}$$		
$CO_2 emissions_{WW\ flood}$	:	total CO_2 emissions from land converted to Flooded Land [Gg CO_2/yr]
P	:	number of days without ice cover during a year[day]
$A_{flood,\ total\ surface}$	:	total reservoir surface area, including flooded land, lakes and rivers, [ha]
$E(CO_2)_{diff}$	:	average daily diffusive emission [kg CO_2/ha/day]
f_A	:	fraction of the total reservoir area that was flooded within the last 10 yrs

Source : *2006 IPCC Guidelines, Vol.4, Appendix 2, Equation 2A.1*

6.5.2.2.2 Emission and Removal Factor

The default CO_2 diffusive emission factor for ice-free period for the climate zone of warm temperate and moist which is 8.1 kg CO_2/ha/day as presented in the *2006 IPCC Guidelines* was used.

6.5.2.2.3 Activity Data

Activity data for land converted to wetlands were based on areas of lands classified as ditches, reservoirs and fish farms in the *Cadastral Statistics*. To calculate CO_2 emissions, the area of land converted to flooded land increased in year *t* from that in year *t−10* was used.

The area of land converted to wetlands in 2022 was 11 kha, representing a decrease of 2 kha compared 2021.

| Table 6-43 | Activity Data Source for Land Converted to Wetlands

Period	Activity Data	Name of Statistics	Published by
1980-2022	Area of ditches, reservoirs and fish farms	*Cadastral Statistics*	Ministry of Land, Infrastructure, and Transport (MOLIT)

| Table 6-44 | Activity Data for Land Converted to Wetlands

(Unit: kha)

Activity Data	1990	2000	2010	2018	2021	2022
Area of managed wetlands under or equal to 10 years after conversion	39	42	27	16	11	11

6.5.2.3 Uncertainty and Time-series Consistency

6.5.2.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

6.5.2.3.2 Time-series Consistency

Emissions from land converted to wetlands were calculated using methods, emission factors and activity data consistently for the entire time series to ensure time-series consistency.

6.5.2.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

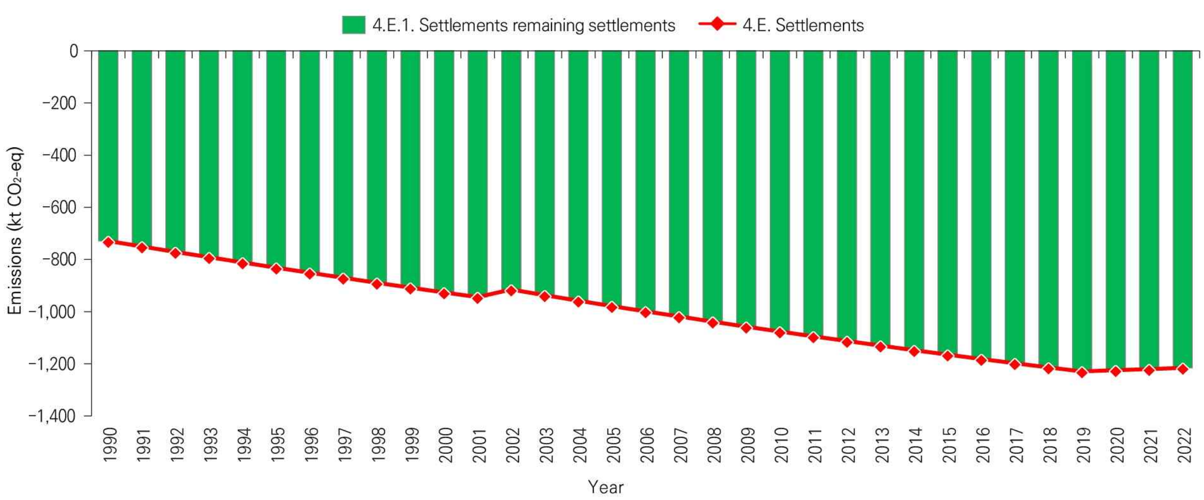
6.5.2.5 Improvement Plan

Under this subcategory, emissions from ditches, reservoirs and fish farms which were classified as land converted to wetlands were estimated. ROK will explore the potential to disaggregate data into flooded lands to estimate CH_4 emissions from molecular diffusion across the air-water interface, and into non-flooded land to estimate emissions and removals from vegetation, soils and dead organic matter to improve the accuracy of data under this subcategory.

6.6 Settlements (4.E.)

Settlements (4.E.) refer to all land used for residential purpose and socio-economic activities. Under this category of settlements, the amount of carbon sequestered by biomass is estimated[21]. Two methods are available to estimate the sequestered carbon in trees: crown cover[22] area method, and individual tree growth method. ROK used crown cover area of trees in settlements which were derived from aerial orthoimages to estimate CO_2.

In 2022, CO_2 removals in settlements were 1,216 kt CO_2-eq, representing an increase of 487 kt CO_2-eq from 1990. CO_2 removals in settlements increased since 1990 until reaching peak in 2019, followed by a slight decline through 2022. Such changes in CO_2 removals were influenced by changes in crown cover area of trees which were likely related to human activities such as urban landscaping and green spaces.



| Figure 6-7 | Trends in CO_2 Removals from Settlements (1990-2022)

21) In accordance with the *2006 IPCC Guidelines*, biomass including trees, shrubs and herbaceous vegetation are subject to estimation and reporting of carbon stock changes under this category. However as relevant data were not available in ROK, the amount of carbon sequestered by only trees in settlements were calculated in this inventory.

22) The area of ground surface within settlements covered by trees that are taller than 2 meters

| Table 6-45 | Removals from Settlements

(Unit: kt CO_2-eq)

(Sub)Category	1990	2000	2010	2018	2021	2022
4.E. Settlements	**-729**	**-926**	**-1,076**	**-1,214**	**-1,220**	**-1,216**
4.E.1. Settlements remaining settlements	-729	-926	-1,076	-1,214	-1,220	-1,216
4.E.2. Land converted to settlements	IE[1]	IE	IE	IE	IE	IE

Note: 1) Emissions and removals from Land converted to settlements (4.E.2.) are allocated to Settlements remaining settlements (4.E.1.) due to unavailability of data in accordance with the *2006 IPCC Guidelines*.

6.6.1 Settlements remaining settlements(4.E.1.)

6.6.1.1 Category Description

	Gas	Methodology	Emission Factor	Activity Data	Carbon Pool
2022	CO_2	Tier 2a	D	Total crown cover area	Living biomass (above-ground, below-ground)

Under the subcategory of Settlements remaining settlements (4.E.1.), CO_2 removals were estimated based on carbon stock changes in biomass using crown cover area of trees within settlements.

In 2022, the amount of carbon sequestered in settlements remaining settlements were 1,216 kt CO_2-eq, representing an increase of 487 kt CO_2-eq from 1990.

| Table 6-46 | Removals from Settlements Remaining Settlements

(Unit: kt CO_2-eq)

Sub-category	1990	2000	2010	2018	2021	2022
Settlements remaining settlements	-729	-926	-1,076	-1,214	-1,220	-1,216

6.6.1.2 Methodology

6.6.1.2.1. Method

Carbon stock changes in settlements remaining settlements were estimated using the biomass increment in trees within settlements which was calculated using the gain-loss method and annual biomass increment based on crown cover area of Tier 2a methodology outlined in the *2006 IPCC Guidelines.*

Annual change in carbon stocks in biomass in land remaining in a particular land-use category (Gain-loss method)		
$$\Delta C_{LB} = \Delta C_G - \Delta C_L$$		
ΔC_{LB}	:	annual change in carbon stocks in biomass for each land sub-category, considering the total area [t C/yr]
ΔC_G	:	annual increase in carbon stocks due to biomass growth for each land sub-category, considering the total area [t C/yr]
ΔC_L	:	annual decrease in carbon stocks due to biomass loss for each land sub-category, considering the total area [t C/yr]

Source : *2006 IPCC Guidelines, Vol.4, Ch.2, Equation 2.7*

Annual biomass increment based on total crown cover area		
$$\Delta C_G = AT \times CRW$$		
ΔC_G	:	annual carbon accumulation attributed to biomass increment in Settlements Remaining Settlements [t C/yr]
AT	:	crown cover area [ha]
CRW	:	crown cover area-based growth rate [t C/ha·yr]

Source : *2006 IPCC Guidelines, Vol.4, Ch.8, Equation 8.2*

6.6.1.2.2 Emission and Removal Factor

The default value of crown cover area-based growth rates of 2.9 t C/ha·yr suggested in the *2006 IPCC Guidelines* was used.

| Table 6-47 | Crown Cover Area-Based Growth Rates (CRW)

Region	Annual Carbon Accumulation Rate(tC/ha·yr)	Source
United States (global default)	2.9[1)]	*2006 IPCC Guidelines*
Australia	3.6[2)]	

Note: * Default values used for settlements in yellow shaded cells ( ).
1) Nowak and Crane 2002; average of 10 U.S. cities
2) Brack 2002; modeling analysis in Canberra
Source : *2006 IPCC Guidelines, Vol.4, Ch.8, table 8.1*

6.6.1.2.3 Activity Data

Activity data for settlements remaining settlements include areas of lands under 19 land categories in the *Cadastral Statistics* as well as *Digital Cadastral Map* and aerial orthoimage. To estimate the crown cover area of trees within settlements, a systematic sampling method was used for 2002, 2019 and 2022 to select sample plots covering approximately 10 percent of settlements, using a 500 m × 500 m grid as a unit. The crown cover area of the selected sample plots for the respective three year periods was obtained through visual interpretation of aerial orthoimages. For the rest of the time series, interpolation and extrapolation methods were used to calculate crown cover areas. Subsequently, the crown cover area for the entire settlement was estimated by reflecting the ratio of the total settlement area and the sample plot area to the crown cover area of sample plots.

| Table 6-48 | Activity Data Source for Settlements Remaining Settlements

Period	Activity Data	Name of Statistics	Published by
1990-2022	Area of settlements in 19 land categories	*Cadastral Statistics*	Ministry of Land, Infrastructure, and Transport (MOLIT)
2002, 2019 and 2022[1)]		*Digital Cadastral Map*	
1996-2005	Crown cover area in settlements	*The 4th Forest Aerial Orthoimage*	Korea Forest Service (KFS)
2002, 2019 and 2022[1)]		Aerial Orthoimage	National Geographic Information Institute (NGII)

Note: 1) For the rest of the time series, interpolation and extrapolation methods were used to calculate crown cover areas in settlements.

| Table 6-49 | Activity Data for Settlements Remaining Settlements

(Unit: kha)

Activity Data	1990	2000	2010	2018	2021	2022
Area of settlements	541	693	885	1,062	1,114	1,129
Total crown coverage area	69	87	101	114	115	114

6.6.1.3 Uncertainty and Time-series Consistency

6.6.1.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

6.6.1.3.2 Time-series Consistency

Emissions from settlements remaining settlements were estimated using methods and emission factors consistently for the entire time series. As the crown cover area of sample plots per year were available only for 2002, 2019 and 2022, the values for the remaining years were either extrapolated or interpolated in accordance with the *2006 IPCC Guidelines* to ensure time-series consistency.

6.6.1.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

6.6.2 Land converted to settlements (4.E.2.)

In accordance with Approach 1 of the *2006 IPCC Guidelines*, land converted to settlements was included in Settlements remaining settlements (4.E.1.).

6.7 Other Land (4.F.)

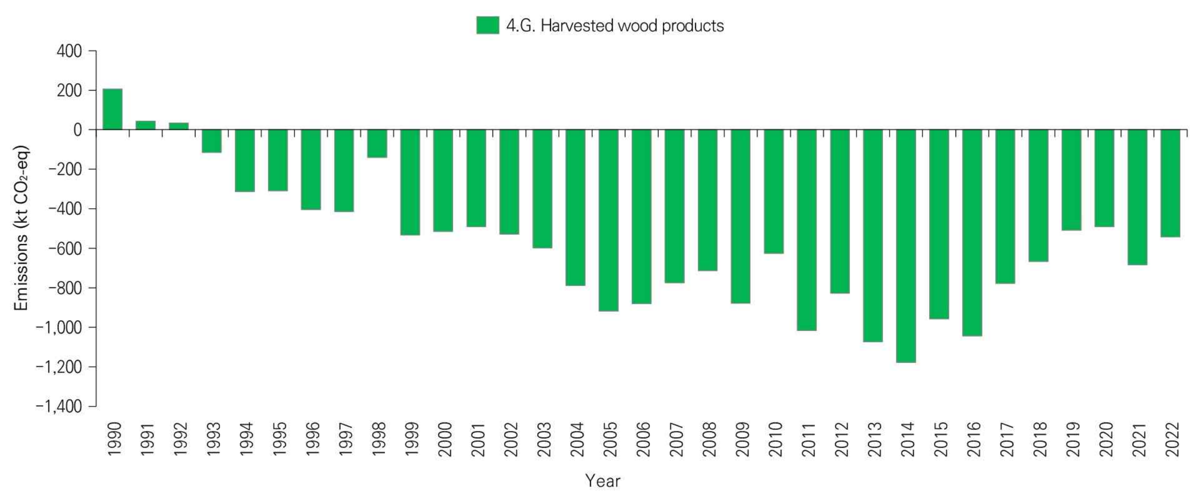
In accordance with the *2006 IPCC Guidelines,* Other land (4.F.) refers to bare soil, rock and ice as well as any land that is not included under five land-use categories of forest land, cropland, grassland, wetlands and settlements. As there is no data on other land in ROK, emissions were not estimated in this inventory.

6.8 Harvested Wood Products (HWP) (4.G.)

Harvested Wood Products (HWP) constitutes a carbon reservoir and is one of the carbon pools in the LULUCF sector. In the year when raw timber harvested is converted into wood products, it stores carbon. The storage of carbon held in harvested wood products is released as CO_2 to the atmosphere and the rate of emissions varies depending on the half−life of each product. Emissions and removals from this category are estimated based on the annual production volume by wood product type, carbon stock in HWP in the current year and carbon emissions from HWP in prior years.

In accordance with the *2006 IPCC Guidelines*, CH_4 emissions released during the process of disposal including landfill of HWP are reported under the Waste sector. Emissions of CH_4 and N_2O from burning of HWP used for energy are included in the Energy sector.

In 2022, CO_2 removals from HWP were 543 kt CO_2−eq. This category produced emissions of 206 kt CO_2−eq in 1990 which sequestered carbon since 1993. Such changes were attributed to the production volume of wood products. In 1990, the volume of wood product produced was 0.6 million m³ which significantly increased to 2.1 million m³ in 2022.



| Figure 6−8 | Trends in Emissions and Removals from Harvested Wood Products (HWP) (1990−2022)

| Table 6−50 | Emissions and Removals from Harvested Wood Products (HWP)

(Unit: kt CO_2−eq)

Category	1990	2000	2010	2018	2021	2022
4.G. Harvested Wood Products (HWP)	206	−515	−625	−667	−684	−543

6.8.1 Category Description

2022	Gas	Methodology	Emission Factor	Activity Data	Carbon Pool
	CO_2	Tier 2	D	Production volume of sawnwood, fiberboard and paper	Harvested Wood Products (HWP)

Under this category, emissions and removals from wood products of domestic harvest which are categorized into sawnwood, wood-based panels such as plywood, particleboard, fiberboard as well as paper and paperboard. In ROK, plywood and particle board are rarely made from domestic timber while paperboard is produced mostly from recycled or waste paper rather than pulp from timber. Accordingly, CO_2 emissions and removals from only the products from sawnwood, fiberboard and paper were estimated.

CO_2 removals from HWP were 543 kt CO_2-eq. For three consecutive years from 1990 to 1992, emissions of 206 kt CO_2-eq, 43 kt CO_2-eq and 34 kt CO_2-eq occurred respectively. From 1993 onward, the category has been a carbon sink.

| Table 6-51 | Emissions and Removals by Product Type

(Unit: kt CO_2-eq)

Product Type	1990	2000	2010	2018	2021	2022
Sawnwood	4	-35	-101	-139	-118	-174
Fiberboard	105	-369	-653	-599	-503	-472
Paper	97	-111	129	71	-63	104
Total	206	-515	-625	-667	-684	-543

6.8.2 Methodology

6.8.2.1 Method

The carbon stock changes in wood products of domestic harvest were calculated using the Tier 2 Stock-Difference Method in which the carbon held in “products in use” was reflected. Estimates from such changes were made by using the carbon inflow to the carbon pool in the current year and the outflow from the pool based on half-life (HL=ln(2)/k).

Estimation of carbon stock and annual change in HWP pools		
$$Inflow_l(i) = HWP_l(i) \cdot CF_l \cdot 10^{-6}$$ $$C_l(i+1) = e^{-k} \cdot C_l(i) + [\frac{(1-e^{-k})}{k}] \cdot Inflow_l(i)$$ $$\triangle C_l(i) = C_l(i+1) - C_l(i)$$		
i	:	year
$Inflow_l(i)$	:	the inflow of carbon stock to the HWP pool during year i [Mt C]
$HWP_l(i)$	:	calculated domestic consumption of the particular semi-finished HWP commodity class l in the year i [m^3 or Mg]
CF_l	:	carbon conversion factor of the particular semi-finished HWP commodity class l [Mg C/m^3 or Mg C/Mg]
$C_l(i)$	:	the carbon stock in the particular HWP commodity class l in the beginning of the year i [Mt C]
k	:	decay constant of first-order decay for each HWP commodity class l [yr^{-1}]
$\Delta C_l(i)$	:	carbon stock change of the HWP commodity class l during the year i [Mt C]

Source : *2006 IPCC Guidelines, Vol.4, Ch.12, Equation 12.1; 2019 Refinement Vol.4, Ch.12, Equation 12.6*

Estimation of total emissions and removals arising from the HWP pool in use		
$$\triangle CO_2(i) = -44/12 \cdot \sum_{l=1}^{n} \triangle C_l(i)$$		
$\Delta CO_2(i)$	:	Accumulated CO_2 stock in year i [Mt CO_2]

Source: *2019 Refinement, Vol.4, Ch.12, Equation 12.1*

According to the equation, the carbon stock in use in the beginning of the year ($C_l(i)$) is estimated based on the carbon stock of the previous year. To calculate the carbon stock in use in the beginning of 1990 ($C_l(t_0)$), the average of the inflow of carbon stocks ($Inflow_l(i)$) over five years from 1990 to 1994 was calculated and divided by the decay constant (k) in accordance with the *2019 Refinement.*

Approximation of the carbon stocks in the HWP pool in use at the initial time, I.E. from which activity data are available
$$C_l(t_0) = \frac{Inflow_{l_{average}}}{k}$$ $$With: Inflow_{l_{average}} = \left[\sum_{i=t_0}^{t_4} Inflow_l(i)\right]/5$$

Source : *2019 Refinement, Vol.4, Ch.12, Equation 12.4*

6.8.2.2 Emission and Removal Factor

Default values from the *2019 Refinement* were used for emission and removal factors required for estimation of the carbon stock of the HWP pool in use which include basic density (D), carbon fraction (FR), carbon conversion factor (CF) and the half−life (H_L).

| Table 6−52 | Carbon Conversion Factor and Half−Life Default Values for Harvested Wood Products (HWP)

Sector	Basic Density (Mg/m³)	Carbon Fraction (Mg C/Mg)	Carbon Conversion Factor (Mg C/m³)	Half−Life (years)	Source
Sawnwood	0.458	0.5	0.229	35	*2019 Refinement*
Coniferous trees	0.45	0.5	0.225		
Broadleaf trees	0.56	0.5	0.28		
Wood−based panels	0.595	0.454	0.269	25	
Fiberboard (MDF)	0.691	0.427	0.295		
Particleboard	0.596	0.451	0.269		
Oriented Strand Board	0.573	0.463	0.265		
Plywood	0.542	0.493	0.267		
Paper and paperboard	0.9	−	0.386	2	

Note: The unit of the basic density (Mg/Mg) and carbon conversion factor (MgC/Mg) applied to paper and paperboard were in units of Mg.

Source : *2019 Refinement, Vol.4, Ch.12, Table 12.1, Table 12.3*

6.8.2.3 Activity Data

According to the *2006 IPCC Guidelines,* HWP are categorized into sawnwood, wood−based panels such as plywood, particleboard, fiberboard), and paper and paperboard. In ROK, emissions and removals from products of domestic harvest are estimated. As plywood and particleboard products are rarely made from domestic timber, and paperboard is produced mostly from recycled or waste paper rather than pulp from timber, only the HWP from sawnwood, fiberboard and paper were estimated.

For sawnwood, data on the production volume of domestically produced sawnwood from the *Market Survey of Timber Products* (KFS) for the 2008 to 2022 period were used. For the 1990 to 2007 time period for which statistics were not available, the production volume was estimated by using ① the average rate of sawnwood use of five years from 2008 to 2012 (the fraction of domestic timber used for sawnwood) sourced from the *Market Survey of Timber Products*, ② The sawmill yield rate (the fraction of sawnwood produced from timber for sawnwood purpose), and ③ the supply of domestic timber by purpose sourced from the *Statistical Yearbook of Forestry* (KFS) for the 1990 to 2007 period.

For fiberboard, the production volume of fiberboard using domestic timber was calculated by reflecting the proportion of domestic timber in the production volume of fiberboard from 2008 through 2022 of which data were provided in the *Market Survey of Timber Products.* For data prior to 2008, the production volume was estimated by using ① the proportion of domestic timber in raw materials for fiberboard for the 2008 to 2012 period sourced from the *Market Survey of Timber Products*, and ② the production volume of medium-density fiberboard from 1990 through 2007 sourced from the *Statistical Yearbook of Forestry.*

For paper, the paper production in the 1990 to 2022 time period was obtained by using the annual supply rate of domestic pulp per year as well as the production volume of papers presented in the *Statistical Yearbook of Forestry.*

| Table 6-53 | Activity Data Source for Harvested Wood Products (HWP)

Period	Activity Data	Name of Statistics	Published by
1990-2007	Production volume of sawnwood	*Statistical Yearbook of Forestry*	Korea Forest Service (KFS)
2008-2022		*Market Survey of Timber Products*	
1990-2007	Production volume of fiberboard	*Statistical Yearbook of Forestry*	
2008-2022		*Market Survey of Timber Products*	
1990-2022	Production volume of paper	*Statistical Yearbook of Forestry*	

| Table 6-54 | Activity Data for Harvested Wood Products (HWP) by Product Type

(Unit: Thousand ㎥; kt (Paper))

Production Volume	1990	2000	2010	2018	2021	2022
Sawnwood	120	167	268	345	328	399
Fiberboard	66	541	963	1,065	1,015	998
Paper[1)]	307 (414)	650 (878)	471 (636)	571 (771)	627 (847)	503 (679)
Total	600	1,586	1,867	2,182	2,189	2,077

Note: 1) The values in parentheses for paper represent the unit of production volume converted from weight to volume by applying a bulk density of 1.35.

6.8.3 Uncertainty and Time-series Consistency

6.8.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

6.8.3.2 Time-series Consistency

Emissions and removals from HWP were estimated using methods, emission and removal factors as well as activity data consistently. As data on the production volumes of sawnwood and paper have been collected in the *Market Survey of Timber Products* from 2008, data for the 1990 to 2007 time series were estimated by using relevant data provided in the *Statistical Yearbook of Forestry*. To maintain time-series consistency, the approach of tracking changes in activity data and emissions across the time series was used.

6.8.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

6.8.5 Improvement Plan

ROK plans to develop removal factors by collecting values of basic properties for density and carbon fraction for domestically harvested wood as well as country-specific values of half-life reflecting the use and activities associated with harvested wood practiced in ROK following the IPCC methodologies.

SECTION 07

Waste

7 Waste

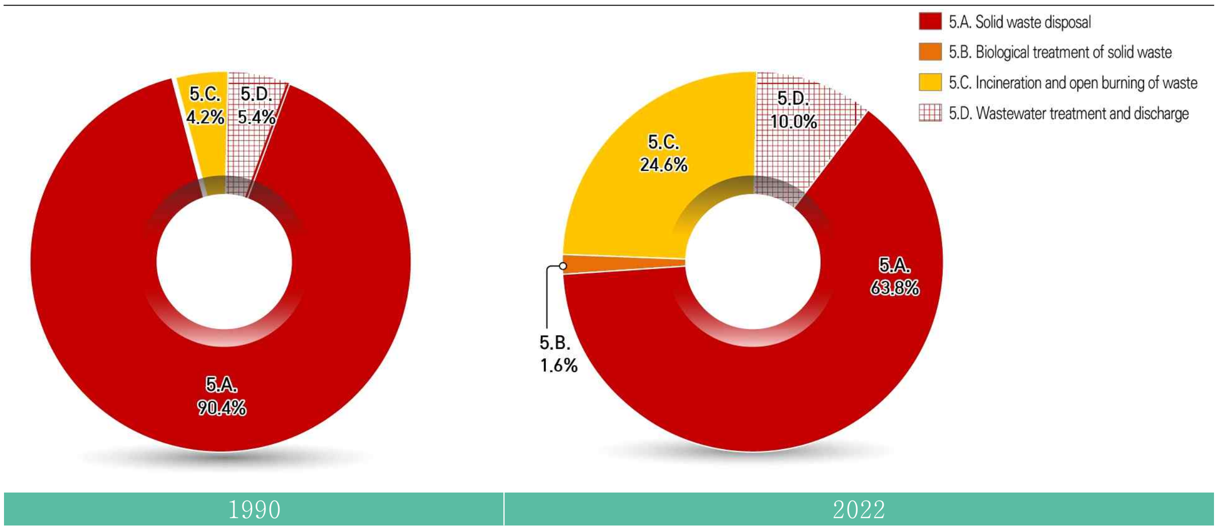
7.1 Overview

Under the Waste sector, greenhouse gas emissions generated during waste management and treatment processes are reported in categories of Solid waste disposal (5.A.), Biological treatment of solid waste (5.B.), Incineration and open burning of waste (5.C.), and Wastewater treatment and discharge (5.D.).

Methane (CH_4) from the anaerobic decomposition of organic matter in disposed waste in landfills are estimated and categorized into the reporting category of solid waste disposal while CH_4 and nitrous oxide (N_2O) emissions released during the biological decomposition treatment such as composting and anaerobic digestion of organic waste by microorganisms are included in the category of biological treatment of solid waste. In the category of incineration and open burning of waste, emissions of carbon dioxide (CO_2), CH_4 and N_2O emissions from combustion of wastes of fossil origin are included. CH_4 and N_2O emissions from wastewater that is treated or disposed anaerobically are reported under the category of wastewater treatment and discharge.[1)]

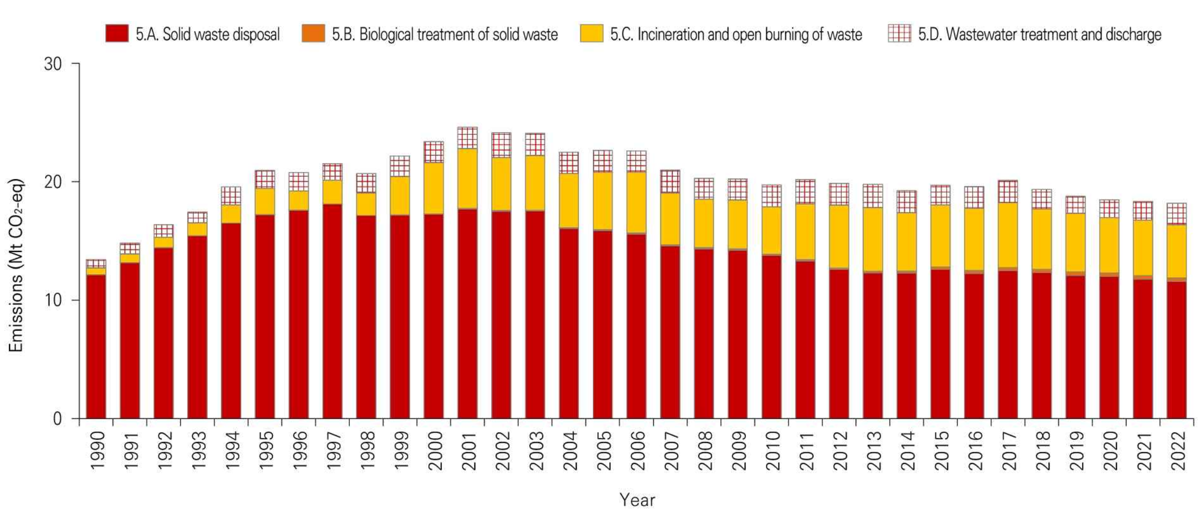
In 2022, emissions from the Waste sector were 18.2 Mt CO_2-eq, accounting for 2.5 percent of national total emissions, which also represented a decrease of 0.8 percent from 2021. The largest emission source in the Waste sector was the solid waste disposal which emitted 11.6 Mt CO_2-eq representing 63.8 percent of total emissions from the Waste sector. Waste incineration and open burning was the second largest source with emissions of 4.5 Mt CO_2-eq accounting for 24.6 percent, followed by the wastewater treatment and discharge with 1.8 Mt CO_2-eq emissions. The biological treatment of solid waste which emitted 0.3 Mt CO_2-eq, representing 10.0 percent and 1.6 percent respectively. Key categories in the Waste sector include CH_4 emissions from solid waste disposal and CO_2 from waste incineration and open burning (see Section 1.4 Key Category Analysis).

1) In accordance with the *2006 IPCC Guidelines,* CO_2 emissions from wastes of biogenic origin should be excluded from national total emissions.



| Figure 7-1 | Category as a Portion of Total Waste Emissions (1990 and 2022)

Emissions from landfill which accounted for 90.4 percent in 1990 of total sectoral emissions decreased to 63.8 percent in 2022 while the portion of incineration increased from 4.2 percent to 24.6 percent. Despite of such increase in both emissions and the portion as a category in the waste sector, the amount of recovered energy from waste incineration also increased which contributed to slowing down the growth of emissions from the respective source. Heat recovery from incineration has been consistently increasing since 1990 which led to the energy recovery from more than 80 percent of combusted municipal waste since 2005.



| Figure 7-2 | Trends in Emissions from Waste Sector (1990-2022)

| Table 7-1 | Emissions from Waste Sector (1990-2022)

(Unit: Mt CO_2-eq.)

Category	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
5.A. Solid waste disposal	12.1	13.2	14.4	15.5	16.5	17.2	17.6	18.1	17.2	17.2	17.3
5.B. Biological treatment of solid waste	NE	NE	NE	NE	0.004	0.001	0.002	0.005	0.004	0.02	0.03
5.C. Incineration and open burning of waste	0.6	0.7	0.9	1.1	1.5	2.2	1.6	2.0	1.9	3.2	4.3
5.D. Wastewater treatment and discharge	0.7	0.9	1.1	0.9	1.5	1.5	1.6	1.4	1.6	1.7	1.8
Total	**13.4**	**14.8**	**16.4**	**17.4**	**19.6**	**21.0**	**20.8**	**21.5**	**20.7**	**22.2**	**23.4**

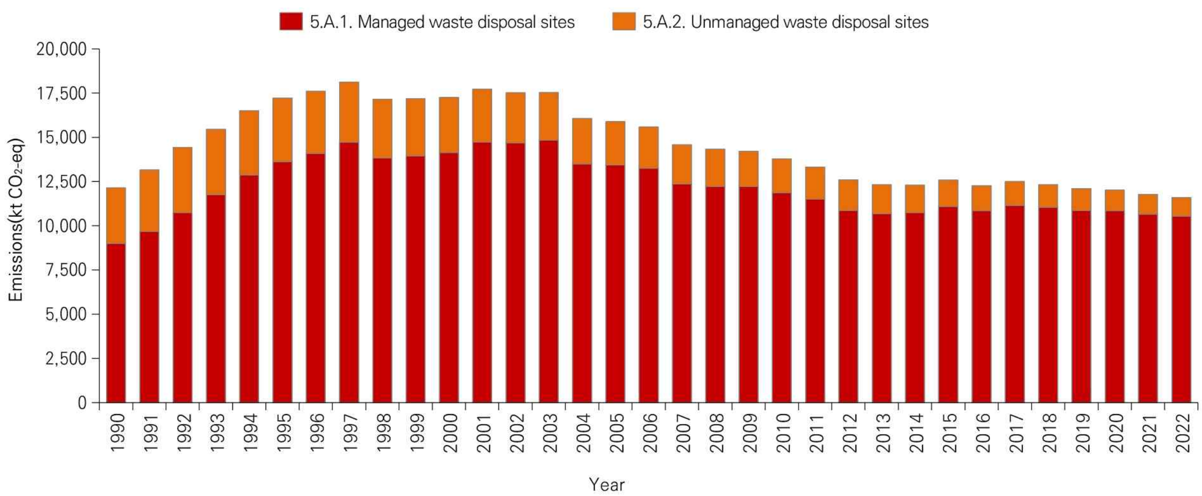
Category	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
5.A. Solid waste disposal	17.7	17.5	17.5	16.1	15.9	15.6	14.6	14.3	14.2	13.8	13.3
5.B. Biological treatment of solid waste	0.03	0.05	0.05	0.05	0.07	0.09	0.09	0.09	0.10	0.09	0.11
5.C. Incineration and open burning of waste	5.0	4.5	4.6	4.6	4.8	5.1	4.4	4.1	4.1	4.0	4.7
5.D. Wastewater treatment and discharge	1.8	2.1	1.9	1.8	1.9	1.8	1.9	1.8	1.8	1.9	2.0
Total	**24.6**	**24.1**	**24.1**	**22.5**	**22.6**	**22.6**	**21.0**	**20.3**	**20.2**	**19.7**	**20.2**

Category	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
5.A. Solid waste disposal	12.6	12.3	12.3	12.6	12.3	12.5	12.3	12.1	12.0	11.8	11.6
5.B. Biological treatment of solid waste	0.11	0.13	0.15	0.22	0.25	0.25	0.28	0.29	0.28	0.30	0.29
5.C. Incineration and open burning of waste	5.3	5.4	4.9	5.2	5.3	5.5	5.1	4.9	4.7	4.7	4.5
5.D. Wastewater treatment and discharge	1.8	2.0	1.8	1.7	1.8	1.9	1.7	1.4	1.5	1.6	1.8
Total	**19.9**	**19.8**	**19.2**	**19.7**	**19.6**	**20.1**	**19.4**	**18.8**	**18.5**	**18.3**	**18.2**

7.2 Solid Waste Disposal (5.A.)

This reporting category is divided by landfill management type into Managed waste disposal sites (5.A.1.), Unmanaged waste disposal sites (5.A.2.), and Uncategorized waste disposal sites (5.A.3.).[2] In ROK, a uncategorized waste disposal site does not exist.

In 2022, emissions from solid waste disposal sites (SWDS) were 11,597 kt CO_2-eq, accounting for 63.8 percent of total waste emissions which also represented a decrease of 1.4 percent from 2021. Managed and unmanaged waste disposal accounted for 91.0 percent and 9.0 percent of total emissions from solid waste disposal in 2022 respectively.



| Figure 7-3 | Trends in Solid Waste Disposal CH_4 Emissions (1990-2022)

| Table 7-2 | Emissions from Solid Waste Disposal Sites (SWDS)

(Unit: kt CO_2-eq.)

Sub-category	1990	2000	2010	2018	2021	2022
5.A.1. Managed waste disposal sites	9,000	14,145	11,881	11,049	10,666	10,551
5.A.2. Unmanaged waste disposal sites	3,149	3,113	1,907	1,278	1,100	1,046
Total	12,149	17,258	13,788	12,327	11,766	11,597

2) In ROK, waste disposal sites are classified into sanitary landfills and non-sanitary landfills where sanitary landfills correspond to managed waste disposal sites under the *2006 IPCC Guidelines* and non-sanitary landfills refer to unmanaged waste disposal sites.

7.2.1 Managed Waste Disposal Sites (5.A.1.)

7.2.1.1 Category Description

2022	Gas	Methodology	Emission Factor	Activity Data
	CH_4	Tier 2	CS, D	Amount of landfill wastes at managed waste disposal sites

Managed waste disposal site refers to solid waste landfills that are designed to have controlled placement of waste which includes mechanical compacting, levelling of the waste, landfill gas collection and processing system, cover material as well as leachate drainage and treatment system.[3)]

SWDS is divided into three types of anaerobic, semi-aerobic and active aeration depending on the way waste is managed and the depth of the site. Degradation of organic material in solid waste in a landfill produces CH_4 under anaerobic conditions. As semi-aerobic and aerobic SWDS do not exist in ROK, emissions only from managed anaerobic disposal sites were estimated.

The amount of recovered CH_4 that was used for energy including electricity or thermal energy were subtracted from the amount of CH_4 reported under the reporting category of solid waste disposal, and instead accounted for in the Energy sector.

In 2022, emissions from managed SWDS were 10,551 kt CO_2-eq, accounting for 91.0 percent of total emissions from solid waste disposal, which also represented a decrease of 1.1 percent from 2021.

| Table 7-3 | Emissions from Managed Waste Disposal Sites (SWDS)

(Unit: kt CO_2-eq.)

Sub-category	1990	2000	2010	2018	2021	2022
Managed SWDS	9,000	14,145	11,881	11,049	10,666	10,551

7.2.1.2 Methodology

7.2.1.2.1 Method

To estimate emissions from managed SWDS, the First Order Decay (FOD) method from the *2006 IPCC Guidelines* was used.

3) *2006 IPCC Guidelines, Vol.5, Ch.3, Table 3.1*

CH$_4$ emissions from solid waste disposal sites

$$Emission(E) = [\sum CH_4generated_{x,T} - R_T] \times (1 - OX_T)$$
$$DDOCm = W \times DOC \times DOC_f \times MCF$$
$$DDOC_{maT} = DDOC_{mdT} + (DDOC_{maT-1} \times e^{-k})$$
$$DDOC_{m,decompT} = DDOC_{maT-1} \times (1 - e^{-k})$$
$$CH_4generated_{x,T} = DDOC_{m,decompT} \cdot F \cdot 16/12$$

Emission (E)	:	CH_4 emitted in year T [Gg]
T	:	inventory year
x	:	waste category or type/material
R_T	:	recovered CH_4 in year T [Gg]
OX_T	:	oxidation factor for year T (fraction)
$DDOC_m$	:	mass of decomposable DOC deposited [Gg]
$DDOC_{maT}$	:	$DDOC_m$ accumulated in SWDS at the end of year T [Gg]
$DDOC_{maT-1}$	:	$DDOC_m$ accumulated in SWDS at the end of year (T−1) [Gg]
$DDOC_{mdT}$	:	$DDOC_m$ deposited into the SWDS in year T [Gg]
$DDOC_{m,decompT}$	:	$DDOC_m$ decomposed in SWDS in year T [Gg]
W	:	mass of waste deposited [Gg]
MCF	:	CH_4 correction factor
DOC	:	degradable organic carbon in the year of deposition, fraction [Gg−C/Gg−waste]
DOC_f	:	fraction of DOC that can decompose (fraction)
F	:	fraction of CH_4 in generated landfill gas (volume fraction)
k	:	decay rate constant, k=1n(2)/$t_{1/2}$ (y^{-1})

Source: *2006 IPCC Guidelines, Vol.5, Ch.3, Equations 3.1−3.6*

7.2.1.2.2 Emission Factor

Default emission factors from the *2006 IPCC Guidelines* and country−specific emission factors were used for managed SWDS.

Degradable organic carbon (*DOC*) refers to the organic carbon in waste that is biodegradable. Default DOC values from the *2006 IPCC Guidelines* were used except waste materials for which country−specific emission factors are available.

Fraction of degradable organic carbon which decomposes (DOC_F) refers to the fraction of carbon that is ultimately degraded under anaerobic conditions. Country-specific emission factors were used for food waste, paper and wood while the default value of 0.5 (under the assumption that the DOC values include lignin) from the *2006 IPCC Guidelines* was used for other waste materials.

Decay rate constant (k) is the rate at which decomposition of wastes at SWDS occurs and results in CH_4 emissions, and its country-specific emission factor of 0.05 was applied. For methane fraction in generated landfill gas (F), the country-specific emission factor of 0.5629 was used.

Oxidation factor (OX) is the amount of CH_4 that is oxidized by microorganisms in the soil or other material covering the waste, and the default value of 0.1 provided in the *2006 IPCC Guidelines* was applied.

Methane correction factor (MCF) is used to adjust the amount of CH_4 generated that vary depending on the landfill management type which includes anaerobic, semi-aerobic and active aeration. The *2006 IPCC Guidelines* provides default values of *MCF* for each type of site and, as SWDS in ROK is categorized into anaerobic managed SWDS, the default *MCF* value of 1.0 was used.

| Table 7-4 | Parameters for Managed Waste Disposal Sites (SWDS)

Fraction of CH_4 in Generated Landfill Gas (F)[1]	Methane Correction Factor (MCF)[2]	Oxidation Factor (OX)[3]	Decay Rate Constant (k)[4]
0.5629	1.0	0.1	0.05

Note: 1) Country-specific emission factor developed in 2016
2) *2006 IPCC Guidelines, Vol.5, Ch.3, Table 3.1*
3) *2006 IPCC Guidelines, Vol.5, Ch.3, Table 3.2*
4) Country-specific emission factor developed in 2014[4)]

4) Country-specific emission factors were developed in 2014 based on methane emissions from SWDS per unit of metropolitan area, city and county estimated using the least squares method.
- Metropolitan area: Developed emission factors based on methane emissions from 3 out of 11 SWDS in metropolitan areas over three years from 2008 to 2010.
- City: Developed emission factors based on methane emissions from 5 out of 9 SWDS in cities over five years from 2007 to 2011.
- County: Developed emission factors based on methane emissions from 12 SWDS in county over three years from 2009 and 2011.

| Table 7-5 | Emission Factors for Managed Waste Disposal Sites (*DOC* and *DOC_F*)

Waste Type	Waste Material	DOC		DOC_F	
		Value	Source	Value	Source
• Municipal Solid Waste • Industrial Waste • Construction Waste • Hazardous Waste	Food Waste	0.1319	CS[1]	0.6343	CS[2]
	Paper	0.3349		0.6256	
	Wood	0.3685		0.4446	
	Rubber and Leather	0.4625		0.5	*2006 IPCC Guidelines*
	Textiles	0.3415			
	Other Combustibles	0.2850			
	Domestic Sludge	0.1036			
	Industrial Sludge	0.1845			
	Plastics	–	*2006 IPCC Guidelines*	–	
	Non-combustibles				

Note: 1) Country-specific DOC values per waste material were developed during the 2014 and 2016 period using data from elemental analysis and proximate analysis on waste materials with high emissions in ROK from the *National Waste Management Statistics published in 1997, 2002, 2007 and 2013* which are nationally approved statistics.

2) Country-specific DOC_F values were developed by conducting a biochemical methane potential test on waste materials. Data from proximate analysis and elemental analysis were conducted to develop values for paper, food waste and wood.

Source: *2006 IPCC Guidelines, Vol.5, Ch.2, Table 2.4*

7.2.1.2.3 Activity Data

a) Amount of Managed Waste Disposal Sites

In accordance with the *2006 IPCC Guidelines*, it is good practice to use historical statistical data on solid waste disposal that go back for the whole period of 50 years from the starting year of the inventory which, in this case, is from 1940 through 1990. However data on waste generation from the 1940s and 1950s in ROK are not available due to the Korean War (1950-1953) and the absence of data collection system for managed SWDS. Therefore the year 1961 in which the first waste management law, the *Excreta and Sewage Cleaning Act*, was enacted was set as the starting year of statistics on solid waste disposal.

From 1961 onward, waste statistics have been collected in three phases as follows.

In Phase Ⅰ, covering the 1961 to 1984 period for which waste statistics were not adequately available, the amount of waste generated and the fraction of waste disposed to SWDS were estimated using statistical methods such as regression analysis and extrapolation based on functional relationships and taking into account variables such as population, number of households, economic growth rate, and waste management policies such as the implementation of the volume-based waste fee system.[5)]

In Phase Ⅱ, data for the 1985 to 1995 time period were collected and compiled as national waste statistics[6] in accordance with *Article 39* of the *Wastes Control Act* and *Article 64* of its *Enforcement Rules*. However, due to the absence of waste classification system back then, data on waste generation and treatment activities were not disaggregated by waste material which were later extrapolated as shown in Table 7-6.

In Phase Ⅲ from 1996 to the present, wastes have been classified into categories of municipal waste, industrial waste, construction waste, and hazardous waste. In compliance with *Article 58* of the *Wastes Control Act* and *Article 81* of its *Enforcement Rules,* national waste statistics such as the *National Waste Generation and Treatment Report*[7] which are published annually by the Ministry of Environment (MOE) have been used as activity data.

Data on the amount of solid waste disposal for the reporting period were collected and estimated as described in the table below.

| Table 7-6 | Activity Data Collection for Solid Waste Disposal (1961-Present)

<table>
<tr><th>Waste Type</th><th>Data</th><th>1961-1980</th><th>1981-1984</th><th>1985-1991</th><th>1992-1993</th><th>1994-1995</th><th>1996-2018</th><th>2019-Present</th></tr>
<tr><td rowspan="2">Municipal Solid Waste</td><td>Amount of Waste</td><td colspan="2">Regression analysis</td><td colspan="5" rowspan="2">National Waste Generation and Treatment Report (MOE)</td></tr>
<tr><td>Fraction of Landfill</td><td colspan="2">Extrapolated</td></tr>
<tr><td rowspan="2">Industrial Waste</td><td>Amount of Waste</td><td colspan="3">Extrapolated</td><td colspan="2" rowspan="4">Estimated based on the average generation rate of industrial waste and construction waste for the years between 1996-1998[2]</td><td colspan="2" rowspan="4"></td></tr>
<tr><td>Fraction of Landfill</td><td colspan="3">Expert judgment (Assumed that the fraction decreased linearly from 79% in 1961)</td></tr>
<tr><td rowspan="2">Construction Waste</td><td>Amount of Waste</td><td colspan="3">Backward estimation by applying the trend equation from the 1992 to 2007 period</td></tr>
<tr><td>Fraction of Landfill</td><td colspan="3">Expert judgment (Linearly decreased from 79% in 1961 to 20% in 1992)</td></tr>
<tr><td rowspan="2">Hazardous Waste[1]</td><td>Amount of Waste</td><td rowspan="2">Expert judgment (No waste generated)</td><td colspan="3">Extrapolated</td><td colspan="2" rowspan="2">Hazardous Waste Generation and Treatment Report (MOE)[3]</td><td rowspan="2"></td></tr>
<tr><td>Fraction of Landfill</td><td colspan="3">Extrapolated</td></tr>
</table>

▭ : National statistics

Note: 1) Hazardous waste is assumed to be generated from 1981 as the industry sector grew rapidly since then.

2) From 1992 to 1995, construction waste was included in industrial waste in the *National Waste Generation and Treatment Report (MOE).*

3) Since 2019, the *Hazardous Waste Generation and Treatment Report* has been integrated into the *National Waste Generation and Treatment Report.*

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5) *Estimation of Data for GHG Emissions from the Waste Sector,* Korea Environmental Corporation (KECO) (2010)

6) *National Report and Plan for Waste Management*, Ministry of Environment (MOE)

7) The *National Waste Generation and Treatment Report* which contains survey data on waste generation, treatment, and recycling is used as fundamental activity data for establishing national targets and master plan for resource conservation and recovery.

According to waste management policies, unmanaged landfills have been converted to managed landfills since 1990, and only managed landfills have been in operation since 2003. The annual ratio of managed landfills to unmanaged landfills was determined using data on landfills in the *Greenhouse Gas Emissions Database for the Environmental Sector* as shown in Table 7-8.

| Table 7-7 | Activity Data Source for Solid Waste Disposal

Period	Activity Data	Name of Statistics	Published by
1990-2022	Amount of landfill waste at SWDS	*National Waste Generation and Treatment Report*	Ministry of Environment (MOE)

| Table 7-8 | Ratio of Managed to Unmanaged Waste Disposal Sites (SWDS)[1)]

(Unit: %)

Type	1990	2000	2010	2018	2021	2022
Managed SWDS	61	97	100	100	100	100
Unmanaged SWDS	39	3	0	0	0	0

Note: 1) Using data on landfill operation plans, cover materials, landfill gas collection and treatment systems, and leachate drainage and treatment system from 1,640 waste disposal sites nationwide, the ratio of managed to unmanaged SWDS was estimated.

Source: *Greenhouse Gas Emissions Database for the Environmental Sector*, KECO (2006)

Activity data on solid waste disposed to managed SWDS per waste type and material were estimated using the ratio of managed to unmanaged SWDS as shown in the following Table 7-9 and Table 7-10.

| Table 7-9 | Annual Waste Generation at Managed Waste Disposal Sites by Waste Type

(Unit: kt)

Waste Type	1990	2000	2010	2018	2021	2022
Municipal Solid Waste	17,362.3	7,700.3	3,211.0	2,746.8	2,918.2	2,356.3
Industrial Waste	2,420.1	6,688.3	8,507.9	7,686.8	6,165.1	6,028.5
Construction Waste	1,506.3	3,534.6	803.1	1,075.9	492.3	106.9
Hazardous Waste	87.2	336.1	668.2	1,137.0	881.8	949.8
Total	**21,375.9**	**18,259.2**	**13,190.2**	**12,646.5**	**10,457.5**	**9,441.6**

Source: *National Waste Generation and Treatment Report,* MOE (1990-2022), *Hazardous Waste Generation and Treatment Report,* MOE (1990-2018)

| Table 7-10 | Annual Waste Generation at Managed Waste Disposal Sites by Waste Material

(Unit: kt)

Waste Material	1990	2000	2010	2018	2021	2022
Food Waste	4,756.7	1,829.0	70.8	165.9	168.2	162.6
Paper	2,499.4	1,426.5	570.9	428.7	532.3	361.4
Wood	675.2	665.5	137.1	86.2	60.8	46.9
Rubber and leather	434.5	309.0	97.0	78.1	23.7	28.2
Textile	24.8	32.7	9.0	8.0	93.2	70.8
Other combustible waste	166.0	1,850.9	1,856.8	1,956.9	2,601.9	1,615.7
Domestic sludge	0.0	301.5	105.6	291.3	10.7	8.7
Industrial sludge	564.4	471.9	381.7	786.9	364.6	438.9
Plastics	955.0	794.4	393.8	359.9	502.8	492.4
Non-combustibles	11,299.9	10,577.8	9,567.3	8,484.6	6,099.3	6,216.0
Total	**21,375.9**	**18,259.2**	**13,190.2**	**12,646.5**	**10,457.5**	**9,441.6**

b) Landfill Gas Recovery

Landfill gas primarily consists of CH_4 and CO_2. The first landfill gas-to-energy facility which capture landfill gas for energy recovery of CH_4 was established in 1998 and increased to 14 facilities as of 2022. In 2022, the amount of CH_4 recovery was 94.8 kt CH_4 as shown in Table 7-11.

| Table 7-11 | Amount of CH_4 Recovery at Managed Waste Disposal Sites

(Unit: kt CH_4)

Amount	1990	2000	2010	2018	2021	2022
CH_4 Recovered	NO	64.5	136.1	101.1	94.9	94.8

Annual amount of CH_4 recovery has been based on statistics from the *National Waste Generation and Treatment Report* (MOE) since 2010. For data prior to 2010 as well as the amount recovered at SWDS to which waste is not disposed anymore, the survey conducted by the Korea Environment Corporation (KECO) were used.

7.2.1.3 Uncertainty and Time-series Consistency

7.2.1.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

7.2.1.3.2 Time-series Consistency

Emissions from managed SWDS were estimated using methods and emission factors consistently for the entire reporting period. Activity data primarily used for estimation of

CH_4 emissions were from *National Waste Generation and Treatment Report* while data not included in the aforementioned national report were either derived from independent surveys or calculated using gap filling techniques such as extrapolation, regression analysis and backward estimation to ensure time-series consistency.

7.2.1.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

7.2.2 Unmanaged Waste Disposal Sites (5.A.2.)

7.2.2.1 Category Description

	Gas	Methodology	Emission Factor	Activity Data
2022	CH_4	Tier 2	CS, D	Amount of landfill wastes at unmanaged waste disposal sites

Any SWDS that are not classified as a managed waste disposal site are categorized into a unmanaged waste disposal site. According to SWDS classification presented in the *2006 IPCC Guidelines,* unmanaged SWDS are divided into deep site and shallow site depending on whether the depth of the landfill is greater or less than 5 metres.

Unmanaged SWDS produce less CH_4 than anaerobic managed SWDS since air is readily introduced to the waste layer allowing wastes at unmanaged SWDS decompose aerobically. However uncontrolled dumping at unmanaged SWDS lead to negative environmental impacts such as air pollution and water contamination. In ROK, the number of unmanaged waste disposal sites gradually decreased since the introduction of waste management policies associated with hygienic treatment which led to the ceased operations of unmanaged shallow sites with the depth less than 5 metres in 2002 followed by the closure of those with the depth over 5 metres in 2003. Accordingly, relevant activity data do not exist since 2003.

In 2022, emissions from the unmanaged waste disposal sites were 1,046 kt CO_2-eq. accounting for 9.0 percent of total emissions from the solid waste disposal, which also represented a decrease of 4.9 percent from 2021.

| Table 7-12 | Emissions from Unmanaged Waste Disposal Sites

(Unit: kt CO_2-eq.)

Sub-category	1990	2000	2010	2018	2021	2022
Unmanaged waste disposal sites	3,149	3,113	1,907	1,278	1,100	1,046

7.2.2.2 Methodology

7.2.2.2.1 Method

CH_4 emissions from unmanaged waste disposal sites were calculated using the same First Order Decay (FOD) method as for managed waste disposal sites as described in Section 7.2.1.2.1.

7.2.2.2.2 Emission factor

Parameters used to estimate CH_4 emissions from unmanaged SWDS are the same as those used for managed sites which include decay rate constant (k), methane correction factor (MCF), oxidation factor (OX) and the fraction of CH_4 in generated landfill gas (F). Country specific factor was used for k while default values from the *2006 IPCC Guidelines* were used for three other parameters (MCF, OX and F).

| Table 7-13 | Parameters for Unmanaged Waste Disposal Sites

Parameters	Average Depth ≥ 5m	Average Depth < 5m
MCF	0.8	0.4
OX	0	
F	0.5	

Source: *2006 IPCC Guidelines, Vol.5, Ch.2, Table 3.1-3.2; p.3.15*

7.2.2.2.3 Activity Data

Activity data for unmanaged SWDS were obtained by applying the ratio of managed to unmanaged SWDS as presented in Table 7-8 to the amount of landfills per waste type and waste material.

The amounts of landfills at SWDS of the depth over 5 meters by waste type and waste material are presented in Tables 7-14 and 7-15, and the landfill amounts at SWDS of the depth less than 5 meters are presented in Tables 7-16 and 7-17.

According to the *Enforcement Rule* of the *Wastes Control Act,* disposal practices and CH_4 recovery of hazardous waste occur only at managed SWDS.

| Table 7-14 | Amount of Landfill at Unmanaged Waste Disposal Sites per Waste Type (Average Depth ≥ 5m)

(Unit: kt)

Waste Type	1990	2000	2010	2018	2021	2022
Municipal Solid Waste	8,290.0	241.9	NO	NO	NO	NO
Industrial Waste	1,155.5	210.1	NO	NO	NO	NO
Construction Waste	719.2	111.0	NO	NO	NO	NO
Hazardous Waste	0.0	0.0	NO	NO	NO	NO
Total	**10,164.7**	**563.0**	**NO**	**NO**	**NO**	**NO**

Source: *National Waste Generation and Treatment Report,* MOE (1990-2022); *Hazardous Waste Generation and Treatment Report,* MOE (1990-2018); *Greenhouse Gas Emissions Database for the Environmental Sector,* KECO (2006)

| Table 7-15 | Amount of Landfill at Unmanaged Waste Disposal Sites per Waste Material (Average Depth ≥ 5m)

(Unit: kt)

Waste Material	1990	2000	2010	2018	2021	2022
Food waste	2,271.2	57.5	NO	NO	NO	NO
Paper	1,193.4	44.8	NO	NO	NO	NO
Wood	322.4	20.9	NO	NO	NO	NO
Rubber and leather	207.5	9.7	NO	NO	NO	NO
Textile	11.9	1.0	NO	NO	NO	NO
Other combustible waste	37.6	58.1	NO	NO	NO	NO
Domestic sludge	0.0	9.5	NO	NO	NO	NO
Industrial sludge	269.5	11.4	NO	NO	NO	NO
Plastics	456.0	24.9	NO	NO	NO	NO
Non-combustibles	5,395.3	325.2	NO	NO	NO	NO
Total	**10,164.7**	**563.0**	**NO**	**NO**	**NO**	**NO**

| Table 7-16 | Amount of Landfill at Unmanaged Waste Disposal Sites per Waste Type (Average Depth < 5m)

(Unit: kt)

Waste Type	1990	2000	2010	2018	2021	2022
Municipal Solid Waste	2,856.4	26.2	NO	NO	NO	NO
Industrial Waste	398.1	22.8	NO	NO	NO	NO
Construction Waste	247.8	12.0	NO	NO	NO	NO
Hazardous Waste	0.0	0.0	NO	NO	NO	NO
Total	**3,502.4**	**61.1**	**NO**	**NO**	**NO**	**NO**

Source: *National Waste Generation and Treatment Report,* MOE (1990-2022); *Hazardous Waste Generation and Treatment Report,* MOE (1990-2018); *Greenhouse Gas Emissions Database for the Environmental Sector,* KECO (2006)

| Table 7-17 | Amount of Landfill at Unmanaged Waste Disposal Sites per Waste Material (Average Depth < 5m)

(Unit: kt)

Waste Material	1990	2000	2010	2018	2021	2022
Food waste	782.6	6.2	NO	NO	NO	NO
Paper	411.2	4.9	NO	NO	NO	NO
Wood	111.1	2.3	NO	NO	NO	NO
Rubber and leather	71.5	1.1	NO	NO	NO	NO
Textile	4.1	0.1	NO	NO	NO	NO
Other combustible waste	13.0	6.3	NO	NO	NO	NO
Domestic sludge	0.0	1.0	NO	NO	NO	NO
Industrial sludge	92.8	1.2	NO	NO	NO	NO
Plastics	157.1	2.7	NO	NO	NO	NO
Non-combustibles	1,859.0	35.3	NO	NO	NO	NO
Total	**3,502.4**	**61.1**	**NO**	**NO**	**NO**	**NO**

7.2.2.3 Uncertainty and Time-series Consistency

7.2.2.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

7.2.2.3.2 Time-series Consistency

CH_4 emissions from the unmanaged waste disposal sites were estimated using method and emission factors consistently for the entire reporting period. Activity data were primarily from *National Waste Generation and Treatment Report* while data not included in national statistics were calculated using gap-filling techniques based on expert judgment and relevant data from reliable sources to ensure time-series consistency.

7.2.2.4 QA/QC

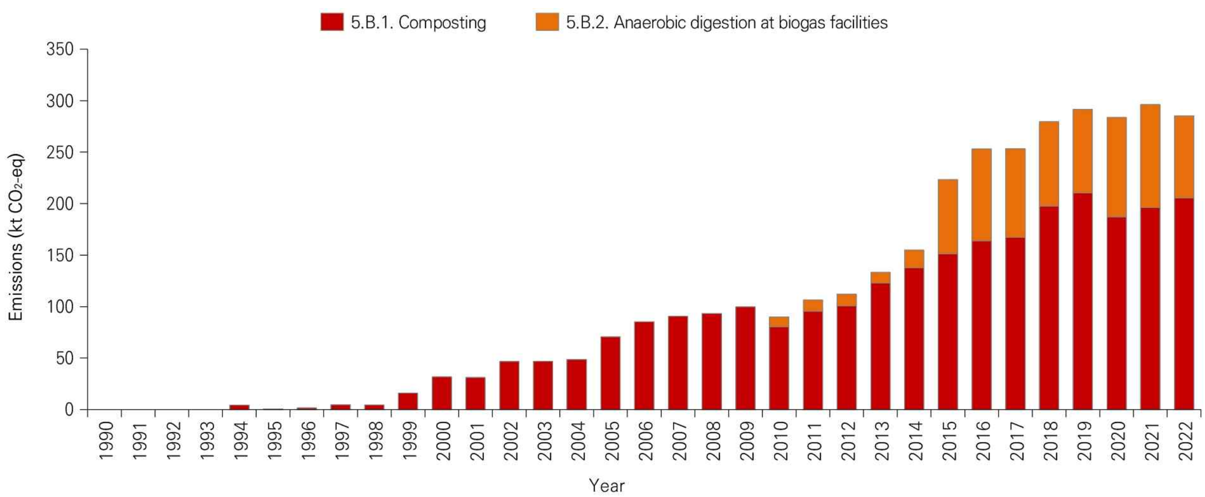
General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

7.3 Biological Treatment of Solid Waste (5.B.)

In the category of Biological treatment of solid waste (5.B.), CH_4 and N_2O emissions are generated during the aerobic process of Composting (5.B.1.) of organic wastes such as food waste, animal and plant residues, and sludge, or from Anaerobic digestion at biogas facilities (5.B.2.).

In 2022, biological treatment of solid waste produced emissions of 285 kt CO_2-eq, accounting for 1.6 percent of total emissions in the waste sector, which also represented a 3.8 percent decrease from 2021. Composting accounted for the majority of emissions from this reporting category with 72.1 percent while 27.9 percent were from anaerobic digestion at biogas facilities.

Emissions from composting were 206 kt CO_2-eq which increased by 4.8 percent from 2021 while anaerobic digestion at biogas facilities emitted 79 kt CO_2-eq which decreased by 20.6 percent.



| Figure 7-4 | Trends in Biological Treatment of Solid Waste Emissions (1990-2022)

| Table 7-18 | Emissions from Biological Treatment of Solid Waste

(Unit: kt CO_2-eq.)

Sub-category	1990	2000	2010	2018	2021	2022
5.B.1. Composting	NE	32	80	198	196	206
5.B.2. Anaerobic digestion at biogas facilities	NE	NE	9	82	100	79
Total	NE	32	90	279	296	285

7.3.1 Composting (5.B.1.)

7.3.1.1 Category Description

2022	Gas	Methodology	Emission Factor	Activity Data
	CH_4, N_2O	Tier 2	CS	Amount of composted waste

Composting involves aerobic processes through which degradable organic carbon in the waste material is converted into CO_2 by microorganisms. Organic wastes, after processes of separation, shredding and crushing at composting facilities, are reduced in material and biological activity. CH_4 emissions are produced in small quantity from anaerobic sections while N_2O are generated during both nitrification and denitrification of ammonia nitrogen which is a product of the decomposition process of organic matter.

In 2022, emissions from composting were 206 kt CO_2−eq, accounting for 72.1 percent of the emissions from biological treatment of solid waste, which also represented an increase of 4.8 percent from 2021.

| Table 7−19 | Emissions from Composting

(Unit: kt CO_2−eq.)

Sub−category	1990	2000	2010	2018	2021	2022
Composting	NE[1)]	32	80	198	196	206

Note: 1) Activity data for the 1990 to 1993 period were unavailable and it was considered that the likely level of emissions in the respective period were insignificant as emissions in 1994 were less than 5 kt CO_2−eq,, accounting for less than 0.05 percent of total national emissions as defined in Article 32 of the Modalities, Procedures and Guidelines (MPGs). Accordingly, emissions were not estimated.

7.3.1.2 Methodology

7.3.1.2.1 Method

CH_4 and N_2O emissions from composting were estimated by multiplying the amount of waste treated at the biological treatment plant by emission factors in accordance with the equation provided in the *2006 IPCC Guidelines.*

CH_4 and N_2O emissions from biological treatment (composting)	
$$\text{Emissions} = EF \times M \times 10^{-3}$$	
Emissions	: total $CH_4 \cdot N_2O$ emissions in inventory year [tonnes GHG/yr]
EF	: $CH_4 \cdot N_2O$ emission factor for treatment (composting) [g GHG/kg waste]
M	: mass of organic waste treated by composting [tonnes waste/yr]

Source: *2006 IPCC Guidelines, Vol.5, Ch.4, Equations 4.1-4.2*

7.3.1.2.2 Emission Factor

Country-specific emission factors for CH_4 and N_2O were used.[8)]

| Table 7-20 | Emission Factors for Composting

CH_4 Emission Factor (g CH_4/kg waste)	N_2O Emission Factor (g N_2O/kg waste)
0.26	0.15

7.3.1.2.3 Activity Data

Activity data used for emissions from composting were based on the *National Waste Generation and Treatment Report*. Data for the 1990 to 1993 period were not available and it is likely that the level of emissions in the respective period was insignificant.

| Table 7-21 | Amount of Waste in Composting

(Unit: kt)

Activity Data	1990	2000	2010	2018	2021	2022
Amount of waste composted	NE[1)]	672.1	1,710.3	4,203.6	4,170.9	4,371.3

Note: 1) Activity data for the 1990 to 1993 period were unavailable and it was considered that the likely level of emissions in the respective period were insignificant as emissions in 1994 were less than 5 kt CO_2-eq, accounting for less than 0.05 percent of total national emissions as defined in Article 32 of the Modalities, Procedures and Guidelines (MPGs).

Source: *National Waste Generation and Treatment Report*, MOE (1990-2022)

| Table 7-22 | Activity Data Source for Composting

Period	Activity Data	Name of Statistics	Published by
1994-2022	Amount of waste composted	*National Waste Generation and Treatment Report*	Ministry of Environment (MOE)

8) Country-specific emission factors were developed in 2019 based on values of on-site measurement of greenhouse gas concentration at three composting facilities and two anaerobic digestion facilities in 2017 and 2018.

7.3.1.3 Uncertainty and Time-series Consistency

7.3.1.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

7.3.1.3.2 Time-series Consistency

Emissions from composting were estimated using methodological approach, emission factors and activity data consistently for the entire reporting period to ensure time-series consistency.

7.3.1.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

7.3.2 Anaerobic Digestion at Biogas Facilities (5.B.2.)

7.3.2.1 Category Description

	Gas	Methodology	Emission Factor	Activity Data
2022	CH_4	Tier 1	D	Amount of waste treated by anaerobic digestion at biogas facilities, amount of methane recovery

Anaerobic digestion at biogas facilities refers to the process during which organic material is decomposed by microorganisms under anaerobic conditions by maintaining temperature, moisture content, and pH close to their optimal values which results in CH_4 and N_2O emissions.

In 2022, emissions from anaerobic digestion at biogas facilities were 79 kt CO_2-eq, accounting for 27.9 percent of total emissions from biological treatment of solid waste, which also represented a 20.6 percent decrease from 2021.

| Table 7-23 | Emissions from Anaerobic Digestion in Biogas Facilities

(Unit: kt CO_2-eq.)

Sub-category	1990	2000	2010	2018	2021	2022
Anaerobic Digestion in Biogas Facilities	NE	NE	9	82	100	79

Note: As emissions in 2010 from which initial activity data were collected were insignificant accounting for less than 0.05 percent of total national emissions as defined in Article 32 of the Modalities, Procedures and Guidelines (MPGs), it was considered that the likely level of emissions prior to 2010 were zero or insignificant. Accordingly, emissions in the 1990 to 2009 period were not estimated.

7.3.2.2 Methodology

7.3.2.2.1 Method

Following the *2006 IPCC Guidelines*, CH_4 emissions from anaerobic digestion at biogas facilities were estimated by first multiplying the amount of waste treated at biogas facilities by emission factors to calculate the amount of CH_4 generated. Then the total amount of CH_4 recovered was subtracted from the amount of CH_4 generated to calculate total CH_4 emissions.

CH_4 emissions from biological treatment (anaerobic digestion at biogas facilities)

$$\text{Emissions} = [EF \times M \times 10^{-3}] - R$$

Emissions	:	total CH_4 emissions in inventory year [t CH_4/yr]
EF	:	CH_4 emission factor for treatment (anaerobic digestion at biogas facilities) [g CH_4/kg waste]
M	:	mass of organic waste treated by anaerobic digestion at biogas facilities [t waste/yr]
R	:	total amount of CH_4 recovered [t CH_4/yr]

Source: *2006 IPCC Guidelines, Vol.5, Ch.4, Equation 4.1*

The amount of CH_4 generated at biogas facilities was calculated by arithmetic estimation which simply multiplied the mass of waste presented in national waste statistics by the given emission factor. However the amount of CH_4 recovered was measured and quantified directly on site at each biogas facility. For this reason, it was observed from some biogas facilities that the amount of CH_4 recovered was larger than the amount of CH_4 generated. In this case, to avoid underestimation of emissions from this subcategory, the whole amount of CH_4 leaked[9] was considered as emissions.

9) To calculate the leakage, an IPCC default value of 5 percent was applied to the amount of CH_4 generated. The amount of CH_4 generated was calculated by dividing the amount of CH_4 recovered by recovery efficiency of 0.95 based on expert judgment. (Leakage = (Amount of CH_4 recovered / 0.95) × 0.05)

7.3.2.2.2 Emission Factor

A default CH_4 emission factor on a wet weight basis provided by the *2006 IPCC Guidelines* was used. As a moisture content of waste treated in ROK is over 60 percent in average, a default value of 0.8 was applied.

| Table 7-24 | Emission Factor for Anaerobic Digestion at Biogas Facilities

CH_4 Emission Factor (g CH_4/kg waste)	N_2O Emission Factor (g N_2O/kg waste)	Remarks	Source
0.8	-	On a wet weight basis	*2006 IPCC Guidelines*

Source: *2006 IPCC Guidelines, Vol.5, Ch.4, Table 4.1*

7.3.2.2.3 Activity Data

Activity data used for anaerobic digestion at biogas facilities which include the amount of waste treated (Table 7-26) and CH_4 recovered (Table 7-27) were based on the *National Waste Generation and Treatment Report.* To enhance accuracy of data through cross-validation, the Report on *Biogasification of Organic Waste Resources* which has been released since 2015 was also used.

| Table 7-25 | Activity Data Source for Anaerobic Digestion at Biogas Facilities

Period	Activity Data	Name of Statistics	Published by
2010-2022	Amount of waste treated by anaerobic digestion at biogas facilities, amount of methane recovery	*National Waste Generation and Treatment Report*	Ministry of Environment (MOE)
2015-2022		*Report on Biogasification of Organic Waste Resources*	

| Table 7-26 | Waste Treated by Anaerobic Digestion at Biogas Facilities

(Unit: kt)

Activity Data	1990	2000	2010	2018	2021	2022
Amount of waste treated	NE[1)]	NE	121	2,796	3,246	4,751

Note: 1) As emissions in 2010 from which initial activity data were collected were insignificant, accounting for less than 0.05 percent of total national emissions as defined in Article 32 of the Modalities, Procedures and Guidelines (MPGs), it was considered that the likely level of emissions prior to 2010 were zero or insignificant. Accordingly, emissions in the 1990 to 2009 period were not estimated.

Source: *National Waste Generation and Treatment Report,* MOE (1990-2022)

| Table 7-27 | CH_4 Recovery from Anaerobic Digestion at Biogas Facilities

(Unit: kt CH_4)

Activity Data	1990	2000	2010	2018	2021	2022
Amount of CH_4 recovered	NE	NE	6.3	55.1	67.6	53.4

7.3.2.3 Uncertainty and Time-series Consistency

7.3.2.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

7.3.2.3.2 Time-series Consistency

Emissions from anaerobic digestion at biogas facilities were estimated using methodological approach, emission factors and activity data consistently for the entire reporting period to ensure time-series consistency.

7.3.2.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

7.4 Incineration and Open Burning of Waste (5.C.)

7.4.1 Waste Incineration (5.C.1.)

7.4.1.1 Category Description

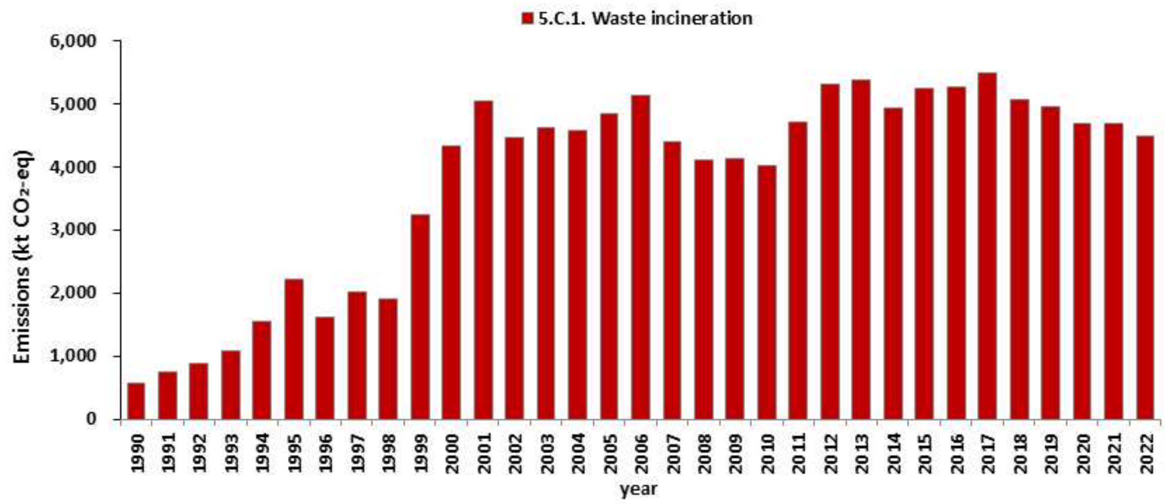
2022	Gas	Methodology	Emission Factor	Activity Data
	CO_2, CH_4, N_2O	Tier 2	D, CS	Amount of waste incinerated

Emissions of CO_2, CH_4, and N_2O generated from the combustion of wastes of fossil origin such as plastics, synthetic fibers and waste oil are reported under either Waste incineration (5.C.1.) or Open burning of waste (5.C.2.). Consistent with the *2006 IPCC Guidelines,* emissions from incineration with energy recovery are reported in the Energy sector. In ROK, emissions from incineration of municipal wastes and industrial wastes which were used as an alternative fuel in cement kilns with energy recovery at waste-to-energy facilities were included in the Energy sector. At some incineration facilities, the percentage of wastes incinerated with energy recovery was unknown as relevant data were not available. Emissions from such facilities were reported under the Waste sector to avoid double counting.

Open burning of waste refers to the combustion of waste in open-air or open dumps where emissions are released directly into the air without passing through a chimney or stack. In ROK, open burning of waste does not occur as it is prohibited by the *Wastes Control Act*.[10]

In 2022, emissions from waste incineration and open burning were 4,484 kt CO_2-eq, accounting for 24.6 percent of total emissions from the Waste sector, which also represented a decrease of 4.5 percent from 2021.

10) In accordance with Article 25 of the *Wastes Control Act* and Article 10 of its *Enforcement Rule*, open burning of waste is allowed only at the nationally-approved waste management plants.



| Figure 7-5 | Trends in Emissions from Waste Incineration (1990-2022)

| Table 7-28 | Emissions from Waste Incineration

(Unit: kt CO_2-eq.)

Waste Type		1990	2000	2010	2018	2021	2022
Municipal Solid Waste		198	440	188	647	860	588
Industrial Waste	Industrial Solid Waste	253	2,574	2,505	2,976	2,573	2,617
	Sewage Sludge	0.1	4	74	76	88	93
Construction Waste		59	564	487	434	243	250
Hazardous Waste		51	737	693	818	813	814
Clinical Waste		IE[1)]	5	60	121	116	122
Total		561	4,324	4,007	5,072	4,693	4,484

Note: 1) In domestic statistics, clinical waste was included in hazardous waste until 1999.

7.4.1.2 Methodology

7.4.1.2.1 Method

CO_2 emissions from waste incineration were estimated using the incinerated amount of waste per waste material and the fraction of incineration facilities without energy recovery capabilities in accordance with the equation from the *2006 IPCC Guidelines*.

CO₂ emissions from waste incineration	

CO_2 emissions from waste incineration

$$CO_2\ Emissions = \sum_{i,j}\{SW_{i,j} \times EF_{i,j} \times OF_i\} \times 44/12$$

CO_2 Emissions	:	CO_2 emissions [tonnes CO_2-eq]
SW	:	total amount of waste incinerated in year t [tonnes waste]
EF	:	emission factor [tonnes CO_2-eq/tonne waste]
OF	:	oxidation factor [fraction]
i	:	types of waste (municipal solid waste, industrial waste, construction waste, hazardous waste)
j	:	waste material

Source: *2006 IPCC Guidelines, Vol.5, Ch.5, Equation 5.2*

CH_4 and N_2O emissions were estimated using the incinerated amount of waste and the percentage of wastes incinerated without energy recovery which were multiplied by country-specific emission factors.

CH_4 and N_2O emissions from waste incineration

$$Emissions = IW_i \times EF_{i,j} \times 10^{-6}$$

Emissions	:	CH_4·N_2O emissions [tonnes CH_4 OR tonnes N_2O]
IW	:	total amount of waste incinerated in year t [tonnes waste]
EF	:	emission factor [tonnes CH_4/tonne waste OR tonnes N_2O/tonne waste]
i	:	types of waste (municipal solid waste, industrial waste, construction waste, hazardous waste)
j	:	type of gas (CH_4, N_2O)

Source: *2006 IPCC Guidelines, Vol.5, Ch.5, Equations 5.4-5.5*

7.4.1.2.2 Emission Factor

CO_2 emission factors for waste incineration were calculated by multiplying CO_2 parameters which include the dry matter content (*DM*), the amount of organic carbon content in dry matter (*CF*) and the fraction of fossil carbon in organic carbon (*FCF*).

$$EF_{i,j} = DM_{i,j} \times CF_{i,j} \times FCF_{i,j}$$

EF : emission factor
DM : dry matter content
CF : organic carbon content
FCF : the fraction of fossil carbon in organic carbon
i : types of waste (municipal solid waste, industrial waste, construction waste, hazardous waste)
j : type of gas

For CO_2 parameters per waste material, default values and country-specific values were used as presented in Table 7-29.

| Table 7-29 | CO_2 Parameters for Waste Incineration[1)2)3)]

Waste Type (Domestic Classification System)	Waste Material	Dry Matter Content (DM)	Organic Carbon Content (CF)[11)]	Fraction of Fossil Carbon (FCF)	Waste Type (CRT Classification)
Municipal Solid Waste	Paper/Cardboard	0.7951	0.4276	0.01	Municipal Solid Waste (MSW)
	Waste Fibers	0.7763	0.5176	0.2	
	Food Waste	0.4	0.38	-	
	Rubber/Leather	0.9343	0.5705	0.2	
	Plastics	0.8605	0.7630	1	
	Wood	0.85	0.5	-	
	Glass	1	NA	NA	
	Metal	1	NA	NA	
	Other (Combustibles)	0.5548	0.5137	1	
	Other (Non-combustibles)	0.9	0.03	1	
Industrial Waste	Sewage Sludge	0.227	0.4566	0	Sewage Sludge
	Waste Paper	0.6997	0.4252	0.01	Industrial Waste (except sewage sludge)
	Waste Fibers	0.9897	0.5488	0.16	
	Waste Synthetic Resin	0.9803	0.6695	0.8	
	Waste Synthetic Rubber	0.9978	0.8293	0.17	
	Waste Leather	0.9843	0.5779	0.03	
	Wastewater Treatment Sludge	0.425	0.4737	0.9	
	Process Sludge	0.3197	0.4246	0.9	
	Water Treatment Sludge	0.1677	0.4143	0.9	
	Animal and Plant Residues	0.435	0.5222	0	
	Used Cooking Oil	0.985	0.7305	0	
	Waste Wood	0.8846	0.6060	0	
	Incineration Ash	0.8684	0.3097	0.03	

Waste Type (Domestic Classification System)	Waste Material	Dry Matter Content (DM)	Organic Carbon Content (CF)[11]	Fraction of Fossil Carbon (FCF)	Waste Type (CRT Classification)
	Other	0.9	0.04	0.03	
Construction Waste	Waste Wood	0.8846	0.606	0	Industrial Waste
	Waste Synthetic Polymers	0.9803	0.6695	0.8	
	Waste Fibers	0.9897	0.5488	0.16	
	Waste Paperboard	0.966	0.4069	0.01	
	Waste Board Materials	0.983	0.2216	0.9	
	Waste Panels	0.985	0.6179	0.9	
	Other	0.9	0.04	0.03	
Hazardous Waste	Process Sludge	0.3197	0.4246	0.9	Hazardous Waste
	Other Waste Organic Solvents	0.1783	0.4000	0.9	
	Incinerator Ash	0.9943	0.2652	0.9	
	Waste Pesticides	0.3233	0.3503	0.9	
	Waste Sewage Sludge	0.5667	0.2796	0.9	
	Waste Oils	0.9650	0.6207	1	
	Waste Toxic Substances	0.3823	0.6054	0.9	
	Waste Catalysts	0.9840	0.1199	0.9	
	Waste Paint and Lacquer	0.4763	0.7865	0.9	
	Waste Synthetic Rubber	0.8354	0.8162	0.17	
	Waste Synthetic Polymers	0.8312	0.6757	0.8	
	Waste Adsorbents and Absorbents	0.9970	0.8227	0.9	
	Halogenated Organic Solvents	0.0057	0.7554	0.9	
	PCB–containing Waste	0.8793	0.9190	0.9	
	Other	0.9	0.04	0.03	
	Clinical Waste	0.6945	0.5123	0.4	Clinical Waste

Note: 1) Country–specific values in grey shaded cells ( ).

2) Fossil carbon content (FCF) for other waste as per *2006 IPCC Guidelines, Vol.5, Ch.2, Table 2.4–2.5* in blue shaded cells ( ).

3) Fossil carbon content (FCF) and oxidation factors for industrial waste and clinical waste according to *2006 IPCC Guidelines, Vol.5, Ch.5, Table 5.2* in orange shaded cells ( ).

Source: *2006 IPCC Guidelines, Vol.5, Ch.2, Table 2.4–2.6; Ch.5, Table 5.2*

11) Country–specific values for organic carbon content (CF) per waste material were developed in 2014 using data from elemental analysis and proximate analysis in the *National Waste Management Statistics (2013)*.

For CH_4 and N_2O, country-specific emission factors were used.

| Table 7-30 | Non-CO_2 Emission Factors for Waste Incineration

Waste Type	CH_4 Emission Factor (g CH_4/t waste)	N_2O Emission Factor (g N_2O/t waste)
Municipal Solid Waste	6.1	52.1
Industrial Waste	13.9	129.7
Sewage Sludge	18.0	449.1
Construction Waste and Hazardous Waste[1)]	13.9	129.7
Clinical Waste	2.8	94.5

Note: 1) National emission factors[12)] for industrial waste were also used for construction waste and hazardous waste.

7.4.1.2.3 Activity Data

Activity data for waste incineration were derived from *National Waste Generation and Treatment Report* and *Hazardous Waste Generation and Treatment Report* which are published annually by MOE pursuant to *Article 58* of the *Wastes Control Act* and *Article 81* of its *Enforcement Rules*. Waste data were extrapolated for the time period in which data were unavailable as shown in Table 7-31.

According to the *2006 IPCC Guidelines,* emissions from incineration facilities with energy recovery are excluded from the waste incineration sector.

| Table 7-31 | Waste Incineration Data Sources and Estimation Method per Waste Type

<table>
<tr><th colspan="2">Waste Type</th><th>1990-1993</th><th>1994-1995</th><th>1996-present</th></tr>
<tr><td colspan="2">Municipal Solid Waste[1)]</td><td>Extrapolated due to unavailability of data</td><td colspan="2">National Waste Generation and Treatment Report (MOE)</td></tr>
<tr><td rowspan="2">Industrial Waste</td><td>Sludge</td><td colspan="2" rowspan="2">Extrapolated due to unavailability of data</td><td rowspan="3">Hazardous Waste Generation and Treatment Report (MOE)</td></tr>
<tr><td>Non-Sludge</td></tr>
<tr><td colspan="2">Construction Waste[2)]</td><td colspan="2">Extrapolated due to unavailability of data</td></tr>
<tr><td colspan="2">Hazardous Waste</td><td>Extrapolated due to unavailability of data</td><td colspan="2">Hazardous Waste Generation and Treatment Report (MOE)</td></tr>
<tr><td colspan="2">Clinical Waste</td><td colspan="2">Included in hazardous waste</td><td>Hazardous Waste Generation and Treatment Report(MOE)
※Disaggregated from hazardous waste since 2000</td></tr>
</table>

Note: 1) The exact amount of incinerated wastes for the 1990 to 1993 period were extrapolated as relevant data were not available.

2) As the volume of industrial waste and construction waste were aggregated in national statistics in the 1990 to 1995 period, the construction waste volume for the respective period was calculated using the average ratio of industrial waste and construction waste in the 1996 to 1998 period.

※ *Activity data for the volume of waste incinerated at energy recovery facilities were sourced from the National Waste Generation and Treatment Report.*

12) National emission factors per waste material were developed in the 2011 to 2021 time period by measuring greenhouse gas concentration at facilities equipped with incinerators of fixed bed, fluidized bed, continuous or batch systems.

| Table 7-32 | Activity Data Source for Waste Incineration

Period	Activity Data	Name of Statistics	Published by
1990-2022	Amount of waste incinerated	*National Waste Generation and Treatment Report, Hazardous Waste Generation and Treatment Report*	Ministry of Environment (MOE)

| Table 7-33 | Amount of Waste Incinerated per Waste Type

(Unit: kt)

Waste Type		1990	2000	2010	2018	2021	2022
Municipal Solid Waste		544.9	1,985.6	3,872.2	5,023.5	5,640.2	5,530.1
Industrial Waste	Industrial Solid Waste	536.5	2,897.4	2,296.6	2,911.1	2,474.3	2,502.6
	Sewage Sludge	1.1	35.1	617.3	635.1	733.5	775.6
Construction Waste		107.3	755.8	335.6	238.6	135.9	146.0
Hazardous Waste		41.1	584.1	513.0	607.8	593.3	587.1
Clinical Waste		IE	9.7	109.1	221.4	211.9	223.8
Total		**1,231.0**	**6,267.8**	**7,743.8**	**9,637.5**	**9,789.2**	**9,765.4**

Note: Emissions from incineration with energy recovery are reported in the Energy Sector, not in the Waste Sector.
Source: *National Waste Generation and Treatment Report,* MOE (1990-2022); *Hazardous Waste Generation and Treatment Report,* MOE (1990-2018)

7.4.1.3 Uncertainty and Time-series Consistency

7.4.1.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

7.4.1.3.2 Time-series Consistency

Emissions from waste incineration were estimated using methodological approach, emission factors and activity data consistently for the entire time series. For years for which no data were available, data were extrapolated to ensure time series consistency.

7.4.1.4 QA/QC

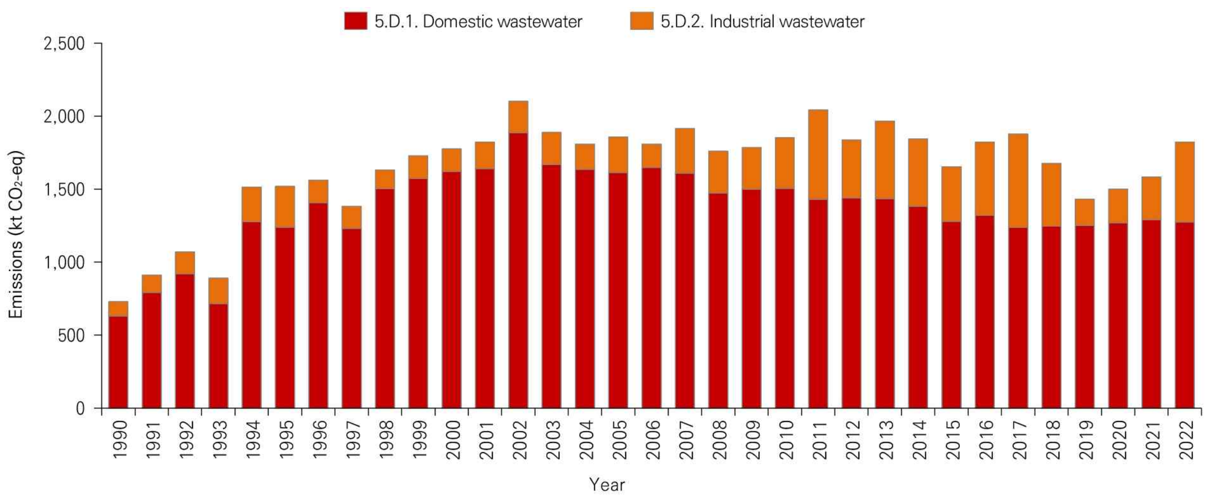
General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

7.5 Wastewater Treatment and Discharge (5.D.)

Emissions produced during the anaerobic treatment or disposal of wastewater are reported under either Domestic wastewater (5.D.1.) or Industrial wastewater (5.D.2.).

In 2022, wastewater treatment and discharge emitted 1,823 kt CO_2−eq, accounting for 10.0 percent of total emissions in the Waste sector, which also represented a 15.2 percent increase from 2021. Domestic wastewater represented 69.9 percent of emissions from this reporting category in 2022 while industrial wastewater accounted for 30.1 percent.

Domestic wastewater emissions were 1,275 kt CO_2−eq which decreased by 1.2 percent from 2021 while industrial wastewater treatment emissions increased by 87.3 percent, emitting 548 kt CO_2−eq.[13)]



| Figure 7−6 | Trends in Wastewater Treatment Emissions (1990−2022)

| Table 7−34 | Emissions from Wastewater Treatment and Discharge

(Uint: kt CO_2−eq.)

Sub−category	1990	2000	2010	2018	2021	2022
5.D.1. Domestic wastewater	631	1,621	1,505	1,247	1,291	1,275
5.D.2. Industrial wastewater	98	155	349	429	293	548
Total	730	1,776	1,854	1,676	1,583	1,823

13) Industrial wastewater statistics for 2022 were not available in time for publication of this report due to delays in finalizing relevant data. Accordingly, this report was prepared based on the preliminary estimate of emissions from industrial wastewater.

7.5.1 Domestic wastewater (5.D.1.)

7.5.1.1. Category Description

	Gas	Methodology	Emission Factor	Activity Data
2022	CH_4, N_2O	Tier 2	D, CS	BOD and nitrogen concentrations in domestic wastewater, amount of methane recovered

Emissions from domestic wastewater are produced from two sources: public sewage treatment and untreated/uncollected sewage.

Public sewage treatment refers to the treatment of wastewater from domestic sources and commercial areas through sewers at large-scale wastewater treatment plants managed by local governments. In ROK, wastewater at public sewage treatment plants are treated most commonly through aerobic system using aeration tank, and most are equipped with advanced treatment systems to additionally remove nutrients like nitrogen (N) and phosphorus (P). At such public sewage treatment plants, CH_4 emissions are produced during the decomposition of organic matter under anaerobic conditions while N_2O emissions occur during denitrification as an intermediate of the advanced treatment process.

Emissions from untreated and uncollected sewage occur when wastewater in regions where sewers are not installed is discharged to a receiving water environment and anaerobically disposed. Although most sewage in ROK is treated at public wastewater treatment plants[14], wastewater treated at privately owned sewage treatment plants and septic tanks in remote areas where sewers are not installed are classified as untreated and uncollected sewage.

In 2022, emissions from domestic wastewater were 1,275 kt CO_2-eq, accounting for 69.9 percent of the total emissions from wastewater treatment and discharge, which also represented a decrease of 1.2 percent from 2021.

| Table 7-35 | Emissions from Domestic Wastewater

(Unit: kt CO_2-eq.)

Sub-category	1990	2000	2010	2018	2021	2022
Domestic Wastewater	631	1,621	1,505	1,247	1,291	1,275

14) Wastewater from over 95 percent of the populations in ROK are discharged through sewers as of 2022.

7.5.1.2. Methodology

1) Method

CH_4 and N_2O emissions from public sewage treatment were estimated using the methodology outlined in the *2006 IPCC Guidelines.*

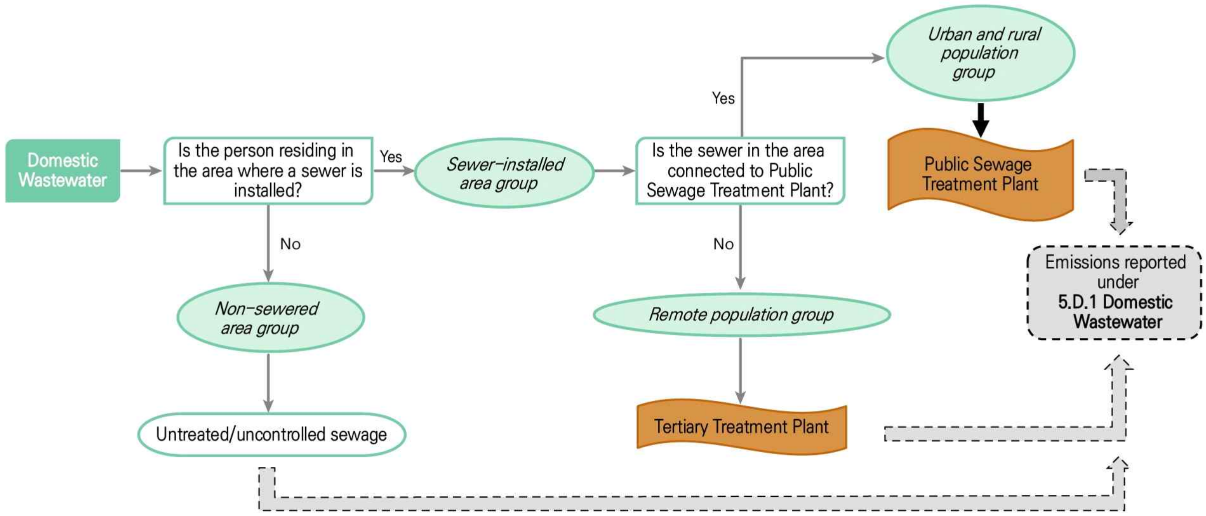
For CH_4 emissions, as the equation from the *2006 IPCC Guidelines* which uses parameters of population by income group and degree of utilization of treatment system does not reflect ROK's national circumstances, it was modified by replacing respective parameters with those that better reflect the unique wastewater treatment system in ROK. Accordingly, emissions were estimated by multiplying BOD concentrations for each population group (see Table 7-36) and for each treatment system (primary, biological, advanced and tertiary treatment) by corresponding emission factors. From such estimated emissions, the amount of CH_4 recovered is subtracted, and then the amount of CH_4 leaked from anaerobic digester[15] is added.

| Table 7-36 | Population Group for Domestic Wastewater

Population Group		Description	Reporting Category
Sewer-installed area group	Urban and rural population group	Population that reside in areas where sewers connected to the public sewage treatment plant are installed and thus their sewage is treated at public sewage treatment plants	5.D.1. Domestic wastewater
	Remote population group	Population that reside in areas where sewers connected to tertiary treatment plants are installed and thus their sewage is treated at tertiary treatment plants located in their residing area	
Non-sewered area group		Population that reside in areas where no sewers are installed	

Source: *2024 Sewer Statistics Preparation Guide,* KECO (2024)

15) As the amount of CH_4 recovered at some public sewage treatment plants exceeds the amount of CH_4 generated for the same reason as for Anaerobic digestion at biogas facilities (5.B.2.) as described in Section 7.3.2.2.1, the amount of CH_4 leaked was considered as emissions to avoid underestimation.



| Figure 7-7 | Domestic Wastewater Treatment Process

CH₄ emissions from public sewage treatment of domestic wastewater	
※ Used if the amount of recovered CH_4 is larger than the amount of CH_4 generated	
$$\text{Emissions} = \sum_{i,j}\{(TOW_{i,j} - S_{i,j}) \cdot EF_{i,j}\} - R + L_m$$	
Emissions	: CH_4 emissions from public sewage treatment and discharge [tonnes CH_4/yr]
i	: population group: urban and rural, and remote
j	: each treatment system (primary, biological, advanced and tertiary treatment)
TOW	: total organics in wastewater (BOD concentrations) [tonnes BOD/yr]
S	: organic component removed as sludge [tonnes BOD/yr] * *A default value of 0 is applied due to lack of activity data*
$EF_{I,j}$	: CH_4 emission factor [tonnes CH_4 /tonne BOD]
R	: amount of CH_4 recovered [tonnes CH_4/yr]
L_m	: *amount of CH_4 leaked [tonnes CH_4/yr]*

Source: *2006 IPCC Guidelines, Vol.5, Ch.6, Equation 6.1 (adjusted)*

To calculate the amount of biogas (CH_4) leaked from public sewage treatment plants, the amount of CH_4 recovered was multiplied by the rate of sewage sludge (e.g. wastewater from livestock manure), and then a 5 percent of CH_4 loss was applied. Activity data for such calculation were from the *Sewer Statistics.* Data on biogas production from anaerobic digesters have been available since 2015.[16]

16) Anaerobic digesters for wastewater treatment were introduced in 2015.

CH_4 leakage from digester		
$$Leakage = R/(1-\eta) \times C \times K \times 0.7143 \times 365 \times 10^{-3}$$		
Leakage	:	CH_4 emissions leaked from anaerobic digester [tonnes CH_4/yr]
R	:	amount of biogas(CH_4) generated [m^3/day]
η	:	loss of CH_4 [5%]
C	:	CH_4 concentrations in biogas [60%]
K	:	loss of biogas in digester [5%]
0.7143	:	conversion factor (CH_4 volume to mass) [16/22.4]

Source: *Country-specific methodology*

The N_2O[17] emissions from public sewage treatment were estimated by multiplying nitrogen concentrations per population group (urban and rural population group, remote population group) and treatment system (primary, biological, advanced and tertiary treatment) by country-specific N_2O emission factor.

N_2O emissions from public sewage treatment of domestic wastewater		
$$N_2O \text{ Emissions} = \sum_{i,j}(TN_{i,j} \cdot EF_{i,j})$$		
N_2O Emissions	:	N_2O emissions from domestic wastewater discharge [t N_2O/yr]
TN	:	N concentrations in the effluent per population group and per treatment system [t N/yr]
EF	:	N_2O emission factor per population group and per treatment system [t N_2O/t N]
i	:	population group: urban and rural, and remote
j	:	each treatment system (primary, biological, advanced and tertiary treatment)

Source: *2006 IPCC Guidelines, Vol.5, Ch.6, Equation 6.7 (adjusted)*

CH_4 emissions from untreated and uncollected wastewater were estimated in accordance with the *2006 IPCC Guidelines* by multiplying the emission factor by BOD concentrations in untreated and uncollected wastewater.

17) In ROK, most wastewater is transported to public sewage treatment plants, and data on nitrogen concentrations per plant are reported in the *Sewer Statistics*. Nitrogen concentrations in effluent discharged to a receiving water environment is managed in compliance with effluent water quality standards of the *Sewerage Act*.

CH$_4$ emissions from untreated and uncollected domestic wastewater		
$$CH_4\,Emissions = AD \times EF$$		
CH$_4$ emissions	:	CH$_4$ emissions from untreated/uncollected wastewater [tonnes CH$_4$/yr]
AD	:	BOD in untreated and uncollected wastewater [tonnes BOD/yr]
EF	:	CH$_4$ emission factor [tonnes CH$_4$/tonne BOD]

Source: *Country-specific methodology*

2) Emission Factor

Since the degree of utilization of treatment system per income group as suggested by the *2006 IPCC Guidelines* does not fully reflect the national circumstance of ROK, country-emission factors were developed for each wastewater treatment system based on the *Sewer Statistics* which include primary, biological, advanced and tertiary treatments. For biological and advanced treatments, country-specific emission factors were used while emission factors for primary and tertiary treatments were derived from values provided by research conducted by MOE in 2000 and 2002.

| Table 7-37 | Emission Factor per Sewage Treatment

(Unit: t CH$_4$/t BOD, t N$_2$O/t N)

Sewage Treatment	Primary Treatment[2)]	Biological Treatment[1)]	Advanced Treatment[1)]	Tertiary Treatment[2)]
CH$_4$ Emission Factor	0.01532 (Recovery Rate: 76.8%)	0.02245	0.00779	0.0017698
N$_2$O Emission Factor	0.00174	0.018	0.0122	0.0056814

Note: 1) Emissions from 5 to 9 plants of domestic sewage treatment were measured in the 2015 to 2021 period to develop country-specific emission factors.
2) Source: *Research on Greenhouse Gas Emissions from Environmental Infrastructure Facilities,* MOE (2002); *Research and Statistics on Greenhouse Gas Emissions in the Environmental Sector,* MOE (2002)[18)]

The emission factor for untreated and uncollected wastewater was calculated by multiplying the maximum CH$_4$ producing capacity by methane correction factor (MCF).

$$EF = B_0 \times MCF$$		
EF	:	CH$_4$ emissions factor [kg CH$_4$/kg BOD]
B$_0$	:	maximum CH$_4$ producing capacity [kg CH$_4$/kg BOD]
MCF	:	methane correction factor

Source: *2006 IPCC Guidelines, Vol.5, Ch.6, Equation 6.2*

18) Emission factors were developed based on emissions generated at major tertiary treatment plants.

The default value of 0.6 kg CH_4/kg BOD for B_0, and 0.1 for *MCF* for sea, river and lake discharge under the untreated system presented in the *2006 IPCC Guidelines* were used. The CH_4 emission factor for untreated and uncollected wastewater of 0.06 tonnes CH_4 per tonnes BOD was applied.

3) Activity Data

Total organic in wastewater ($TOW_{i,j}$) used as activity data for public sewage treatment are distinguished between organics loading of sewage from urban and rural population group per treatment system ($TOW_{1,j}$) and organics loadings in sewage produced by the remote population group (TOW_2).

Organics loading in the influent for each treatment system of primary, biological and advanced treatment ($TOW_{1,j}$) were estimated using the volume of sewage discharged at the plant, BOD and N concentrations as well as the removal rate. For biological and advanced treatment, $TOW_{1,j}$ is estimated based on organics loadings in sewage while the removal rate was applied to organics loadings for primary treatment in order to correspond to the emission factor which was calculated reflecting the removal rate.

The fraction of urban and rural population group (T_1) and remote population group (T_2) was obtained by dividing the respective population group by the population of the sewer-installed area group.

For organics loading and removal rates, weighted averages were calculated based on influent and effluent concentrations at each treatment plant as well as the total volume of wastewater discharged.

Total organically degradable material in domestic wastewater (public sewage treatment)

※ Used only for primary treatment

$$TOW_{1,j} = Q_j \times T_1 \times C \times (\lambda^*) \times 365 \times 10^{-6}$$

TOW_1	:	total organics in wastewater [tonnes BOD/yr *or* tonnes N/yr]
Q	:	the volume of sewage per treatment [m^3/day]
T_1	:	fraction of urban and rural population group [%]
C	:	organics concentrations of the influent [mg/L]
λ*	:	removal rate of organics
j	:	each treatment system (primary, biological, advanced and tertiary treatment)

Source: *Country-specific methodology*

As the volume of sewage and organics loading in sewage produced by the remote population group (TOW_2) were unavailable, the former was obtained by applying the fraction of the corresponding population to the total volume of sewage treated at public sewage treatment plants. For organics loading, the same value for public sewage treatment was used for tertiary treatment as well.

Total organically degradable material in domestic wastewater (tertiary treatment)

$$TOW_2 = Q \times T_2 \times C \times 365 \times 10^{-6}$$

TOW_2	:	total organics in wastewater [t BOD/yr or t N/yr]
Q	:	the volume of sewage treated at public sewage treatment plants [m3/day]
T_2	:	fraction of remote population group [%]
C	:	organics concentration of the influent at public sewage treatment plants [mg/L]

Source: *Country-specific methodology*

| Table 7-38 | Activity Data Source for Public Sewage Treatment

Period	Activity Data	Name of Statistics	Published by
1990-2022	BOD and nitrogen concentrations in domestic wastewater	*Sewer Statistics*	Ministry of Environment (MOE)
2015-2022	Amount of methane recovered	*Sewer Statistics, Report on Biogasification of Organic Waste Resources*	

| Table 7-39 | BOD and N Concentrations for Public Sewage Treatment (CH_4)

(Unit: CH_4 kt BOD/yr; N_2O kt T-N/yr)

Gas	Activity Data	1990	2000	2010	2018	2021	2022
CH_4	BOD concentrations	133.4	567.5	1,010.8	1,184.1	1,261.4	1,255.7
N_2O	N concentrations	13.2	188.3	257.1	279.4	298.4	300.1

Source: *Sewer Statistic*, MOE (1990-2022)

For the amount of methane recovered from public sewage treatment, data on biogas generated in digester from the *Sewer Statistics* were used. For the 1990 to 2014 period, relevant data were not available and thus the recovered amounts of CH_4 were not estimated.

| Table 7-40 | Amount of CH_4 recovered from Public Sewage Treatment

(Unit: kt CH_4)

Activity Data	1990	2000	2010	2018	2021	2022
Amount of CH_4 recovered	NE	NE	NE	86.3	74.4	72.6

Activity data for untreated and uncollected wastewater include the total organics loadings in untreated and uncollected wastewater discharged to a receiving water environment which were calculated by multiplying the organics loadings in sewage per capita of sewer-installed area group by the population of the non-sewered area group. The same value of organics concentration of the influent used for public sewage treatment was also used for the BOD concentrations in untreated and uncollected wastewater. For years in which relevant data were not available, interpolation method was applied.

Total organically degradable material in domestic wastewater (untreated and uncollected)

$$TOW_3 = \{[WT \times BOD_{inf}] / P_{sew}\} \times P_{non} \times 365 \times 10^{-6}$$

TOW_3 : total organics in untreated and uncollected wastewater [t BOD/yr]

WT : the volume of sewage treated at public sewage treatment plants [m3/day]

BOD_{inf} : BOD concentrations of influent [mg/L]

P_{sew} : sewer-installed area group

P_{non} non-sewered area group

Source: *Country-specific methodology*

| Table 7-41 | Activity Data for Untreated and Uncollected Wastewater (Population per Group)

(Unit: 1,000 people)

Category	1990	2000	2010	2018	2021	2022
Sewer-installed Area Group	14,120	33,843	46,358	49,834	49,968	50,059
Non-sewered Area Group	28,749	14,134	5,077	3,239	2,764	2,569

Source: *Sewer Statistics*, MOE (1990-2022)

| Table 7-42 | Activity Data for Untreated and Uncollected Wastewater (Volume and BOD)

(Unit: thousand m^3/day, mg/L)

Category	1990	2000	2010	2018	2021	2022
Volume of Untreated/uncollected Wastewater	6,999.8	6,586.5	2,128.6	1,297.7	1,117.6	1,018
BOD Concentrations	122.7	99.0	142.5	162.5	171.1	173.4

Source: *Sewer Statistics*, MOE (1990-2022)

7.5.1.3 Uncertainty and Time-series Consistency

7.5.1.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

7.5.1.3.2 Time-series Consistency

CH_4 and N_2O emissions from domestic wastewater were estimated using methodology, emission factors and activity data consistently for the entire time period. For years in which activity data for untreated and uncollected wastewater were not available, interpolation method was applied to ensure consistency.

7.5.1.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

7.5.2 Industrial Wastewater (5.D.2.)

7.5.2.1 Category Description

2022	Gas	Methodology	Emission Factor	Activity Data
	CH_4	Tier 2	CS	COD concentrations in industrial wastewater

Industrial wastewater refers to wastewater generated from industrial activities other than households and commercial activities. CH_4 emissions are produced when organics in industrial wastewater are treated or disposed anaerobically. In ROK, industrial wastewater is treated at industrial wastewater treatment plants in accordance with the *Water Environment Conservation Act*. If such industrial wastewater does not meet the criteria to be released after treatment at industrial wastewater plants and thus requires further treatment, it is then transported to public sewage treatment plants for the final treatment in compliance with the *Water Environment Conservation Act* and *Sewerage Act*.[19)]

19) Treatment of industrial wastewater at tertiary treatment plants requires an approval of the Public Sewage Administration after examining the capacity of public sewage plants and water quality standards. The standards for effluent water quality vary depending on the volume of the wastewater requiring further treatment and different types of regions as categorized by the *Water Environment Conservation Act*.

Under this reporting category, emissions from industrial wastewater treatment plants were reported while those from industrial wastewater that was further treated at public sewage treatment plants before being released were included in Domestic wastewater (5.D.1.).

In ROK, industries are classified into 11 sectors, and CH_4 emissions from industrial wastewater of respective sectors are reported. In 2022, emissions from industrial waste were 548 kt CO_2−eq., a 87.3 percent increase from 2021, and accounted for 30.1 percent of total emissions from wastewater treatment and discharge.

| Table 7−43 | Emissions from Industrial Wastewater

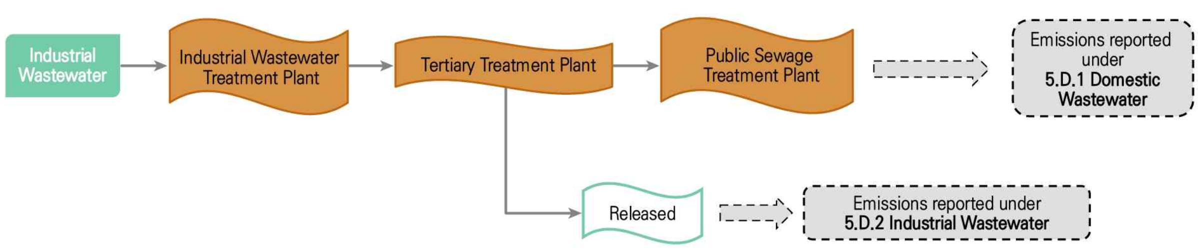
(Unit: kt CO_2−eq.)

Source	1990	2000	2010	2018	2021	2022
Industrial Wastewater	98	155	349	429	293	548

7.5.2.2 Methodology

7.5.2.2.1 Method

Emissions from industrial wastewater were estimated following the *2006 IPCC Guidelines* by multiplying the total organically degradable material loads (COD) per industrial sector by country−specific emission factor for each sector. For CH_4 recovery from industrial wastewater, the default value of 0 (zero) presented in the *2006 IPCC Guidelines* was applied.



| Figure 7−8 | Industrial Wastewater Treatment Process

CH$_4$ emissions from industrial wastewater		
$$CH_4\ Emissions = \sum_i (IND_i \cdot EF_i) - R$$		
CH$_4$ Emissions	:	CH$_4$ emissions from industrial wastewater [t CH$_4$/yr]
IND	:	total organically degradable material in wastewater [t COD/yr]
EF	:	CH$_4$ emission factor for industrial sector i [t CH$_4$/t COD]
i	:	industrial sector
R	:	amount of CH$_4$ recovered ※ *The default value of 0 was applied for R (CH$_4$ recovery) due to lack of data.*

Source: *2006 IPCC Guidelines, Vol.5, Ch.6, Equation 6.4*

7.5.2.2.2 Emission Factor

Country−specific emission factors per industrial sector were used.

| Table 7−44 | CH$_4$ Emission Factor for Industrial Wastewater

(Unit: t CH$_4$/ t COD)

Industrial Sector	Chemical	Electrical and Electronics	Food and Beverages	Pulp and Paper	Leather and Footwear	Textiles	Non−Metallic	Utilities	Wastewater Treatment Industry	Metal	Others
Country−specific Emission Factor	0.00168	0.00160	0.01000	0.00340	0.00360	0.00148	0.00020	0.00028	0.03250	0.00330	0.00576

Note: For each industrial sector, greenhouse gas concentrations were measured at two to four major plants to develop country−specific emission factors in the 2013 to 2020 period.

7.5.2.2.3 Activity Data

Activity data for industrial wastewater were from statistics published by National Institute of Environment Research. Respective statistics provide the volume of industrial wastewater from 11 industrial sectors under greenhouse gas inventory and corresponding BOD concentrations, as described in Table 7−47, which were converted to COD using conversion factors that were developed based on expert judgment to estimate emissions.

| Table 7−45 | Activity Data Source for Industrial Wastewater

Period	Activity Data	Name of Statistics	Published by
1990−2022	COD concentrations in industrial wastewater per sector	*Industrial Wastewater Generation and Treatment Report*	Ministry of Environment (MOE)

| Table 7-46 | Classification of Industrial Sector for Industrial Wastewater

GHG Inventory (11 sectors)	National Statistics (24 sectors) (until 2010)	National Statistics (34 types) (2011-present)
• Chemical	• Chemical	• Production of chemical substances and chemical product (except pharmaceuticals) • Production of medical substances and pharmaceuticals
• Electrical and Electronics	• Electrical and Electronics	• Production of electronic components, computers, video, audio, and communication equipment • Production of electrical equipment
• Food and Beverages	• Food and Beverages • Seafood sales	• Food production • Beverage production • Wholesale and commodity trading
• Pulp and Paper	• Tobacco, Pulp and Paper, Wood Products	• Tobacco production • Production of wood and wood products (except furniture) • Production of pulp, paper, and paper products
• Leather and Footwear	• Leather and Footwear	• Production of clothing, clothing accessories, and fur products • Production of leather, bags, and shoes
• Textiles	• Textiles	• Textile manufacturing (except clothing)
• Non-Metallic	• Non-Metallic	• Production of non-metallic mineral products
• Utilities	• Utilities	• Electricity, gas, steam, and air conditioning supply • Water supply services
• Wastewater Treatment Industry	• Wastewater Treatment Industry	• Waste collection, transportation, treatment, and raw material recycling
• Metal	• Processed Metal • Assembly Metal	• Primary metal manufacturing • Production of metal products (except machinery and furniture)
• Others	• Mining facilities • Publishing, printing, and photography • Petroleum refining • Testing facilities • Transportation equipment • Laundry facilities • Water purification facilities • Hospital facilities • Cleaning and condensation facilities • Electroplating facilities • Other • Rubber and Plastic facilities	• Coal, oil, and natural gas mining • Metal mining • Non-metallic mineral mining (except for fuel purpose) • Printing and reproduction of recorded media • Production of coke, briquettes, and refined petroleum product • Production of rubber and plastic products • Production of furniture • Health services • Other services • Electroplating facilities • Vehicle repair and car washing or cleaning facilities • Water purification facilities in industrial plants • Waste gas, dust removal, cleaning, and condensation facilities in industrial plants • Chemical testing facilities • Facilities not classified under any of 81 types of facilities specified in the *Enforcement Rules of the Water Environment Conservation Act.*

| Table 7-47 | COD Load per Industrial Sector for Wastewater Treatment

(Unit: kt COD)

Industrial Sector	1990	2000	2010	2018	2021	2022
Chemical	63.5	111.1	193.6	125.8	156.0	144.7
Electrical and Electronics	0.1	14.2	55.9	32.5	27.6	23.9
Food and Beverages	151.6	136.2	138.1	142.8	116.6	127.9
Pulp and Paper	214.2	250.9	134.2	169.1	126.6	139.4
Leather and Footwear	28.8	21.5	16.1	7.1	3.2	4.6
Textiles	172.4	71.3	59.3	48.8	42.7	42.5
Non-Metallic	4.1	14.2	5.1	2.5	4.0	4.2
Power and Water	48.3	69.1	37.6	108.4	71.6	64.0
Wastewater Treatment Industry	0.3	19.0	213.4	367.0	225.1	507.8
Metal	86.9	332.8	490.9	65.2	83.7	71.3
Other	86.4	206.7	260.9	137.7	149.3	122.6
Total	856.5	1,247.2	1,605.3	1,207.0	1,006.3	1,253.0

Source : *BOD-COD Load per industrial sector*, NIER (2004-2013); *Generation and Treatment of Industrial Wastewater*, MOE (1990-2022)

7.5.2.3 Uncertainty and Time-series Consistency

7.5.2.3.1 Uncertainty

The results of the uncertainty analysis are summarized in Section 1.6.

7.5.2.3.2 Time-series Consistency

Emissions from industrial wastewater were estimated using methodological approach, emission factors and activity data consistently for the entire reporting period to ensure time-series consistency.

7.5.2.4 QA/QC

General quality assurance and quality control (QA/QC) procedures were applied in accordance with the *2006 IPCC Guidelines* (see Section 1.5).

Annex

Annex

Annex 1. Key Category Analysis

The Republic of Korea has identified 23 categories in level assessments and 27 categories in trend assessments as key categories that cumulatively accounted for up to 95 percent of total emissions in 1990 and 2022, both for including and excluding LULUCF as presented in Table A-1 and Table A-2.

| Table A-1 | 2022 Level Assessment (including LULUCF)

* Key categories in grey shaded cells ( )

Rank	CRT Code and Source/Sink Category		Gas	2022 Emissions (kt CO_2-eq)	Tier 1 Level Assessment (Sum=1)	Cumulative Percentage
1	1.A.1.	Energy Industries: Solid Fuels	CO_2	169,441	0.220	0.220
2	1.A.2.	Manufacturing and Construction: Solid Fuels	CO_2	100,287	0.130	0.351
3	1.A.3.b.	Road Transportation	CO_2	92,736	0.121	0.471
4	1.A.1.	Energy Industries: Gaseous Fuels	CO_2	68,905	0.090	0.561
5	4.A.1.	Forest Land Remaining Forest Land	CO_2	-39,540	0.051	0.612
6	1.A.4.	Other Sectors: Gaseous Fuels	CO_2	31,698	0.041	0.653
7	2.B.8.	Petrochemical and Carbon Black Production	CO_2	31,276	0.041	0.694
8	2.F.1.	Refrigeration and Air Conditioning	Fluorinated gases	29,238	0.038	0.732
9	2.C.1.	Iron and Steel Production	CO_2	27,710	0.036	0.768
10	2.A.1.	Cement Production	CO_2	23,227	0.030	0.798
11	1.A.2.	Manufacturing and Construction: Gaseous Fuels	CO_2	20,699	0.027	0.825
12	1.A.1.	Energy Industries: Liquid Fuels	CO_2	17,691	0.023	0.848
13	1.A.4.	Other Sectors: Liquid Fuels	CO_2	15,023	0.020	0.868
14	1.A.2.	Manufacturing and Construction: Liquid Fuels	CO_2	12,839	0.017	0.885
15	5.A.	Solid Waste Disposal	CH_4	11,597	0.015	0.900
16	3.C.	Rice Cultivation	CH_4	7,112	0.009	0.909

Rank	CRT Code and Source/Sink Category		Gas	2022 Emissions (kt CO_2-eq)	Tier 1 Level Assessment (Sum=1)	Cumulative Percentage
17	2.E.	Electronics Industry	Fluorinated gases	6,956	0.009	0.918
18	3.A.	Enteric Fermentation	CH_4	6,742	0.009	0.927
19	1.A.2.	Manufacturing and Construction: Other Fossil Fuels	CO_2	6,489	0.008	0.935
20	5.C.	Waste Incineration and Open Burning	CO_2	4,263	0.006	0.941
21	2.A.2.	Lime Production	CO_2	3,962	0.005	0.946
22	3.B.	Manure Management	CH_4	3,490	0.005	0.950
23	2.G.	Other Product Manufacture and Use	Fluorinated gases	3,153	0.004	0.954
24	1.A.5.	Non-specified: Liquid Fuels	CO_2	3,028	0.004	0.958
25	4.B.2.	Land Converted to Cropland from Other Land	CO_2	2,859	0.004	0.962
26	3.B.	Manure Management	N_2O	2,564	0.003	0.965
27	1.B.1.	Solid Fuels	CH_4	2,417	0.003	0.969
28	2.F.3.	Fire Extinguishers	Fluorinated gases	1,837	0.002	0.971
29	1.A.3.a.	Domestic Aviation	CO_2	1,729	0.002	0.973
30	1.A.3.b.	Road Transportation	N_2O	1,686	0.002	0.975
31	3.D.1.	Direct Emissions	N_2O	1,677	0.002	0.978
32	1.A.3.d.	Domestic Navigation: Liquid Fuels	CO_2	1,378	0.002	0.979
33	3.D.2.	Indirect Emissions	N_2O	1,248	0.002	0.981
34	4.E.1.	Settlement Remaining Settlements	CO_2	-1,216	0.002	0.983
35	2.F.2.	Foam Blowing Agents	Fluorinated gases	1,112	0.001	0.984
36	2.A.4.	Other Uses of Carbonates	CO_2	972	0.001	0.985
37	5.D.	Wastewater Treatment and Discharge	N_2O	968	0.001	0.987
38	5.D.	Wastewater Treatment and Discharge	CH_4	855	0.001	0.988
39	1.B.2.b.	Natural Gas	CH_4	811	0.001	0.989
40	1.A.4.	Other Sectors: Solid Fuels	CO_2	785	0.001	0.990
41	1.A.1.	Energy Industries: Solid Fuels	N_2O	768	0.001	0.991
42	1.A.3.b.	Road Transportation	CH_4	672	0.001	0.992
43	2.D.	Non-Energy Use of Fuels and Solvent Use	CO_2	613	0.001	0.992
44	4.G.	Harvested Wood Products	CO_2	-543	0.001	0.993
45	4.D.1.	Wetlands Remaining Wetlands: Inland Wetlands	CH_4	376	<0.001	0.994

Rank	CRT Code and Source/Sink Category		Gas	2022 Emissions (kt CO_2-eq)	Tier 1 Level Assessment (Sum=1)	Cumulative Percentage
46	1.A.4.	Other Sectors: Biomass	CH_4	365	<0.001	0.994
47	1.A.1.	Energy Industries: Gaseous Fuels	N_2O	327	<0.001	0.995
48	2.A.3.	Glass Production	CO_2	260	<0.001	0.995
49	2.B.8.	Petrochemical and Carbon Black Production	CH_4	253	<0.001	0.995
50	5.C.	Waste Incineration and Open Burning	N_2O	219	<0.001	0.995
51	1.A.2.	Manufacturing and Construction: Solid Fuels	N_2O	217	<0.001	0.996
52	1.A.4.	Other Sectors: Other Fossil Fuels	CO_2	209	<0.001	0.996
53	2.C.4.	Magnesium Production	SF_6	205	<0.001	0.996
54	1.A.3.c.	Railways	CO_2	181	<0.001	0.997
55	1.A.1.	Energy Industries: Other Fossil Fuels	CO_2	180	<0.001	0.997
56	5.B.	Biological Treatment of Solid Waste Biological	N_2O	174	<0.001	0.997
57	4.A.1.	Forest Land Remaining Forest Land	CH_4	140	<0.001	0.997
58	1.B.2.a.	Oil	CH_4	124	<0.001	0.997
59	5.B.	Biological Treatment of Solid Waste Biological	CH_4	111	<0.001	0.997
60	2.G.	Other Product Manufacture and Use	N_2O	104	<0.001	0.998
61	2.B.10.	Other	N_2O	103.5	<0.001	0.998
62	2.B.2.	Nitric Acid Production	N_2O	96	<0.001	0.998
63	2.B.9.	Fluorochemical Production	Fluorinated gases	95	<0.001	0.998
64	3.H.	Urea Application	CO_2	92	<0.001	0.998
65	1.A.2.	Manufacturing and Construction: Solid Fuels	CH_4	85	<0.001	0.998
66	1.A.4.	Other Sectors: Liquid Fuels	N_2O	84	<0.001	0.998
67	1.A.2.	Manufacturing and Construction: Biomass	N_2O	84	<0.001	0.998
68	1.A.4.	Other Sectors: Gaseous Fuels	CH_4	79	<0.001	0.999
69	1.A.2.	Manufacturing and Construction: Liquid Fuels	N_2O	75	<0.001	0.999
70	1.A.1.	Energy Industries: Biomass	N_2O	74	<0.001	0.999
71	4.A.1.	Forest Land Remaining Forest Land	N_2O	73	<0.001	0.999
72	1.A.3.e.	Other Transportation	CO_2	68	<0.001	0.999

Rank	CRT Code and Source/Sink Category		Gas	2022 Emissions (kt CO_2-eq)	Tier 1 Level Assessment (Sum=1)	Cumulative Percentage
73	1.A.2.	Manufacturing and Construction: Biomass	CH_4	66	<0.001	0.999
74	1.A.4.	Other Sectors: Solid Fuels	CH_4	62	<0.001	0.999
75	2.C.7.	Other	CO_2	59	<0.001	0.999
76	1.A.2.	Manufacturing and Construction: Other Fossil Fuels	N_2O	58	<0.001	0.999
77	1.A.1.	Energy Industries: Biomass	CH_4	53	<0.001	0.999
78	1.A.4.	Other Sectors: Liquid Fuels	CH_4	49	<0.001	0.999
79	1.A.4.	Other Sectors: Biomass	N_2O	48	<0.001	0.999
80	1.A.2.	Manufacturing and Construction: Other Fossil Fuels	CH_4	46	<0.001	0.999
81	1.B.2.c.	Venting and Flaring	CH_4	38	<0.001	1.000
82	1.A.1.	Energy Industries: Liquid Fuels	N_2O	27	<0.001	1.000
83	4.D.2.	Land Converted to Wetlands from Other Land	CO_2	24	<0.001	1.000
84	4.D.1.	Wetlands Remaining Wetlands: Coastal Wetlands	CO_2	−24	<0.001	1.000
85	1.A.2.	Manufacturing and Construction: Liquid Fuels	CH_4	23	<0.001	1.000
86	1.A.2.	Manufacturing and Construction: Gaseous Fuels	N_2O	21	<0.001	1.000
87	3.F.	Crop Residue Burning	CH_4	21	<0.001	1.000
88	1.A.3.c.	Railways	N_2O	19	<0.001	1.000
89	2.F.4.	Aerosols	Fluorinated gases	17	<0.001	1.000
90	4.B.2.	Land Converted to Cropland from Other Land	N_2O	17	<0.001	1.000
91	1.A.4.	Other Sectors: Other Fossil Fuels	CH_4	16	<0.001	1.000
92	1.A.1.	Energy Industries: Gaseous Fuels	CH_4	15	<0.001	1.000
93	1.A.3.a.	Domestic Aviation	N_2O	15	<0.001	1.000
94	1.A.4.	Other Sectors: Gaseous Fuels	N_2O	15	<0.001	1.000
95	1.A.1.	Energy Industries: Solid Fuels	CH_4	12	<0.001	1.000
96	1.A.5.	Non-specified: Liquid Fuels	CH_4	11	<0.001	1.000
97	2.F.5.	Solvents	Fluorinated gases	11	<0.001	1.000
98	1.A.3.d.	Domestic Navigation: Liquid Fuels	N_2O	10	<0.001	1.000
99	1.A.2.	Manufacturing and Construction: Gaseous Fuels	CH_4	9.6	<0.001	1.000
100	1.B.1.	Solid Fuels	CO_2	8.9	<0.001	1.000
101	1.A.5.	Non-specified: Liquid Fuels	N_2O	6.5	<0.001	1.000

Rank	CRT Code and Source/Sink Category		Gas	2022 Emissions (kt CO_2-eq)	Tier 1 Level Assessment (Sum=1)	Cumulative Percentage
102	3.F.	Crop Residue Burning	N_2O	5.1	<0.001	1.000
103	1.A.1.	Energy Industries: Liquid Fuels	CH_4	4.6	<0.001	1.000
104	1.A.3.d.	Domestic Navigation: Gaseous Fuels	CO_2	3.6	<0.001	1.000
105	1.A.3.d.	Domestic Navigation: Liquid Fuels	CH_4	3.6	<0.001	1.000
106	1.A.4.	Other Sectors: Solid Fuels	N_2O	3.2	<0.001	1.000
107	3.G.	Lime Application	CO_2	2.5	<0.001	1.000
108	1.A.4.	Other Sectors: Other Fossil Fuels	N_2O	2.4	<0.001	1.000
109	1.A.1.	Energy Industries: Other Fossil Fuels	N_2O	2.1	<0.001	1.000
110	2.C.2.	Ferroalloys Production	CO_2	1.9	<0.001	1.000
111	5.C.	Waste Incineration and Open Burning	CH_4	1.8	<0.001	1.000
112	1.A.1.	Energy Industries: Other Fossil Fuels	CH_4	1.6	<0.001	1.000
113	1.B.2.b.	Natural Gas	CO_2	1.4	<0.001	1.000
114	1.A.3.e.	Other Transportation	N_2O	1.3	<0.001	1.000
115	4.C.2.	Land Converted to Grassland from Other Land	CO_2	1.2	<0.001	1.000
116	2.B.10.	Other	CO_2	1.0	<0.001	1.000
117	1.A.3.a.	Domestic Aviation	CH_4	0.56	<0.001	1.000
118	1.A.3.e.	Other Transportation	CH_4	0.34	<0.001	1.000
119	1.B.2.c.	Venting and Flaring	CO_2	0.29	<0.001	1.000
120	1.A.3.c.	Railways	CH_4	0.29	<0.001	1.000
121	1.A.3.d.	Domestic Navigation: Gaseous Fuels	CH_4	0.17	<0.001	1.000
122	1.B.2.a.	Oil	CO_2	0.08	<0.001	1.000
123	1.A.3.d.	Domestic Navigation: Gaseous Fuels	N_2O	0.05	<0.001	1.000
124	1.B.2.c.	Venting and Flaring	N_2O	0.0005	<0.001	1.000
Total				686.462	1.000	

Note: Fluorinated gases in this table indicate the sum of HFCs, PFCs, SF_6, and NF_3.

Annex

| Table A-2 | Trend Assessment (including LULUCF)

＊ Key categories in grey shaded cells ( )

Rank	CRT Code and Source/Sink Category		GHG	Emissions (kt CO_2-eq)		Tier 1 Trend Assessment	Tier 1 Percentage (Sum = 1)	Cumulative Percentage
				1990	2022			
1	1.A.1.	Energy Industries: Solid Fuels	CO_2	18,059	169,441	0.353	0.158	0.158
2	1.A.4.	Other Sectors: Solid Fuels	CO_2	35,438	785	0.253	0.113	0.271
3	1.A.2.	Manufacturing and Construction: Liquid Fuels	CO_2	33,737	12,839	0.206	0.092	0.364
4	1.A.4.	Other Sectors: Liquid Fuels	CO_2	32,253	15,023	0.189	0.085	0.449
5	4.A.1.	Forest Land Remaining Forest Land	CO_2	−38,226	−39,540	0.170	0.076	0.525
6	1.A.1.	Energy Industries: Gaseous Fuels	CO_2	4,800	68,905	0.162	0.072	0.597
7	1.A.1.	Energy Industries: Liquid Fuels	CO_2	19,026	17,691	0.087	0.039	0.636
8	2.F.1.	Refrigeration and Air Conditioning	Fluorinated gases	–	29,238	0.083	0.037	0.673
9	3.C.	Rice Cultivation	CH_4	14,073	7,112	0.081	0.036	0.710
10	1.A.4.	Other Sectors: Gaseous Fuels	CO_2	1,652	31,698	0.078	0.035	0.745
11	1.B.1.	Solid Fuels	CH_4	10,745	2,417	0.070	0.032	0.776
12	1.A.2.	Manufacturing and Construction: Gaseous Fuels	CO_2	509	20,698	0.055	0.025	0.801
13	5.A.	Solid Waste Disposal	CH_4	12,149	11,597	0.054	0.024	0.825
14	2.B.8.	Petrochemical and Carbon Black Production	CO_2	5,254	31,276	0.051	0.023	0.848
15	2.A.1.	Cement Production	CO_2	15,871	23,227	0.048	0.022	0.870
16	1.A.3.b.	Road Transportation	CO_2	31,003	92,736	0.041	0.018	0.888
17	1.A.4.	Other Sectors: Solid Fuels	CH_4	2,864	61.96	0.020	0.009	0.897
18	2.E.	Electronics Industry	Fluorinated gases	–	6,956	0.020	0.009	0.906
19	1.A.2.	Manufacturing and Construction: Other Fossil Fuels	CO_2	–	6,489	0.018	0.008	0.915
20	2.C.1.	Iron and Steel Production	CO_2	13,041	27,710	0.015	0.007	0.921
21	1.A.2.	Manufacturing and Construction: Solid Fuels	CO_2	37,677	100,287	0.014	0.006	0.928
22	1.A.3.d.	Domestic Navigation: Liquid Fuels	CO_2	2,457	1,378	0.014	0.006	0.934
23	2.A.2.	Lime Production	CO_2	257	3,962	0.009	0.004	0.938
24	5.C.	Waste Incineration and Open Burning	CO_2	530	4,263	0.008	0.004	0.942
25	4.B.2.	Land Converted to Cropland from Other Land	CO_2	−30	2,859	0.008	0.004	0.946

Rank	CRT Code and Source/Sink Category		GHG	Emissions (kt CO_2-eq)		Tier 1 Trend Assessment	Tier 1 Percentage (Sum = 1)	Cumulative Percentage
				1990	2022			
26	3.A.	Enteric Fermentation	CH_4	3,753	6,742	0.008	0.003	0.949
27	2.G.	Other Product Manufacture and Use	Fluorinated gases	168	3,153	0.008	0.003	0.953
28	2.B.10.	Other	CO_2	1,058	1.0	0.008	0.003	0.956
29	3.D.1.	Direct Emissions	N_2O	1,719	1,677	0.008	0.003	0.959
30	3.D.2.	Indirect Emissions	N_2O	1,520	1,248	0.007	0.003	0.963
31	1.A.5.	Non-specified: Liquid Fuels	CO_2	182	3,028	0.007	0.003	0.966
32	2.B.9.	Fluorochemical Production	Fluorinated gases	1,042	95	0.007	0.003	0.969
33	1.A.3.c.	Railways	CO_2	882	181	0.006	0.003	0.972
34	2.F.3.	Fire Extinguishers	Fluorinated gases	-	1,837	0.005	0.002	0.974
35	4.E.1.	Settlements Remaining Settlements	CO_2	-729	-1,216	0.005	0.002	0.976
36	3.B.	Manure Management	CH_4	1,968	3,490	0.004	0.002	0.978
37	2.F.2.	Foam Blowing Agents	Fluorinated gases	-	1,112	0.003	0.001	0.979
38	1.A.3.e.	Other Transportation	CO_2	451	68	0.003	0.001	0.981
39	4.G.	Harvested Wood Products	CO_2	206	-543	0.003	0.001	0.982
40	3.H.	Urea Application	CO_2	432	92	0.003	0.001	0.983
41	5.D.	Wastewater Treatment and Discharge	CH_4	681	855	0.002	0.001	0.985
42	5.D.	Wastewater Treatment and Discharge	N_2O	49	968	0.002	0.001	0.986
43	3.B.	Manure Management	N_2O	1,343	2,564	0.002	0.001	0.987
44	1.B.2.b.	Natural Gas	CH_4	23	811	0.002	0.001	0.988
45	1.A.1.	Energy Industries: Solid Fuels	N_2O	75	768	0.002	0.001	0.988
46	1.B.1.	Solid Fuels	CO_2	187	8.9	0.001	0.001	0.989
47	2.A.4.	Other Uses of Carbonates	CO_2	202	972	0.001	0.001	0.990
48	2.B.2.	Nitric Acid Production	N_2O	219	96	0.001	0.001	0.990
49	2.B.10.	Other	N_2O	198	104	0.001	0.001	0.991
50	1.A.4.	Other Sectors: Biomass	CH_4	0.007	365	0.001	<0.001	0.991
51	1.A.4.	Other Sectors: Solid Fuels	N_2O	144	3.2	0.001	<0.001	0.992
52	1.A.3.b.	Road Transportation	N_2O	524	1,686	0.001	<0.001	0.992
53	4.C.2.	Land Converted to Grassland from Other Land	CO_2	-670	1.2	0.001	<0.001	0.993
54	1.A.4.	Other Sectors: Liquid Fuels	N_2O	171	84	0.001	<0.001	0.993
55	4.B.2.	Land Converted to Cropland from Other Land	N_2O	143	16.5	0.001	<0.001	0.993
56	1.A.3.a.	Domestic Aviation	CO_2	816	1,729	0.001	<0.001	0.994

Rank	CRT Code and Source/Sink Category		GHG	Emissions (kt CO_2-eq)		Tier 1 Trend Assessment	Tier 1 Percentage (Sum = 1)	Cumulative Percentage
				1990	2022			
57	4.D.1.	Wetlands Remaining Wetlands: Inland Wetlands	CH_4	279	376	0.001	<0.001	0.994
58	1.A.1.	Energy Industries: Gaseous Fuels	N_2O	2.3	327	0.001	<0.001	0.995
59	2.D.	Non-Energy Use of Fuels and Solvent Use	CO_2	357	613	0.001	<0.001	0.995
60	1.A.4.	Other Sectors: Liquid Fuels	CH_4	114	49	0.001	<0.001	0.995
61	1.A.3.c.	Railways	N_2O	90	19	0.001	<0.001	0.996
62	1.A.4.	Other Sectors: Other Fossil Fuels	CO_2	-	209	0.001	<0.001	0.996
63	2.C.4.	Magnesium Production	SF_6	0.80	205	0.001	<0.001	0.996
64	4.D.2.	Land Converted to Wetlands from Other Land	CO_2	86	24	0.001	<0.001	0.996
65	1.A.3.b.	Road Transportation	CH_4	191	672	0.001	<0.001	0.997
66	1.A.1.	Energy Industries: Other Fossil Fuels	CO_2	-	180	0.001	<0.001	0.997
67	1.A.2.	Manufacturing and Construction: Liquid Fuels	N_2O	100	75	0.001	<0.001	0.997
68	5.B.	Biological Treatment of Solid Waste	N_2O	-	174	<0.001	<0.001	0.997
69	5.C.	Waste Incineration and Open Burning	N_2O	30	219	<0.001	<0.001	0.997
70	4.A.1.	Forest Land Remaining Forest Land	CH_4	0.02	140	<0.001	<0.001	0.998
71	2.B.8.	Petrochemical and Carbon Black Production	CH_4	50	253	<0.001	<0.001	0.998
72	2.A.3.	Glass Production	CO_2	57	260	<0.001	<0.001	0.998
73	5.B.	Biological Treatment of Solid Waste	CH_4	-	111	<0.001	<0.001	0.998
74	2.G.	Other Product Manufacture and Use	N_2O	-	104	<0.001	<0.001	0.998
75	3.F.	Crop Residue Burning	CH_4	44	21	<0.001	<0.001	0.998
76	1.A.2.	Manufacturing and Construction: Biomass	N_2O	-	84	<0.001	<0.001	0.998
77	1.A.1.	Energy Industries: Biomass	N_2O	-	74	<0.001	<0.001	0.999
78	4.A.1.	Forest Land Remaining Forest Land	N_2O	0.008	73	<0.001	<0.001	0.999
79	1.A.2.	Manufacturing and Construction: Liquid Fuels	CH_4	38	23	<0.001	<0.001	0.999
80	1.A.4.	Other Sectors: Gaseous Fuels	CH_4	4.0	79	<0.001	<0.001	0.999
81	1.A.2.	Manufacturing and Construction: Biomass	CH_4	-	66	<0.001	<0.001	0.999

Rank	CRT Code and Source/Sink Category		GHG	Emissions (kt CO_2-eq)		Tier 1 Trend Assessment	Tier 1 Percentage (Sum = 1)	Cumulative Percentage
				1990	2022			
82	1.A.1.	Energy Industries: Liquid Fuels	N_2O	36	27	<0.001	<0.001	0.999
83	2.C.3.	Aluminium Production	CO_2	23	-	<0.001	<0.001	0.999
84	2.C.7.	Other	CO_2	-	59	<0.001	<0.001	0.999
85	1.A.2.	Manufacturing and Construction: Other Fossil Fuels	N_2O	-	58	<0.001	<0.001	0.999
86	1.A.1.	Energy Industries: Biomass	CH_4	-	53	<0.001	<0.001	0.999
87	1.A.2.	Manufacturing and Construction: Solid Fuels	N_2O	65	217	<0.001	<0.001	0.999
88	1.A.4.	Other Sectors: Biomass	N_2O	0.007	48	<0.001	<0.001	0.999
89	1.A.2.	Manufacturing and Construction: Other Fossil Fuels	CH_4	-	46	<0.001	<0.001	0.999
90	1.A.1.	Energy Industries: Liquid Fuels	CH_4	20	4.6	<0.001	<0.001	1.000
91	4.D.1.	Wetlands Remaining Wetlands: Coastal Wetlands	CO_2	-21	-23.7	<0.001	<0.001	1.000
92	1.A.3.d.	Domestic Navigation: Liquid Fuels	N_2O	17	10	<0.001	<0.001	1.000
93	1.B.2.c.	Venting and Flaring	CH_4	1.9	38	<0.001	<0.001	1.000
94	1.B.2.a.	Oil	CH_4	38	124	<0.001	<0.001	1.000
95	1.A.2.	Manufacturing and Construction: Solid Fuels	CH_4	43	85	<0.001	<0.001	1.000
96	1.A.3.e.	Other Transportation	N_2O	10	1.3	<0.001	<0.001	1.000
97	3.F.	Crop Residue Burning	N_2O	11	5.1	<0.001	<0.001	1.000
98	1.A.2.	Manufacturing and Construction: Gaseous Fuels	N_2O	0.24	21	<0.001	<0.001	1.000
99	2.F.4.	Aerosols	Fluorinated gases	-	17	<0.001	<0.001	1.000
100	1.A.4.	Other Sectors: Other Fossil Fuels	CH_4	-	16	<0.001	<0.001	1.000
101	1.A.4.	Other Sectors: Gaseous Fuels	N_2O	0.78	15	<0.001	<0.001	1.000
102	1.A.3.d.	Domestic Navigation: Liquid Fuels	CH_4	6.3	3.6	<0.001	<0.001	1.000
103	2.F.5.	Solvents	Fluorinated gases	-	11	<0.001	<0.001	1.000
104	1.A.5.	Non-specified: Liquid Fuels	CH_4	0.69	11	<0.001	<0.001	1.000

Rank	CRT Code and Source/Sink Category		GHG	Emissions (kt CO_2-eq)		Tier 1 Trend Assessment	Tier 1 Percentage (Sum = 1)	Cumulative Percentage
				1990	2022			
105	1.A.1.	Energy Industries: Gaseous Fuels	CH_4	2.4	15	<0.001	<0.001	1.000
106	1.A.2.	Manufacturing and Construction: Gaseous Fuels	CH_4	0.25	10	<0.001	<0.001	1.000
107	1.A.3.e.	Other Transportation	CH_4	2.78	0.3	<0.001	<0.001	1.000
108	1.A.5.	Non-specified: Liquid Fuels	N_2O	0.39	6.5	<0.001	<0.001	1.000
109	3.G.	Lime Application	CO_2	2.5	2.5	<0.001	<0.001	1.000
110	1.A.3.d.	Domestic Navigation: Gaseous Fuels	CO_2	-	3.6	<0.001	<0.001	1.000
111	1.A.3.c.	Railways	CH_4	1.38	0.3	<0.001	<0.001	1.000
112	1.A.3.a.	Domestic Aviation	N_2O	7.1	15.1	<0.001	<0.001	1.000
113	1.A.4.	Other Sectors: Other Fossil Fuels	N_2O	-	2.4	<0.001	<0.001	1.000
114	1.A.1.	Energy Industries: Other Fossil Fuels	N_2O	-	2.1	<0.001	<0.001	1.000
115	2.C.2.	Ferroalloys Production	CO_2	-	1.9	<0.001	<0.001	1.000
116	1.A.1.	Energy Industries: Other Fossil Fuels	CH_4	-	1.6	<0.001	<0.001	1.000
117	1.B.2.b.	Natural Gas	CO_2	0.04	1.4	<0.001	<0.001	1.000
118	1.A.1.	Energy Industries: Solid Fuels	CH_4	5.3	12	<0.001	<0.001	1.000
119	5.C.	Waste Incineration and Open Burning	CH_4	0.35	1.8	<0.001	<0.001	1.000
120	1.A.3.a.	Domestic Aviation	CH_4	0.53	0.56	<0.001	<0.001	1.000
121	1.B.2.c.	Venting and Flaring	CO_2	0.01	0.29	<0.001	<0.001	1.000
122	1.A.3.d.	Domestic Navigation: Gaseous Fuels	CH_4	-	0.17	<0.001	<0.001	1.000
123	1.A.3.d.	Domestic Navigation: Gaseous Fuels	N_2O	-	0.05	<0.001	<0.001	1.000
124	1.B.2.a.	Oil	CO_2	0.02	0.08	<0.001	<0.001	1.000
125	1.B.2.c.	Venting and Flaring	N_2O	-	<0.001	<0.001	<0.001	1.000
Total				271,615	686,462	2.2	1.0	

Note: Fluorinated gases in this table indicate the sum of HFCs, PFCs, SF_6, and NF_3.

The level and trend assessments *excluding* LULUCF identified 21 and 24 categories as key categories that cumulatively accounted for up to 95 percent of total emissions in 1990 and 2022 as presented in Table A-3 and Table A-4.

| Table A-3 | 2022 Level Assessment (excluding LULUCF)

＊ Key categories in grey shaded cells ( )

Rank	CRT Code and Source/Sink Category		GHG	2022 Emissions (kt CO_2-eq)	Tier 1 Level Assessment (Sum = 1)	Cumulative Percentage
1	1.A.1.	Energy Industries: Solid Fuels	CO_2	169,441	0.234	0.234
2	1.A.2.	Manufacturing and Construction: Solid Fuels	CO_2	100,287	0.138	0.372
3	1.A.3.b.	Road Transportation	CO_2	92,736	0.128	0.500
4	1.A.1.	Energy Industries: Gaseous Fuels	CO_2	68,905	0.095	0.596
5	1.A.4.	Other Sectors: Gaseous Fuels	CO_2	31,698	0.044	0.639
6	2.B.8.	Petrochemical and Carbon Black Production	CO_2	31,276	0.043	0.683
7	2.F.1.	Refrigeration and Air Conditioning	Fluorinated gases	29,238	0.040	0.723
8	2.C.1.	Iron and Steel Production	CO_2	27,710	0.038	0.761
9	2.A.1.	Cement Production	CO_2	23,227	0.032	0.793
10	1.A.2.	Manufacturing and Construction: Gaseous Fuels	CO_2	20,699	0.029	0.822
11	1.A.1.	Energy Industries: Liquid Fuels	CO_2	17,691	0.024	0.846
12	1.A.4.	Other Sectors: Liquid Fuels	CO_2	15,023	0.021	0.867
13	1.A.2.	Manufacturing and Construction: Liquid Fuels	CO_2	12,839	0.018	0.885
14	5.A.	Solid Waste Disposal	CH_4	11,597	0.016	0.901
15	3.C.	Rice Cultivation	CH_4	7,112	0.010	0.911
16	2.E.	Electronics Industry	Fluorinated gases	6,956	0.010	0.920
17	3.A.	Enteric Fermentation	CH_4	6,742	0.009	0.929
18	1.A.2.	Manufacturing and Construction: Other Fossil Fuels	CO_2	6,489	0.009	0.938
19	5.C.	Waste Incineration and Open Burning	CO_2	4,263	0.006	0.944
20	2.A.2.	Lime Production	CO_2	3,962	0.005	0.950
21	3.B.	Manure Management	CH_4	3,490	0.005	0.955
22	2.G.	Other Product Manufacture and Use	Fluorinated gases	3,153	0.004	0.959
23	1.A.5.	Non-specified: Liquid Fuels	CO_2	3,028	0.004	0.963
24	3.B.	Manure Management	N_2O	2,564	0.004	0.967
25	1.B.1.	Solid Fuels	CH_4	2,417	0.003	0.970
26	2.F.3.	Fire Extinguishers	Fluorinated gases	1,837.2	0.003	0.973
27	1.A.3.a.	Domestic Aviation	CO_2	1,729	0.002	0.975
28	1.A.3.b.	Road Transportation	N_2O	1,686	0.002	0.977

Annex

Rank	CRT Code and Source/Sink Category		GHG	2022 Emissions (kt CO_2-eq)	Tier 1 Level Assessment (Sum = 1)	Cumulative Percentage
29	3.D.1.	Direct Emissions	N_2O	1,677	0.002	0.980
30	1.A.3.d.	Domestic Navigation: Liquid Fuels	CO_2	1,378	0.002	0.981
31	3.D.2.	Indirect Emissions	N_2O	1,248	0.002	0.983
32	2.F.2.	Foam Blowing Agents	Fluorinated gases	1,112	0.002	0.985
33	2.A.4.	Other Uses of Carbonates	CO_2	972	0.001	0.986
34	5.D.	Wastewater Treatment and Discharge	N_2O	968	0.001	0.987
35	5.D.	Wastewater Treatment and Discharge	CH_4	855	0.001	0.989
36	1.B.2.b.	Natural Gas	CH_4	811	0.001	0.990
37	1.A.4.	Other Sectors: Solid Fuels	CO_2	785	0.001	0.991
38	1.A.1.	Energy Industries: Solid Fuels	N_2O	768	0.001	0.992
39	1.A.3.b.	Road Transportation	CH_4	672	0.001	0.993
40	2.D.	Non-Energy Use of Fuels and Solvent Use	CO_2	613	0.001	0.994
41	1.A.4.	Other Sectors: Biomass	CH_4	365	0.001	0.994
42	1.A.1.	Energy Industries: Gaseous Fuels	N_2O	327	<0.001	0.995
43	2.A.3.	Glass Production	CO_2	260	<0.001	0.995
44	2.B.8.	Petrochemical and Carbon Black Production	CH_4	253	<0.001	0.995
45	5.C.	Waste Incineration and Open Burning	N_2O	219	<0.001	0.996
46	1.A.2.	Manufacturing and Construction: Solid Fuels	N_2O	217	<0.001	0.996
47	1.A.4.	Other Sectors: Other Fossil Fuels	CO_2	209	<0.001	0.996
48	2.C.4.	Magnesium Production	SF_6	205	<0.001	0.996
49	1.A.3.c.	Railways	CO_2	181	<0.001	0.997
50	1.A.1.	Energy Industries: Other Fossil Fuels	CO_2	180	<0.001	0.997
51	5.B.	Biological Treatment of Solid Waste	N_2O	174	<0.001	0.997
52	1.B.2.a.	Oil	CH_4	124	<0.001	0.997
53	5.B.	Biological Treatment of Solid Waste	CH_4	111	<0.001	0.997
54	2.G.	Other Product Manufacture and Use	N_2O	104	<0.001	0.998
55	2.B.10.	Other	N_2O	104	<0.001	0.998
56	2.B.2.	Nitric Acid Production	N_2O	96	<0.001	0.998
57	2.B.9.	Fluorochemical Production	Fluorinated gases	95	<0.001	0.998

Rank	CRT Code and Source/Sink Category		GHG	2022 Emissions (kt CO_2-eq)	Tier 1 Level Assessment (Sum = 1)	Cumulative Percentage
58	3.H.	Urea Application	CO_2	92	<0.001	0.998
59	1.A.2.	Manufacturing and Construction: Solid Fuels	CH_4	85	<0.001	0.998
60	1.A.4.	Other Sectors: Liquid Fuels	N_2O	84	<0.001	0.998
61	1.A.2.	Manufacturing and Construction: Biomass	N_2O	84	<0.001	0.999
62	1.A.4.	Other Sectors: Gaseous Fuels	CH_4	79	<0.001	0.999
63	1.A.2.	Manufacturing and Construction: Liquid Fuels	N_2O	75	<0.001	0.999
64	1.A.1.	Energy Industries: Biomass	N_2O	74	<0.001	0.999
65	1.A.3.e.	Other Transportation	CO_2	68	<0.001	0.999
66	1.A.2.	Manufacturing and Construction: Biomass	CH_4	66	<0.001	0.999
67	1.A.4.	Other Sectors: Solid Fuels	CH_4	62	<0.001	0.999
68	2.C.7.	Other	CO_2	59	<0.001	0.999
69	1.A.2.	Manufacturing and Construction: Other Fossil Fuels	N_2O	58	<0.001	0.999
70	1.A.1.	Energy Industries: Biomass	CH_4	53	<0.001	0.999
71	1.A.4.	Other Sectors: Liquid Fuels	CH_4	49	<0.001	0.999
72	1.A.4.	Other Sectors: Biomass	N_2O	48	<0.001	0.999
73	1.A.2.	Manufacturing and Construction: Other Fossil Fuels	CH_4	46	<0.001	1.000
74	1.B.2.c.	Venting and Flaring	CH_4	38	<0.001	1.000
75	1.A.1.	Energy Industries: Liquid Fuels	N_2O	27	<0.001	1.000
76	1.A.2.	Manufacturing and Construction: Liquid Fuels	CH_4	23	<0.001	1.000
77	1.A.2.	Manufacturing and Construction: Gaseous Fuels	N_2O	21	<0.001	1.000
78	3.F.	Crop Residue Burning	CH_4	21	<0.001	1.000
79	1.A.3.c.	Railways	N_2O	19	<0.001	1.000
80	2.F.4.	Aerosols	Fluorinated gases	17	<0.001	1.000
81	1.A.4.	Other Sectors: Other Fossil Fuels	CH_4	16	<0.001	1.000
82	1.A.1.	Energy Industries: Gaseous Fuels	CH_4	15	<0.001	1.000
83	1.A.3.a.	Domestic Aviation	N_2O	15	<0.001	1.000
84	1.A.4.	Other Sectors: Gaseous Fuels	N_2O	15	<0.001	1.000
85	1.A.1.	Energy and industries: Solid Fuels	CH_4	12	<0.001	1.000
86	1.A.5.	Non-specified: Liquid Fuels	CH_4	11	<0.001	1.000
87	2.F.5.	Solvents	Fluorinated gases	11	<0.001	1.000

Rank	CRT Code and Source/Sink Category		GHG	2022 Emissions (kt CO_2-eq)	Tier 1 Level Assessment (Sum = 1)	Cumulative Percentage
88	1.A.3.d.	Domestic Navigation: Liquid Fuels	N_2O	10	<0.001	1.000
89	1.A.2.	Manufacturing and Construction: Gaseous Fuels	CH_4	10	<0.001	1.000
90	1.B.1.	Solid Fuels	CO_2	8.9	<0.001	1.000
91	1.A.5.	Non-specified: Liquid Fuels	N_2O	6.5	<0.001	1.000
92	3.F.	Crop Residue Burning	N_2O	5.1	<0.001	1.000
93	1.A.1.	Energy Industries: Liquid Fuels	CH_4	4.6	<0.001	1.000
94	1.A.3.d.	Domestic Navigation: Gaseous Fuels	CO_2	3.6	<0.001	1.000
95	1.A.3.d.	Domestic Navigation: Liquid Fuels	CH_4	3.6	<0.001	1.000
96	1.A.4.	Other Sectors: Solid Fuels	N_2O	3.2	<0.001	1.000
97	3.G.	Lime Application	CO_2	2.5	<0.001	1.000
98	1.A.4.	Other Sectors: Other Fossil Fuels	N_2O	2.4	<0.001	1.000
99	1.A.1.	Energy Industries: Other Fossil Fuels	N_2O	2.1	<0.001	1.000
100	2.C.2.	Ferroalloys Production	CO_2	1.9	<0.001	1.000
101	5.C.	Waste Incineration and Open Burning	CH_4	1.8	<0.001	1.000
102	1.A.1.	Energy Industries: Other Fossil Fuels	CH_4	1.6	<0.001	1.000
103	1.B.2.b.	Natural Gas	CO_2	1.4	<0.001	1.000
104	1.A.3.e.	Other Transportation	N_2O	1.3	<0.001	1.000
105	2.B.10.	Other	CO_2	1.0	<0.001	1.000
106	1.A.3.a.	Domestic Aviation	CH_4	0.6	<0.001	1.000
107	1.A.3.e.	Other Transportation	CH_4	0.34	<0.001	1.000
108	1.B.2.c.	Venting and Flaring	CO_2	0.29	<0.001	1.000
109	1.A.3.c.	Railways	CH_4	0.29	<0.001	1.000
110	1.A.3.d.	Domestic Navigation: Gaseous Fuels	CH_4	0.17	<0.001	1.000
111	1.B.2.a.	Oil	CO_2	0.08	<0.001	1.000
112	1.A.3.d.	Domestic Navigation: Gaseous Fuels	N_2O	0.05	<0.001	1.000
113	1.B.2.c.	Venting and Flaring	N_2O	<0.001	<0.001	1.000
Total				724,294	1.000	

Note: Fluorinated gases in this table indicate the sum of HFCs, PFCs, SF_6, and NF_3.

| Table A-4 | Trend Assessment (excluding LULUCF)

* Key categories in grey shaded cells ( )

Rank	CRT Code and Source/Sink Category		GHG	Emissions (kt CO_2eq)		Tier 1 Trend Assessment	Tier 1 Percentage (Sum = 1)	Cumulative Percentage
				1990	2022			
1	1.A.1.	Energy Industries: Solid Fuels	CO_2	18,059	169,441	0.410	0.183	0.183
2	1.A.4.	Other Sectors: Solid Fuels	CO_2	35,438	785	0.264	0.118	0.301
3	1.A.2.	Manufacturing and Construction: Liquid Fuels	CO_2	33,737	12,839	0.212	0.095	0.395
4	1.A.4.	Other Sectors: Liquid Fuels	CO_2	32,253	15,023	0.194	0.086	0.482
5	1.A.1.	Energy Industries: Gaseous Fuels	CO_2	4,800	68,905	0.186	0.083	0.565
6	2.F.1.	Refrigeration and Air Conditioning	Fluorinated gases	–	29,238	0.094	0.042	0.607
7	1.A.4.	Other Sectors: Gaseous Fuels	CO_2	1,652	31,698	0.090	0.040	0.647
8	1.A.1.	Energy Industries: Liquid Fuels	CO_2	19,026	17,691	0.086	0.038	0.685
9	3.C.	Rice Cultivation	CH_4	14,073	7,112	0.083	0.037	0.722
10	1.B.1.	Solid Fuels	CH_4	10,745	2,417	0.073	0.033	0.754
11	1.A.3.b.	Road Transportation	CO_2	31,003	92,736	0.066	0.029	0.784
12	1.A.2.	Manufacturing and Construction: Gaseous Fuels	CO_2	509	20,699	0.063	0.028	0.812
13	2.B.8.	Petrochemical and Carbon Black Production	CO_2	5,254	31,276	0.061	0.027	0.839
14	5.A.	Solid Waste Disposal	CH_4	12,149	11,597	0.054	0.024	0.863
15	2.A.1.	Cement Production	CO_2	15,871	23,227	0.044	0.020	0.883
16	1.A.2.	Manufacturing and Construction: Solid Fuels	CO_2	37,677	100,287	0.040	0.018	0.901
17	2.E.	Electronics Industry	Fluorinated gases	–	6,956	0.022	0.010	0.911
18	1.A.4.	Other Sectors: Solid Fuels	CH_4	2,864	62	0.021	0.010	0.920
19	1.A.2.	Manufacturing and Construction: Other Fossil Fuels	CO_2	–	6,489	0.021	0.009	0.930
20	1.A.3.d.	Domestic Navigation: Liquid Fuels	CO_2	2,457	1,378	0.014	0.006	0.936
21	2.A.2.	Lime Production	CO_2	257	3,962	0.011	0.005	0.941
22	5.C.	Waste Incineration and Open Burning	CO_2	530	4,263	0.010	0.004	0.945
23	2.G.	Other Product Manufacture and Use	Fluorinated gases	168	3,153	0.009	0.004	0.949
24	2.C.1.	Iron and Steel Production	CO_2	13,041	27,710	0.009	0.004	0.953
25	1.A.5.	Non-specified: Liquid Fuels	CO_2	182	3,028	0.008	0.004	0.957
26	2.B.10.	Other	CO_2	1,058	1.0	0.008	0.004	0.960
27	2.B.9.	Fluorochemical Production	Fluorinated gases	1,042	95	0.008	0.003	0.964

Rank	CRT Code and Source/Sink Category		GHG	Emissions (kt CO_2eq)		Tier 1 Trend Assessment	Tier 1 Percentage (Sum = 1)	Cumulative Percentage
				1990	2022			
28	3.D.1.	Direct Emissions	N_2O	1,719	1,677	0.008	0.003	0.967
29	3.D.2.	Indirect Emissions	N_2O	1,520	1,248	0.007	0.003	0.970
30	3.A.	Enteric Fermentation	CH_4	3,753	6,742	0.006	0.003	0.973
31	1.A.3.c.	Railways	CO_2	882	181	0.006	0.003	0.976
32	2.F.3.	Fire Extinguishers	Fluorinated gases	–	1,837	0.006	0.003	0.979
33	2.F.2.	Foam Blowing Agents	Fluorinated gases	–	1,112	0.004	0.002	0.980
34	3.B.	Manure Management	CH_4	1,968	3,490	0.004	0.002	0.982
35	1.A.3.e.	Other Transportation	CO_2	451	68	0.003	0.001	0.983
36	3.H.	Urea Application	CO_2	432	92	0.003	0.001	0.984
37	5.D.	Wastewater Treatment and Discharge	N_2O	49	968	0.003	0.001	0.986
38	1.B.2.b.	Natural Gas	CH_4	23	811	0.002	0.001	0.987
39	5.D.	Wastewater Treatment and Discharge	CH_4	681	855	0.002	0.001	0.988
40	1.A.1.	Energy Industries: Solid Fuels	N_2O	75	768	0.002	0.001	0.989
41	3.B.	Manure Management	N_2O	1,343	2,564	0.002	0.001	0.989
42	2.A.4.	Other Uses of Carbonates	CO_2	202	972	0.002	0.001	0.990
43	1.A.3.b.	Road Transportation	N_2O	524	1,686	0.001	0.001	0.991
44	1.B.1.	Solid Fuels	CO_2	187	8.9	0.001	0.001	0.991
45	2.B.2.	Nitric Acid Production	N_2O	219	96	0.001	0.001	0.992
46	1.A.4.	Other Sectors: Biomass	CH_4	0.007	365	0.001	0.001	0.993
47	2.B.10.	Other	N_2O	198	104	0.001	0.001	0.993
48	1.A.4.	Other Sectors: Solid Fuels	N_2O	144	3.2	0.001	<0.001	0.994
49	1.A.1.	Energy Industries: Gaseous Fuels	N_2O	2.3	327	0.001	<0.001	0.994
50	1.A.4.	Other Sectors: Liquid Fuels	N_2O	171	84	0.001	<0.001	0.995
51	1.A.3.b.	Road Transportation	CH_4	191	672	0.001	<0.001	0.995
52	2.D.	Non-Energy Use of Fuels and Solvent Use	CO_2	357	613	0.001	<0.001	0.995
53	1.A.4.	Other Sectors: Liquid Fuels	CH_4	114	49	0.001	<0.001	0.995
54	1.A.4.	Other Sectors: Other Fossil Fuels	CO_2	–	209	0.001	<0.001	0.996
55	2.C.4.	Magnesium Production	SF_6	0.8	205	0.001	<0.001	0.996
56	1.A.3.c.	Railways	N_2O	90	19	0.001	<0.001	0.996
57	1.A.1.	Energy Industries: Other Fossil Fuels	CO_2	–	180	0.001	<0.001	0.997
58	1.A.3.a.	Domestic Aviation	CO_2	816	1,729	0.001	<0.001	0.997
59	5.B.	Biological Treatment of Solid Waste	N_2O	–	174	0.001	<0.001	0.997
60	1.A.2.	Manufacturing and Construction: Liquid Fuels	N_2O	100	75	0.001	<0.001	0.997

Rank	CRT Code and Source/Sink Category		GHG	Emissions (kt CO_2eq)		Tier 1 Trend Assessment	Tier 1 Percentage (Sum = 1)	Cumulative Percentage
				1990	2022			
61	5.C.	Waste Incineration and Open Burning	N_2O	30	219	<0.001	<0.001	0.998
62	2.B.8.	Petrochemical and Carbon Black Production	CH_4	50	253	<0.001	<0.001	0.998
63	2.A.3.	Glass Production	CO_2	57	260	<0.001	<0.001	0.998
64	5.B.	Biological Treatment of Solid Waste	CH_4	–	111	<0.001	<0.001	0.998
65	2.G.	Other Product Manufacture and Use	N_2O	–	104	<0.001	<0.001	0.998
66	1.A.2.	Manufacturing and Construction: Biomass	N_2O	–	84	<0.001	<0.001	0.998
67	3.F.	Crop Residue Burning	CH_4	44	21	<0.001	<0.001	0.998
68	1.A.1.	Energy Industries: Biomass	N_2O	–	74	<0.001	<0.001	0.999
69	1.A.4.	Other Sectors: Gaseous Fuels	CH_4	4.0	79	<0.001	<0.001	0.999
70	1.A.2.	Manufacturing and Construction: Biomass	CH_4	–	66	<0.001	<0.001	0.999
71	1.A.2.	Manufacturing and Construction: Liquid Fuels	CH_4	38	23	<0.001	<0.001	0.999
72	1.A.2.	Manufacturing and Construction: Solid Fuels	N_2O	65	217	<0.001	<0.001	0.999
73	2.C.7.	Other	CO_2	–	59	<0.001	<0.001	0.999
74	1.A.2.	Manufacturing and Construction: Other Fossil Fuels	N_2O	–	58	<0.001	<0.001	0.999
75	1.A.1.	Energy Industries: Liquid Fuels	N_2O	36	27	<0.001	<0.001	0.999
76	2.C.3.	Aluminium Production	CO_2	23	–	<0.001	<0.001	0.999
77	1.A.1.	Energy Industries: Biomass	CH_4	–	53	<0.001	<0.001	0.999
78	1.A.4.	Other Sectors: Biomass	N_2O	0.007	48	<0.001	<0.001	0.999
79	1.A.2.	Manufacturing and Construction: Other Fossil Fuels	CH_4	–	46.2	<0.001	<0.001	0.999
80	1.A.1.	Energy Industries: Liquid Fuels	CH_4	20	5	<0.001	<0.001	1.000
81	1.B.2.a.	Oil	CH_4	38	124	<0.001	<0.001	1.000
82	1.B.2.c.	Venting and Flaring	CH_4	2	38	<0.001	<0.001	1.000
83	1.A.3.d.	Domestic Navigation: Liquid Fuels	N_2O	17	10	<0.001	<0.001	1.000
84	1.A.3.e.	Other Transportation	N_2O	10	1.3	<0.001	<0.001	1.000
85	1.A.2.	Manufacturing and Construction: Gaseous Fuels	N_2O	0.2	21	<0.001	<0.001	1.000
86	3.F.	Crop Residue Burning	N_2O	11	5.1	<0.001	<0.001	1.000
87	2.F.4.	Aerosols	Fluorinated gases	–	17	<0.001	<0.001	1.000

Rank	CRT Code and Source/Sink Category		GHG	Emissions (kt CO_2eq)		Tier 1 Trend Assessment	Tier 1 Percentage (Sum = 1)	Cumulative Percentage
				1990	2022			
88	1.A.2.	Manufacturing and Construction: Solid Fuels	CH_4	43	85	<0.001	<0.001	1.000
89	1.A.4.	Other Sectors: Other Fossil Fuels	CH_4	–	16	<0.001	<0.001	1.000
90	1.A.4.	Other Sectors: Gaseous Fuels	N_2O	0.8	15	<0.001	<0.001	1.000
91	2.F.5.	Solvents	Fluorinated gases	–	11	<0.001	<0.001	1.000
92	1.A.3.d.	Domestic Navigation: Liquid Fuels	CH_4	6	4	<0.001	<0.001	1.000
93	1.A.5.	Non-specified: Liquid Fuels	CH_4	0.7	11	<0.001	<0.001	1.000
94	1.A.1.	Energy Industries: Gaseous Fuels	CH_4	2.4	15	<0.001	<0.001	1.000
95	1.A.2.	Manufacturing and Construction: Gaseous Fuels	CH_4	0.3	10	<0.001	<0.001	1.000
96	1.A.3.e.	Other Transportation	CH_4	2.8	0.3	<0.001	<0.001	1.000
97	1.A.5.	Non-specified: Liquid Fuels	N_2O	0.4	6.5	<0.001	<0.001	1.000
98	1.A.3.d.	Domestic Navigation: Gaseous Fuels	CO_2	–	3.6	<0.001	<0.001	1.000
99	3.G.	Lime Application	CO_2	2.5	2.5	<0.001	<0.001	1.000
100	1.A.3.c.	Railways	CH_4	1.4	0.3	<0.001	<0.001	1.000
101	1.A.4.	Other Sectors: Other Fossil Fuels	N_2O	–	2.4	<0.001	<0.001	1.000
102	1.A.1.	Energy Industries: Other Fossil Fuels	N_2O	–	2.1	<0.001	<0.001	1.000
103	2.C.2.	Ferroalloys Production	CO_2	–	1.9	<0.001	<0.001	1.000
104	1.A.1.	Energy Industries: Other Fossil Fuels	CH_4	–	1.6	<0.001	<0.001	1.000
105	1.A.3.a.	Domestic Aviation	N_2O	7.1	15	<0.001	<0.001	1.000
106	1.B.2.b.	Natural Gas	CO_2	0.04	1.4	<0.001	<0.001	1.000
107	5.C.	Waste Incineration and Open Burning	CH_4	0.4	1.8	<0.001	<0.001	1.000
108	1.A.3.a.	Domestic Aviation	CH_4	0.5	0.6	<0.001	<0.001	1.000
109	1.B.2.c.	Venting and Flaring	CO_2	0.009	0.3	<0.001	<0.001	1.000
110	1.A.3.d.	Domestic Navigation: Gaseous Fuels	CH_4	–	0.2	<0.001	<0.001	1.000
111	1.A.3.d.	Domestic Navigation: Gaseous Fuels	N_2O	–	0.1	<0.001	<0.001	1.000
112	1.A.1.	Energy Industries: Solid Fuels	CH_4	5.3	12	<0.001	<0.001	1.000
113	1.B.2.a.	Oil	CO_2	0.02	0.1	<0.001	<0.001	1.000
114	1.B.2.c.	Venting and Flaring	N_2O	–	0.0005	<0.001	<0.001	1.000
Total				310,578	724,294	2.2	1.0	

Note: Fluorinated gases in this table indicate the sum of HFCs, PFCs, SF_6, and NF_3.

Annex 2. Uncertainty Assessment

2.1 Methodology

In accordance with Article 29 of the *Modalities, procedures and guidelines for the transparency framework for action and support referred to in Article 13 of the Paris Agreement* (hereinafter referred to as the *MPGs*)[1], the uncertainty assessment was conducted to estimate the uncertainty in the overall emissions and removals for the base year, the latest year and in the emissions trend. By determining the quantitative uncertainty estimates, this assessment will help reduce uncertainties and improve completeness of future inventories. This document defines uncertainty as the range within which the true value corresponds to a 95 percent confidence interval.

As presented in the *2006 IPCC Guidelines*, the uncertainties in activity data, emission factor or emissions are combined to provide uncertainty estimates for the entire inventory. Two approaches are available to provide an estimate of the uncertainty in emissions and removals: Approach 1 of propagation of error, and Approach 2 using Monte Carlo simulation. With Approach 1, uncertainty in emissions or removals is propagated from uncertainties in the activity data, emission factor and other estimation parameters through the error propagation equation. The Monte Carlo simulation involves random samples of model inputs that are generated according to the probability density function (PDF) for each input. The process of entering one random value for each input into the model is repeated to arrive at multiple estimates of the model output. By analyzing the samples of the PDF for the model output, the mean, standard deviation, 95 percent confidence interval, and other properties of the output PDF can be inferred. For emission sources and sinks that require a more complex calculation procedures for estimation, the Monte Carlo simulation technique typically produces better results according to the *2006 IPCC Guidelines*.[2] To estimate uncertainties in the trend using the Approach 2 Monte Carlo method, the PDFs for emissions factors, activity data and other estimation parameters are determined for both 1990 and 2022. Then the mean, standard deviation, 95 percent confidence interval, and other properties of the output PDF are estimated based on the percentage differences between 1990 and 2022.

1) Modalities, procedures and guidelines for the transparency framework for action and support referred to in Article 13 of the Paris Agreement (Decision 18/CMA.1) (UNFCCC, 2018)

2) *2006 IPCC Guidelines, Vol.1 Ch.3, p.3.37*

For uncertainty estimates of the national inventory in 1990 and 2022, ROK used the Monte Carlo simulation technique was used to estimate emissions and trend uncertainties. Under this method, either a normality or lognormality assumption was made for activity data and emission factors as a normal distribution is suitable when the uncertainty range is small and data are symmetrically distributed around the mean while a lognormal distribution is appropriate for non-negative variables with large uncertainty or a positively skewed distribution.

To estimate uncertainty of five sectors of Energy, Industrial Processes and Product Use (IPPU), Agriculture, LULUCF and Waste per CRT levels from Level 3 to Level 5, the simulation was repeated 10,000 times for activity data and emission factors by gas. Random samples of activity data and emission factors from such processes were multiplied by constant values to obtain the random sample of emission estimates of the source or sink category which was then used to estimate the final uncertainty values of the overall emission or removal estimates.

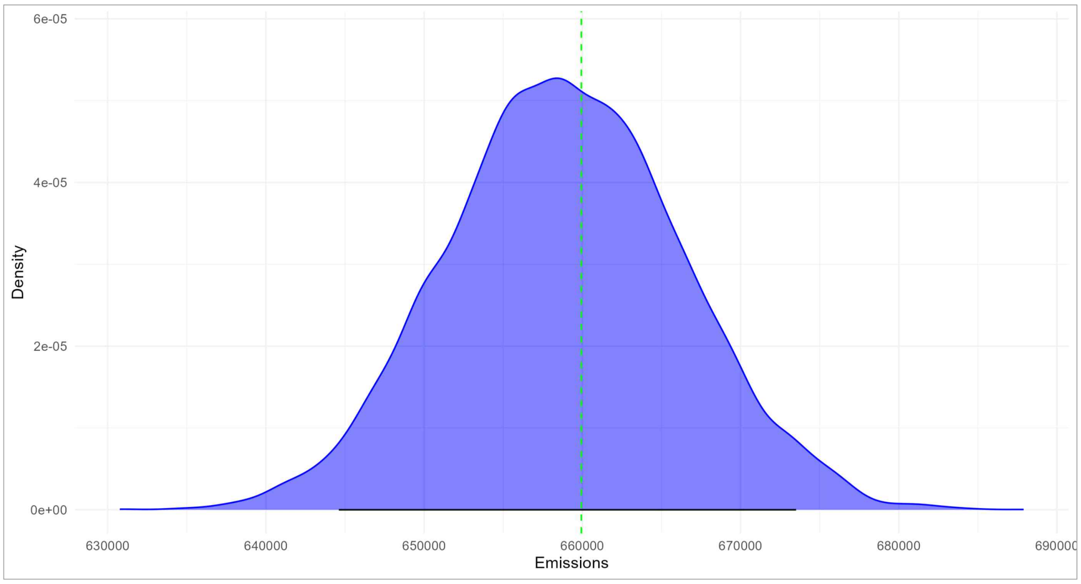
For uncertainty estimates, default values for emission factors and activity data for each sector presented in the *2006 IPCC Guidelines* were primarily used while country-specific uncertainty values, where available, were also used for some sectors. For the source or sink category of which activity data and emission factors cannot be separated into an individual value due to a complex calculation equation, the Monte Carlo simulation was conducted on emission estimates to develop the combined uncertainty.

For (sub)categories in the Energy sector where country-specific emission factors by fuel type were used, the Monte Carlo simulation was run based on the sample mean and standard deviation that were used to develop country-specific emission factors, and by assuming the PDFs for emission factors of the source or sink category. For the Agriculture, LULUCF and Waste sectors, uncertainty values presented by the inventory agencies were used where available. For some (sub)categories in which default emission factors from the *IPCC Guidelines* were used, the default uncertainty values suggested in the *IPCC Guidelines* were used in the Monte Carlo simulation.

Using a 95 percent confidence interval, the overall uncertainty surrounding the total gross emissions in 2022 was estimated to be within the range of -5.0 to 6.4 percent. Emissions estimates of the Energy sector were based on national statistics and thus its uncertainty was assumed to be lower than that of other sectors. In the IPPU sector, a number of (sub)categories were excluded from the uncertainty assessment due to unavailability of uncertainty values. In the Agriculture and Waste sectors where associated emissions were primarily composed of CH_4 and N_2O gases, the uncertainty was relatively high. The uncertainty of total emissions was reduced in 2022 compared to 1990 due to improvements in methods as emissions which were estimated using default emission factors from the IPCC Guidelines in 1990 were calculated using country-specific emission factors for the 2022 inventory, indicating improvements in the emissions estimates over the time series.

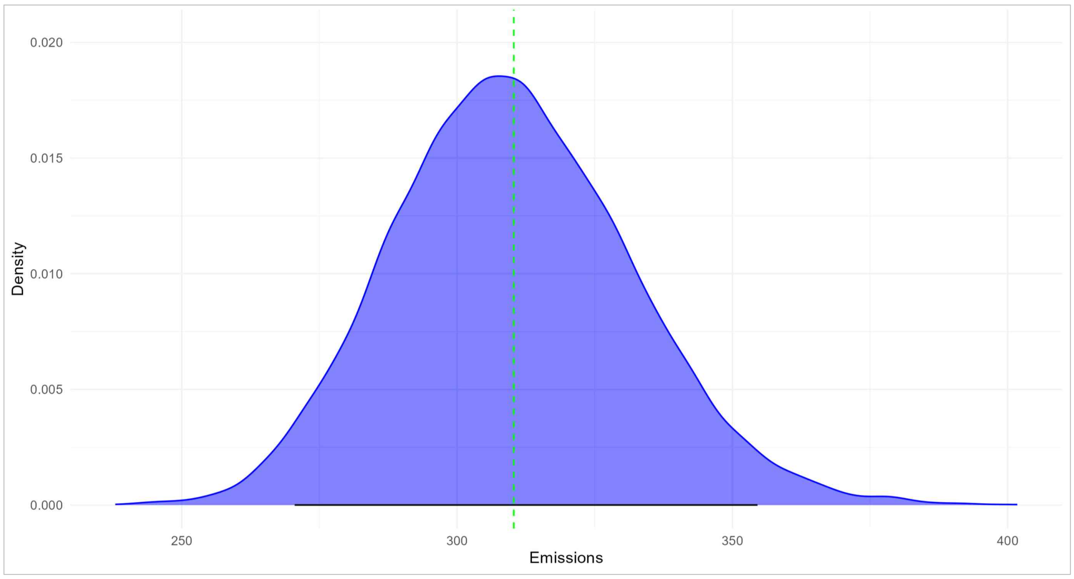
Box A-1 : Probability Density Function by Sector

The probability density function of a normal distribution applied to estimate CO_2 emissions uncertainty in the Energy sector is shown in Figure A-1. The uncertainty interval ranges from -2.4 percent to 2.4 percent.



| Figure A-1 | Uncertainty of CO_2 Emissions (Energy Sector)

The probability density function of a lognormal distribution applied to CH_4 emissions from enteric fermentation of swine in the Agriculture sector is shown in Figure A-2. The uncertainty interval ranges from -12.8 percent to 14.4 percent.



| Figure A-2 | Uncertainty of CH_4 Emissions from Enteric Fermentation of Swine (Agriculture Sector)

Annex 3. Updates in National Greenhouse Gas Inventory

3.1 Updated Methodology and Reporting Guidelines

Greenhouse gas emissions and removals of ROK presented in this document and the first Biennial Transparency Report (BTR1) were estimated in accordance with Article 40 and 50 of the *MPGs* of the Paris Agreement which differ from the reporting guidelines of the Measurement, Reporting and Verification arrangements (hereinafter referred to as the *MRV arrangements*) under the Convention which were applied for ROK's fourth Biennial Update Report (BUR4) submitted to the UNFCCC in 2021.

Updates in reporting guidelines applied for the BUR4 and the BTR1 are as follows.

First, national emissions and removals for the BUR4 were estimated in compliance with the *Revised 1996 IPCC Guidelines* while the national inventory for the BTR1 was prepared based on the *2006 IPCC Guidelines* as required for all Parties to the Paris Agreement.

Second, the global warming potentials (GWPs) in the IPCC Second Assessment Report (AR2) were updated in the IPCC Fifth Assessment Report (AR5).

Third, greenhouse gases subject to reporting increased from six (CO_2, CH_4, N_2O, HFCs, PFCs, SF_6) under the MRV arrangements to seven gases including nitrogen trifluoride (NF_3) under the MPGs.

Lastly, efforts of designated (inventory) agencies in improving the quality of activity data to better correspond to international standards contributed to the enhanced accuracy of data and emission factors, resulting in an improvement in international comparability of national greenhouse gas inventory.

Transitioning to the *2006 IPCC Guidelines* for reporting national emissions and removals, ROK has been committed to strengthening its capacity for inventory preparation and fulfilling obligations to the international community.

| Table A-5 | Comparison between Reporting Guidelines for BUR and BTR

Category	Fourth Biennial Update Report (BUR4)	First Biennial Transparency Report (BTR1)
International Agreement	UNFCCC (MRV Arrangements)	Paris Agreement (MPGs for Transparency Framework)
Inventory Year	1990-2018 (Submitted in 2021)	1990-2022 (Submitted in 2025)
Emissions in Baseline Year (2018)	727.6 Mt CO_2-eq (excluding LULUCF)	783.9 Mt CO_2-eq (excluding LULUCF)
	686.3 Mt CO_2-eq (including LULUCF)	724.3 Mt CO_2-eq (including LULUCF)
IPCC Guidelines	*The Revised 1996 IPCC Guidelines*[1)]	*2006 IPCC Guidelines*[2)]
Greenhouse Gases	CO_2, CH_4, N_2O, HFCs, PFCs, SF_6	CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, NF_3
GWP Reference	*<IPCC Second Assessment Report (AR2)>* • CH_4 : 21 • N_2O : 310 • HFCs : 140-11,700 • PFCs : 6,500-9,200 • SF_6 : 23,900	*<IPCC Fifth Assessment Report (AR5)>* • CH_4 : 28 • N_2O : 265 • HFCs : 116-12,400 • PFCs : 6,630-11,100 • SF_6 : 23,500 • NF_3 : 16,100

Note: 1) For some sources and sinks, methodologies and emission factors from the *2006 IPCC Guidelines, IPCC Good Practice Guidance (2000)*, and *IPCC Good Practice Guidance for LULUCF (2003)* were also used.

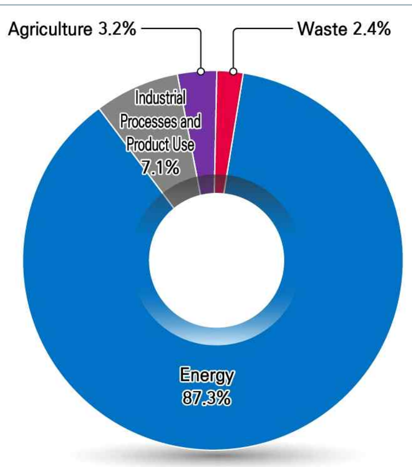
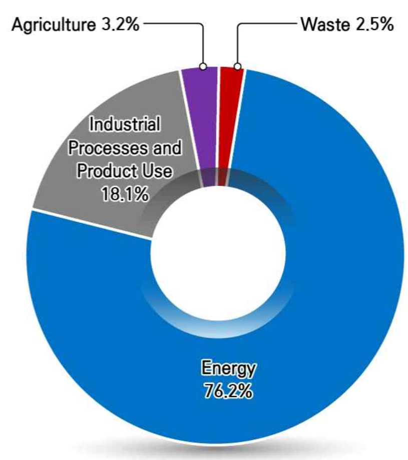
2) For some sources and sinks, methodologies and emission factors from the *2019 Refinement to the 2006 IPCC Guidelines,* the *Revised 1996 IPCC Guidelines, IPCC Good Practice Guidance (2000)*, and *IPCC Good Practice Guidance for LULUCF (2003)* were also used.

3.2 Updated Emissions by Sector

ROK has been preparing and releasing two separate national inventories that were estimated following the *MRV arrangements* under the Convention and *MPGs* under the Paris Agreement respectively. This approach is to ensure transparency in estimation of emissions and removals under two different international reporting requirements, and help the general public to understand the implications of the updated inventory.

In 2022, the Energy sector accounted for 76.2 percent of the total national emissions estimated following the *MRV requirements* whereas it represented 87.3 percent when estimated in accordance with the *MPGs*. The percentage of the IPPU sector increased from 7.1 percent under the *MRV arrangements* to 18.1 percent following the *MPGs*. The Agriculture sector represented 3.2 percent under both reporting systems[3]. The Waste sector showed a slight increase from 2.4 percent to 2.5 percent.

| Table A-6 | Emissions in 2022 under the Convention and Paris Agreement

Reporting Framework	MRV Arrangements under the Convention	MPGs under the Paris Agreement
IPCC Guidelines	*The Revised 1996 IPCC Guidelines*	*2006 IPCC Guidelines*
Greenhouse Gases	6 Gases : CO_2, CH_4, N_2O, HFCs, PFCs, SF_6	7 Gases: CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, NF_3
GWP Reference	*<IPCC Second Assessment Report (AR2)>* • CH_4 : 21 • N_2O : 310 • HFCs : 140–11,700 • PFCs : 6,500–9,200 • SF_6 : 23,900	*<IPCC Fifth Assessment Report (AR5)>* • CH_4 : 28 • N_2O : 265 • HFCs : 116–12,400 • PFCs : 6,630–11,100 • SF_6 : 23,500 • NF_3 : 16,100
2022 Emissions by Sector		

3) An increase in emissions from the Agriculture sector was insignificant which did not influence the percentage of the sector in national emissions.

Emissions from the Energy sector estimated following the *MRV requirements* decreased by 34.1 Mt CO_2-eq from that following the *MPGs* while emissions from the IPPU sector showed an increase of 83.6 Mt CO_2-eq. This was largely due to reallocation of emissions from the subcategory of non-energy products from fuels and solvent use[4] which was previously included under the Energy in the *Revised 1996 IPCC Guidelines* to the IPPU sector under the *2006 IPCC Guidelines*. Another key contributor to such changes in emissions includes the revision of domestic statistics primarily used as activity data for the Energy sector, namely the *Energy Supply and Demand Statistics* (Korea Energy Economics Institute), which involved further disaggregation of data by fuel type. The inclusion of data on hydrofluorocarbons (HFCs) in the IPPU sector in compliance with the Kigali Amendment to the Montreal Protocol was also the primary driver behind emissions change.

Changes in emissions from the Agriculture and Waste sectors were attributable to the updates in GWPs, specifically of CH_4 and N_2O which are primary gases generated in respective sectors, as well as disaggregation of activity data. In the Agriculture sector, livestock population was further disaggregated by animal type and age. In the Waste sector, waste materials were disaggregated which improved the accuracy of emissions estimates from each source.

4) Includes emissions from lubricants and petrochemical processes

| Table A-7 | Comparison of 2022 Emissions under the Convention and Paris Agreement

(Unit: Mt CO_2-eq)

Sector		2022 Emissions			First Biennial Transparency Report (BTR1)
		MRV under Convention (A)	MPGs under Paris Agreement (B)	Difference (A-B)	
Common		▌GWP updated ▌Transition from the *Revised 1996 IPCC Guidelines* to *2006 IPCC Guidelines*: Methodologies and emission factors updated, and new sources added ▌Improved accuracy in activity data and moved to higher tiers using country-specific emission and removal factors			
Energy		587.7	546.2	-41.6	▌*2006 IPCC Guidelines* ▶ Updated oxidation rates[1] ▶ Addition of new sources such as abandoned mines and fugitive emissions from oil and gas extraction ▶ Reallocation of non-energy use of fuels from Energy to IPPU[2] ▌Improved accuracy in activity data ▶ Further disaggregation of fuels in accordance with the updates of *Energy Supply and Demand Statistics* (Korea Energy Economics Institute)[3]
IPPU		51.4	133.6	82.2	▌Inclusion of nitrogen trifluoride (NF_3) as gas subject to reporting ▌*2006 IPCC Guidelines* ▶ Addition of new sources such as caprolactam, glyoxal, and medical use of N_2O ▶ Reallocation of non-energy use of fuels from Energy to IPPU[4] ▌Improved accuracy in activity data ▶ Updated activity data on HFCs used in refrigerants and related applications ▶ Estimated emissions based on data with third-party verification
AFOLU[5]	Agriculture	21.4	23.3	1.9	▌*2006 IPCC Guidelines* ▶ Addition of urea application as a new emission source ▶ Reallocation of CO_2 emissions from lime application from LULUCF to Agriculture ▌Improved accuracy in activity data ▶ Further disaggregation of livestock population by species and age (livestock population remained unchanged)
	LULUCF	-37.77	-37.78	-0.02	▌*2006 IPCC Guidelines* ▶ Reallocation of CO_2 emissions from lime application from LULUCF to Agriculture ▶ Updated stock change factors (SOC) per type of cropland management practice
Waste		16.1	18.2	2.2	▌Improved accuracy in activity data ▶ Further disaggregation of waste materials[6] (total volume of waste remained unchanged)

1) The oxidation rates presented in the *Revised 1996 IPCC Guidelines* (0.98 for coal, 0.99 for oil, and 0.995 for gas) were updated to “1” in the *2006 IPCC Guidelines.*
2) Under the *Revised 1996 IPCC Guidelines,* emissions from non-energy use of fuels were reported under the Energy sector. In the *2006 IPCC Guidelines*, all emissions from non-energy use of fuels were allocated to the IPPU sector and estimated using methodologies and emission factors for each product or process (e.g. emissions per petrochemical product, emissions from blast furnace process in steelmaking).
3) The *Energy Supply and Demand Statistics* (Korea Energy Economics Institute) were updated for the first time in 40 years since its first release in 1983 to reflect the diversity of energy flows. The update included data on production, trade, and consumption for energy commodities that correspond to international standards such as those of IEA and UNFCCC.
   * *The number of categories for energy commodities increased from 29 to 58, and energy flow categories from 41 to 88 (as of 2021).*
4) Under the *Revised 1996 IPCC Guidelines*, there were two separate sectors of “Industrial Processes” and “Solvent and Other Product Use” which, in the *2006 IPCC Guidelines*, have been combined into the “Industrial Processes and Product Use (IPPU)”.
5) The “Agriculture” and “LULUCF” sectors were combined into the “AFOLU” sector under the *2006 IPCC Guidelines* as two sectors share closely-related emission sources. A subcategory of liming which was previously under the LULUCF sector was allocated to the Agriculture sector.
6) Waste materials that were classified into four categories of municipal, industrial, construction and hazardous waste were disaggregated to 111 categories which include 36 subcategories for municipal waste, 31 for industrial waste, 20 for construction waste, and 24 for hazardous waste.

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Annex 5. Common Reporting Tables (CRT)

The Common Reporting Tables of the Republic of Korea are available on the UNFCCC Website at https://unfccc.int/first-biennial-transparency-reports.

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- Ministry of Land, Infrastructure and Transport (MOLIT)
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National Entities for GHG Inventory

Lead Agency	Greenhouse Gas Inventory and Research Center of Korea (GIR)
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Energy (Transport)	Ministry of Land, Infrastructure and Transport (MOLIT)
Energy (Maritime)	Ministry of Oceans and Fisheries (MOF)
Agriculture & LULUCF	Ministry of Agriculture, Food and Rural Affairs (MAFRA) Ministry of Environment (MOE) Ministry of Land, Infrastructure and Transport (MOLIT) Ministry of Oceans and Fisheries (MOF)
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Address: 227 Osongsaengmyeong 8-ro, Osong-eup, Heungdeok-gu, Cheongju-si, Chungcheongbuk-do, Republic of Korea
Postal Code: 28222
Tel: 043-714-7548 Fax: 043-715-7530

Website: http://www.gir.go.kr

The Government of
the Republic of Korea