

INDIA

NATIONAL INVENTORY DOCUMENT

FIRST BIENNIAL TRANSPARENCY REPORT TO THE UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE





NATCOM Cell, Climate Change Divison
Ministry of Environment, Forest and Climate Change
Government of India

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First Biennial Transparency Report to the United Nations Framework Convention on Climate Change

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Lifestyle for Environment

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ES.3. Overview of source and sink category emission estimates and trends

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ABBREVIATIONS

AC	Air Conditioners
AD	Activity Data
AFOLU	Agriculture, Forestry and Other Land Use
AGB	Above Ground Biomass
AITDC	Advanced Industrial Technology Demonstration Centre
AR	Assessment Report
ATF	Aviation Turbine Fuel
BD	Bulk density
BEE	Bureau of Energy Efficiency
BERPD	Bureau of Economic Research and Policy Development
BGB	Below Ground Biomass
BITS	Birla Institute of Technology and Science
Bio-CNG	Bio-Compressed Natural Gas
BOD	Biochemical Oxygen Demand
BTR-1	First Biennial Transparency Report
BUR-4	Fourth Biennial Update Report
$CaCO_3$	Calcium Carbonate
CAMPA	Compensatory Afforestation Fund Management and Planning Authority
CAGR	Compound Annual Growth Rate
CBDR-RC	Common but Differentiated Responsibilities and Respective Capabilities
CBM	Coalbed Methane
CBFS	Carbon Content of Feed Stock
CCF	Carbon Content Factors
CCUS	Carbon Capture, Utilization, and Storage
CDI	Coal Dust Injection
CEA	Central Electricity Authority
CEF	Carbon Emission Factors
CF	Continuous Flooded
CFC	Chlorofluorocarbon
CH_4	Methane
CHNSO	Carbon, Hydrogen, Nitrogen, Sulfur and Oxygen
CHP	Combined Heat and Power
CII	Confederation of Indian Industry
CF	Continuously Flooded
C_2H_2	Acetylene
CL	Cropland
CMA	Conference of the Parties serving as the meeting of the Parties to the Paris Agreement
CMR	Coal Mines Regulations
C:N	Carbon-to-Nitrogen
CO_2	Carbon Dioxide
COD	Chemical Oxygen Demand
CO	Carbon Monoxide
COF	Carbon Oxidation Factors
COP	Conference of the Parties
CPCB	Central Pollution Control Board
CRIDA	Central Research Institute for Dryland Agriculture
CRRI	Central Road Research Institute
CRTs	Common Reporting Tables
CS	Country-Specific
CSIR-CIMFR	Council of Scientific & Industrial Research - Central Institute of Mining and Fuel Research
CSTEP	Center for Study of Science, Technology and Policy
CWPB	Centre-Worked Prebake

ABBREVIATIONS

CY	Calendar year
D	Default
DAD&F	Department of Animal Husbandry and Dairying
DGCIS	Directorate General of Commercial Intelligence and Statistics
DGMS	Directorate General of Mines Safety
DHF	Dilute Hydrofluoric Acid
DOC	Degradable Organic Carbon
DOCf	Fraction of DOC dissimilated
DOM	Dead Organic Matter
DW	Deep Water
EC Act	Energy Conservation Act
EDC	Ethylene Dichloride
EDFA	Ethyl di-fluoroacetate
EF	Emission Factor
EIA	Environment Impact Assessment
EFDB	Emission Factor Database
EPR	Extended Producer Responsibility
ETF	Enhanced Transparency Framework
ETPs	Effluent Treatment Plants
Eurostat	Statistical Office of the European Union
EWC	Etching and wafer cleaning
FAI	Fertilizer Association of India
FCM	Forest Cover Mapping
F-gases	Fluorinated Gases
FL	Forestland
FLL	Flooded Land
FIND-COM	Factor used for Industrial and Commercial co-discharged Protein
FNON-CON	Factor for Non-Consumed Protein
FNRP	Fraction of Nitrogen in Protein
FRA	Global Forest Resources Assessment
FSI	Forest Survey of India
FO	Fuel Oil
FOA	Food and Agriculture Organization
FP	Flood-Prone
GCB	Gas Insulating Agent in Circuit Breakers
GCF	Green Climate Fund
GCV	Gross Calorific Values
GDP	Gross domestic Product
GEF	Global Environment Facility
GFW	Global Forest Watch
Gg	Gigagram
GHG	Green House Gases
GIA	Gas Insulated Switchgear
GIM	Green India Mission
GJ	Giga Joule
GL	Grassland
GNARE	General Network Access Regulations with special provisions for RE
GoI	Government of India
GPG	Good Practice Guidance
GSI	Geological Survey of India
GVA	Gross Value Added
GWP	Global Warming Potential

ABBREVIATIONS

HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbons
HPMP	HCFC Phase-out Management Plan
HSDO	High-Speed Diesel Oil
HSS	Horizontal Stud Søderberg
HTFs	Heat Transfer Fluids
HWP	Harvested Wood Products
HWP IU	HWP in use
IAI	International Aluminium Institute
IARI	Indian Agricultural Research Institute
ICAP	India Cooling Action Plan
ICAR	Indian Council of Agricultural Research
ICAR- NICRA	Indian Council of Agriculture Research - National innovations for climate resilient agriculture
IE	Included Elsewhere
IIP	Indian Institute of Petroleum
IISc	Indian Institute of Science
IIMA	Indian Institute of Management Ahmedabad
IOCL	Indian Oil Corporation Limited
IPCC	Intergovernmental Panel on Climate Change
IPCC GL	IPCC Guidelines
IPMU	Integrated Project Management Unit
IPNGS	Indian Petroleum and Natural Gas Statistics
IPPU	Industrial Processes and Product Use
IRASS	Indian Railways Annual Statistical Statements
ISFR	Indian State of Forest Report
ITSD	India Timber Supply and Demand
ITTO	International Tropical Timber Organization
KCA	Key Category Analysis
Kt	Kilo tonnes
LNG	Liquefied Natural Gas
LDO	Light Diesel Oil
LDAR	Leak Detection and Repair
LULUCF	Land Use, Land-Use Change and Forestry
LT-LEDS	Long-Term Low Emissions Development Strategy
MA	Multiple Aeration
MCF	Methane Correction Factors
MDI	Metered Dose Inhalers
MDFs	Moderately Dense Forests
$MgCO_3$	Magnesium carbonate
MMU	Minimum Mapping Unit
MMS	Manure Management System
MNRE	Ministry of New and Renewable Energy
MoAFW	Ministry of Agriculture and Farmers Welfare
MoC	Ministry of Coal
MoEFCC	Ministry of Environment, Forest and Climate Change
MoP	Ministry of Power
MoPNG	Ministry of Petroleum and Natural Gas
MoR	Ministry of Railways
MoSPI	Ministry of Statistics and Programme Implementation
MPGs	Modalities Procedures and Guidelines
MSW	Municipal Solid Waste
Mt	Million tonne

ABBREVIATIONS

N Sludge	Nitrogen from Sludge
NA	Not Available
NATCOM	National Communications
NAP	National Afforestation Programme
NaCl	Sodium Chloride
NBSS&LUP	National Bureau of Soil Survey and Land Use Planning
NCs	National Communications
NCCBM	National Council for Cement and Building Materials
NDC	Nationally Determined Contribution
NE	Not estimated
NCU	Neem Coated Urea
NCV	Net Calorific Values
NDRI	National Dairy Research Institute
NDVI	Normalized Difference Vegetation Index
NEERI	National Environmental Engineering Research Institute
NF_3	Nitrogen trifluoride
NFI	National Forest Inventory
NGLs	Natural Gas Liquids
NIAS	National Institute of Advanced Studies
NID	National Inventory Document
NH_3	Ammonia
NMVOCs	Non-methane volatile organic compounds
NRSC	National Remote Sensing Centre
NSC	National Steering Committee
N_2O	Nitrous Oxide
NO	Not Occurring
ODS	Ozone Depleting Substances
ODU	Oxidation During Use
OF	Open Forests
OL	Other Land
OTH	Other
PCCs	Pollution Control Committees
PFC	Perfluorocarbons
PM	Particulate Matter
PPAC	Petroleum Planning and Analysis Cell
PTFE	Polytetrafluoroethylene – Teflon
PV	Photovoltaic
QA/QC	Quality Assurance and Quality Control
RCO	Renewable Consumption Obligations
REC	Renewable Energy Certificate
REMCs	Renewable Energy Management Centres
RES	Renewable Energy Sources
RF FP	Rainfed Flood prone;
RF DP	Rainfed Drought Prone
RFA	Recorded Forest Area
RPO	Renewable Purchase Obligations
SA	Single Aeration
S&L	Standard and Labelling
SF	Scaling Factor
SF_6	Sulphur Hexafluoride
SIAM	Society of Indian Automobile Manufacturers
SL	Settlements

ABBREVIATIONS

SLP	Star Labelling Programme
SMAF	Sub-Mission on Agro-forestry
SOC	Soil Organic Carbon
SPCBs	State Pollution Control Boards
SS	Sector-Specific
STP	Sewage Treatment Plants
SWDS	solid waste disposal sites
SWPB	Side-Worked Prebake
T1	Tier 1
T2	Tier 2
T3	Tier 3
TAC	Technical Advisory Committee
TACCC	Transparency, Accuracy, Completeness, Consistency, and Comparability
TER	Technical Expert Reviews
TERI	The Energy and Resources Institute
TFD	Thin-Film Deposition
TFI	Task Force on National Greenhouse Gas Inventories
TiO_2	Titanium dioxide
TNC	Third National Communication
TOF	Trees Outside Forest
TSU	Technical Support Unit
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change
URET	Uniform Renewable Energy Tariff
USDA	Unites States Department of Agriculture
US-EPA	US Environmental Protection Agency
VCM	Vinyl Chloride Monomer
VDF	Very Dense Forests
VKT	Vehicle Kilometres Travelled
VOC	Volatile organic compound
VSS	Vertical Stud Søderberg
WtE	Waste-to-energy
WRI	World Resources Institute

EXECUTIVE SUMMARY

ES.1. Background information on GHG inventories and climate change (e.g. as it pertains to the national context)

This National Inventory Document (NID), an integral part of India's first Biennial Transparency Report (BTR), presents a comprehensive and transparent account of national greenhouse gas (GHG) emissions and removals. It is prepared under the Enhanced Transparency Framework (ETF) of the Paris Agreement, fulfilling India's commitment to robust international climate reporting. Climate change, unequivocally driven by human activities, poses a significant challenge to India's development agenda. The primary GHGs, including Carbon Dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O), and Fluorinated Gases (F-gases), have intensified the natural greenhouse effect, leading to rising global temperatures and disrupting climate patterns.

India's approach is firmly anchored in the principles of Equity and Common but Differentiated Responsibilities and Respective Capabilities (CBDR-RC). With a historical contribution of about 4% to cumulative global emissions and per capita emissions less than one-third of the world's average, India's development model is characterized by its resource efficiency. Concurrently, India is exceptionally vulnerable to climate impacts, including erratic monsoons and rising sea levels. This GHG inventory is a cornerstone of India's ambitious climate action, providing the essential data to track progress towards its Nationally Determined Contribution (NDC) and underscore its leadership in the global effort to combat climate change.

ES.2. Summary of trends related to national emissions and removals

India's GHG emissions trajectory from 2005 to 2022, excluding Land Use, Land-Use Change and Forestry (LULUCF) sector, increased by approximately 69.71% rising from 2,001,288 Gg CO_2eq to 3,396,372 Gg CO_2eq. This trend is primarily driven by the energy sector, which has fuelled the nation's industrialization and modernization. Simultaneously, India has demonstrated remarkable success in enhancing its carbon sinks in the LULUCF sector, which increased by approximately 177.56% over the same period, from -206,020 Gg CO_2eq in 2005 to -571,823 Gg CO_2eq in 2022. Consequently, India's net national emissions (including LULUCF) grew by 57.33% between 2005 and 2022.

These trends must be viewed within India's national context. Despite the absolute increase, India's per capita GHG emissions remain significantly below the global average. Furthermore, the emissions intensity of India's GDP has shown a consistent and substantial decline, indicating a progressive decoupling of economic growth from GHG emissions. This achievement highlights the success of policies focused on energy efficiency, renewable energy deployment, and low-carbon technologies.

ES.3. Overview of source and sink category emission estimates and trends

A sectoral analysis of India's GHG emissions reveals the distinct roles of different economic activities in the national emissions profile.

Energy: The Energy sector is the dominant and fastest-growing source of emissions, responsible for 73% of total emissions in 2022. Emissions from this sector grew by nearly 99.57% between 2005 and 2022, primarily driven by fuel combustion for electricity generation and industrial activities.

Industrial Processes and Product Use (IPPU): The IPPU sector is the second-largest contributor, with emissions increasing by 21.83% from 2005 to 2022, reflecting strong growth in manufacturing and infrastructure development, particularly in cement and metal production.

Agriculture: This sector experienced the least growth in emissions, with a 14.88% increase between 2005 and 2022. Key sources include enteric fermentation, rice cultivation, and agricultural soils.

Land Use, Land-Use Change and Forestry (LULUCF): The LULUCF sector stands out as a significant and growing net sink. CO_2 removals from this sector increased by approximately 177.56% from 2005 to 2022, underscoring the effectiveness of India's large-scale afforestation and conservation programs.

Waste: GHG emissions from the Waste sector, driven by population growth and urbanization, increased by 51.21% over the period.

ES.4. Other information (e.g., indirect GHGs, precursor gases)

This GHG inventory primarily focuses on estimating direct greenhouse gases as mandated by the UNFCCC reporting guidelines: CO_2, CH_4, N_2O, and F-gases (HFCs, PFCs, SF_6, and NF_3). The global warming potential (GWP) values from the IPCC's Fifth Assessment Report (AR5) with a 100-year time horizon are used to aggregate emissions into a common unit of CO_2 equivalent, ensuring comparability.

In addition to direct GHGs, the inventory accounts for indirect emissions for which methodologies are well established. For instance, indirect N_2O emissions from managed agricultural soils and atmospheric deposition are estimated and included within the agriculture sector totals. The inventory also reports CO_2 emissions from biomass combustion as a memo item, which is standard practice to avoid double-counting with the LULUCF sector.

ES.5. Key category analysis (flexibility provided to those developing country Parties that need it in the light of their capacities as per para. 25 of the MPGs)

A Key Category Analysis (KCA) was conducted for 2022 to identify the most significant sources and sinks in India's GHG profile, thereby prioritizing efforts to improve the inventory. In line with the flexibility afforded to developing countries under paragraph 25 of the MPGs, the analysis was performed using IPCC's Approach 1 with a threshold of 85%.

When LULUCF is excluded, the analysis identifies 11 key categories, overwhelmingly dominated by the Energy sector. The top five key categories (without LULUCF) are:

- CO_2 from Electricity Generation
- CO_2 from Road Transportation
- CH_4 from Enteric fermentation
- CO_2 from Other (non-specified industry)
- CO_2 from Iron and steel

Other significant key categories include CO_2 from cement production, CO_2 from Residential, CH_4 from rice cultivation, CO_2 from petroleum refining, Direct N_2O emissions from managed soils and CO_2 from non-metallic minerals. When the LULUCF sector is included in the analysis, CO_2 removals from Forest Land remaining Forest Land and Cropland remaining Cropland are identified as key categories. This powerfully affirms the critical role of India's forests and agricultural lands as a carbon sink, which is essential for understanding the net national emissions balance.

ES.6. Improvements introduced (related to a non-mandatory provision as per para. 7 of the MPGs, with flexibility provided to those developing country Parties that need it, in light of their capacities, as per para. 7(c) of the MPGs)

This first Biennial Transparency Report marks a significant advancement in India's GHG inventory process, incorporating several methodological and procedural improvements aligned with the principles of the ETF. These enhancements demonstrate a strong commitment to continuous improvement and scientific rigor.

Key improvements introduced in this inventory cycle include:

- **Strategic Application of Higher-Tier Methodologies:** Moving beyond default methods, India has strategically applied advanced Tier 2 and Tier 3 methodologies for nationally significant key categories. This includes detailed, country-specific approaches for CO_2 from energy and manufacturing industries and fugitive emissions from coal mining.
- **Development of Country-Specific Emission Factors:** A cornerstone of the improvement has been the development and integration of country-specific (CS) emission factors that accurately reflect India's unique national circumstances. Notable examples include CS factors for CH_4 from rice cultivation and agricultural soils, which are critical for a major agricultural economy.
- **Institutionalization of a Robust QA/QC Framework:** India has implemented a formalized, multi-tiered Quality Assurance and Quality Control (QA/QC) plan. This system, involving routine checks (Tier 1), enhanced sector-specific reviews for key categories (Tier 2), and a comprehensive review by an independent panel of senior national experts (Tier 3), ensures the scientific integrity, transparency, and reliability of the inventory.
- **Enhanced Data Granularity and Traceability:** The inventory process emphasizes improved data collection from national ministries and expert institutions, alongside systematic archiving procedures. This ensures that all data is transparent, traceable, and available to support future inventory cycles and international reviews.

CHAPTER-1

NATIONAL CIRCUMSTANCES, INSTITUTIONAL ARRANGEMENTS AND CROSS-CUTTING INFORMATION

NATIONAL CIRCUMSTANCES, INSTITUTIONAL ARRANGEMENTS AND CROSS-CUTTING INFORMATION

1.1. Background information on GHG inventories and climate change

This National Inventory Document (NID) is India's formal submission under the United Nations Framework Convention on Climate Change (UNFCCC). It presents a comprehensive and transparent account of national greenhouse gas (GHG) emissions and removals. This introductory chapter provides background for the general public and policymakers on the science of climate change, the international framework for addressing it, and India's unique context within this global challenge.

This document has been prepared in accordance with Article 13 of the Paris Agreement, as further operationalized by the Modalities, Procedures and Guidelines (MPGs) adopted in Decision 18/CMA.1 and Decision 5/CMA.3. In addition, India also reports greenhouse gas (GHG) emissions by sources and removals by sinks in the Common Reporting Tables (CRTs). The estimates are consistent with the 2006 IPCC Guidelines.

1.1.1. Greenhouse Gases reported in India's Inventory

Greenhouse gases are atmospheric gases that absorb infrared radiation, trapping heat. The primary GHGs regulated under the UNFCCC framework due to their direct link to human activities and long atmospheric lifetimes are:

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous Oxide (N_2O)
- Fluorinated Gases (F-gases):
  - ➤ Hydrofluorocarbons (HFCs)
  - ➤ Perfluorocarbons (PFCs),
  - ➤ Sulphur Hexafluoride (SF_6)
  - ➤ Nitrogen trifluoride (NF_3)

The greenhouse gases reported by India are:

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous Oxide (N_2O)
- Fluorinated Gases (F-gases):
  - ➤ Hydrofluorocarbons (HFCs)

- Perfluorocarbons (PFCs),
- Sulphur Hexafluoride (SF_6)

Emissions estimates are made using methodologies corresponding to the detailed sectoral Tier 1, Tier 2, and Tier 3 methods in the IPCC Guidelines.

1.1.2. The international climate change regime

The global response to climate change is coordinated through the UNFCCC, adopted at the 1992 Earth Summit. India ratified the Convention in 1993. The UNFCCC established the goal of stabilizing GHG concentrations to prevent "dangerous anthropogenic interference with the climate system," guided by principles of equity and Common but Differentiated Responsibilities and Respective Capabilities (CBDR-RC).

Key developments under the UNFCCC include:

The Kyoto Protocol (1997): This was the first legally binding treaty to set emission reduction targets, but only for developed nations, in line with the CBDR-RC principle.

The Paris Agreement (2015): A landmark agreement that, for the first time, brings all nations into a common cause to undertake ambitious efforts to combat climate change. Its central aim is to keep the global temperature rise this century well below 2°C above pre-industrial levels and to pursue efforts to limit it to 1.5°C.

The Enhanced Transparency Framework (ETF): Established under Article 13 of the Paris Agreement, the ETF creates a common, robust system for all countries to report on their GHG emissions, progress toward their climate targets (known as Nationally Determined Contributions, or NDCs), and the support needed and received. This National Inventory Document is prepared under the ETF. From 2024, all countries are required to submit Biennial Transparency Reports every two years, replacing the previous reporting formats and enhancing accountability for all.

1.1.3. India's national context and contribution

India's approach to climate change is shaped by its unique national circumstances, development aspirations, and deep-rooted commitment to environmental stewardship.

As a large, rapidly growing economy and home to nearly 18% of the global population, India's development is crucial to achieving the global Sustainable Development Goals. Climate change presents a significant challenge to this development agenda. This challenge is not of India's making. India's historical contribution to global GHG emissionsis minimal, at about 4%. Its per capita emissions are less than one-third of the world's average, reflecting a sustainable and less resource-intensive model of development.

At the same time, India is exceptionally vulnerable to the impacts of climate change, including the increasing variability of the monsoon, rising sea levels along its long coastline, and the growing frequency of extreme weather events.

India's response is guided by the UNFCCC's principles of equity and CBDR-RC. India is undertaking ambitious climate action through its Nationally Determined Contribution, which includes bold targets to expand renewable energy, reduce the emissions intensity of its economy, and create additional carbon sinks through afforestation. This GHG inventory is a cornerstone of that effort, providing the data needed to track progress, formulate effective policies, and demonstrate India's unwavering commitment to being a global leader in climate action.

1.2. A description of national circumstances and institutional arrangements

This section outlines the institutional arrangements that India has established to prepare its national greenhouse gas inventory. As a Party to the United Nations Framework Convention on Climate Change and its Paris Agreement, India is committed to the Enhanced Transparency Framework. This framework requires the regular submission of a national inventory of anthropogenic emissions by sources and removals by sinks, in accordance with the provisions and guidelines agreed upon by the Conference of the Parties (COP).

India's submission of its first Biennial Transparency Report, which includes this National Inventory Document, reflects its unwavering commitment to the multilateral process. Preparing a national GHG inventory for a country of India's size, diversity, and complexity involves significant financial costs and the mobilization of extensive technical expertise. The enhanced reporting requirements under the ETF, particularly in the context of India's vast informal sector, introduce new challenges. It is a national priority to ensure that these international reporting obligations are met without diverting essential resources from the implementation of concrete climate actions on the ground.

1.2.1. National Entity

The Ministry of Environment, Forest and Climate Change (MoEFCC) is the nodal ministry in the Government of India responsible for all matters related to climate change, including coordinating and submitting reports to the UNFCCC. Within the MoEFCC, the NATCOM Cell functions as the dedicated Project Management Unit responsible for overseeing the preparation of all national reports, including this BTR and the accompanying National Inventory Document. The National Project Director of the NATCOM Cell serves as the national focal point for coordinating the entire inventory preparation process.

The NATCOM Cell is responsible for ensuring the quality of the national GHG inventory at all stages—planning, preparation, and management. Its key functions include:

- Engaging sector-specific expert institutions for data collection and analysis.
- Commissioning technical studies to develop country-specific methodologies and emission factors.
- Overseeing the collection of activity data from relevant ministries, departments, and statistical agencies.
- Implementing rigorous Quality Assurance and Quality Control (QA/QC) procedures.
- Ensuring robust data verification and archiving processes are integrated into the inventory system.

1.2.2. Inventory preparation process

India has established a robust, centralized, and coordinated framework for preparing its national GHG inventory, designed to ensure transparency, accuracy, consistency, completeness, and comparability. The process is managed through three distinct phases:

Phase 1: Planning. This foundational phase involves setting the strategic direction for the inventory cycle. Key activities include:

- **Resource Mobilization:** Allocation of financial resources and clear assignment of roles and responsibilities to the NATCOM Cell and sectoral expert institutions.
- **QA/QC Plan:** Formulation and approval of a comprehensive Quality Assurance/Quality Control plan, outlining the quality objectives and specific control procedures (Tier 1, 2, and 3) to be followed.
- **Improvement Strategies:** Identification of strategies to enhance the quality of activity data, emission factors, and estimation methods, incorporating findings from India-specific studies.

Phase 2: Preparation This phase involves the technical development and compilation of the GHG inventory.

- **Data Collection and Processing:** A network of 15 national expert institutions, each with specific sectoral expertise, is responsible for collecting activity data, selecting appropriate emission factors, and applying IPCC-approved estimation methodologies. These institutions collaborate closely with a wide range of official data providers, including government ministries, statistical bodies, and industry associations.
- **Estimation and Analysis:** The expert institutions estimate GHG emissionsand removals for all relevant gases and categories. This includes conducting the Key Category Analysis and a quantitative Uncertainty Analysis in accordance with IPCC Guidelines.
- **Compilation and Formatting:** The National Inventory Coordinator, based within the NATCOM Cell, compiles all technical assessments and drafts the National Inventory Document. The quantitative data is compiled into the Common Reporting Tables (CRTs) as mandated by the ETF.

Phase 3: Management This phase focuses on documentation, review, approval, and archiving to ensure institutional memory and continuous improvement.

- **Internal Review:** The draft inventory report and CRTs undergo a rigorous multi-tiered internal review. The inventory prepared by sectoral experts is checked by MoEFCC officials. It is again checked, compiled, and filed in CRTs by an independent inventory expert. Then, the Technical Advisory Committee (TAC), composed of independent national experts, conducts a thorough technical review. Following revisions based on the TAC's feedback, the draft is submitted to the National Steering Committee (NSC). The NSC is a high-level, inter-ministerial body that provides policy-level guidance and grants final approval, ensuring the inventory aligns with national priorities.
- **Submission:** Only after successful completion of this review and approval process, the final BTR is submitted to the UNFCCC Secretariat.

1.2.3. Archiving of information

To ensure transparency, traceability, and institutional continuity, all materials and datasets used to prepare the national GHG inventory are systematically archived in both electronic and physical formats.

The NATCOM Cell and the sectoral expert institutions are responsible for maintaining detailed documentation, which includes:

- Raw and processed activity data, emission factors, and methodologies.
- The final Common Reporting Tables (CRTs).
- Supporting documentation on assumptions, calculations, and data sources.
- Records of QA/QC procedures, recalculations, and planned improvements.
- Official reports and feedback from the internal review processes (TAC and NSC).

These comprehensive archives are preserved securely to facilitate future inventory cycles, enable consistency checks, and support international review processes under the UNFCCC.

1.2.4. Processes for official consideration and approval of inventory

As detailed under the management phase in the previous section, the official consideration and approval process is a structured, multi-level framework designed to ensure the highest standards of quality and policy coherence.

Technical Review by the Technical Advisory Committee (TAC): A panel of independent national experts scrutinizes the draft inventory for technical accuracy, methodological soundness, and compliance with IPCC guidelines.

Final Approval by the National Steering Committee (NSC): A high-level inter-ministerial body reviews the technically vetted draft to ensure its alignment with national policies and priorities. The NSC provides the final endorsement for the inventory.

This multi-tiered process guarantees that the National Inventory Document submitted to the UNFCCC is not only scientifically robust but also officially approved at the highest levels of the Government of India, reflecting a unified national commitment to climate transparency and accountability.

1.3. Brief general description of methodologies (including tiers used) and data sources used

This section provides a general description of the methodologies and data sources applied in the compilation of India's greenhouse gas inventory for its first Biennial Transparency Report. The methodological framework is based on the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, ensuring adherence to international best practices. India remains committed to the principles of transparency, accuracy, completeness,

consistency, and comparability (TACCC). A cornerstone of this commitment is the progressive enhancement of the inventory by integrating higher-tier methodologies and developing country-specific parameters that accurately reflect national circumstances. This approach reduces uncertainties and improves the overall quality and reliability of the emission estimates.

Methodology

The estimation of GHG emissionsand removals for this inventory employs a combination of methodological tiers and data sources tailored to specific source and sink categories. The selection of methods is guided by the significance of the emission source, data availability, and the national capacity to apply advanced approaches.

The methodological tiers used are defined by the IPCC as:

Tier 1: A basic method using default emission factors provided by the IPCC.

Tier 2: A more advanced method using country-specific emission factors or parameters for key activity data.

Tier 3: The most complex methods, often involving detailed modeling and inventory-taking at the plant or site level.

Emission factors are categorized as:

- **D (Default):** Default values provided in the IPCC Guidelines.
- **CS (Country-Specific):** Data developed to reflect India's unique geographical, climatic, and economic conditions.
- **SS (Sector-Specific):** Information sourced directly from industries or specific economic sectors.
- **OTH (Other):** Values taken from sources other than the default ones provided in the IPCC Guidelines

The following is a summary of the methodologies applied across the primary inventory sectors, as detailed in Table 1.1.

1. Energy

The energy sector is the most significant source of GHG emissions. India has employed advanced methods for its most critical sub-categories: Fuel Combustion. For CO_2 emissions from Energy Industries, Manufacturing Industries, and Construction, a combination of Tier 1, Tier 2, and Tier 3 methods has been applied. This represents a highly detailed approach, utilizing a mix of country-specific (CS) and sector-specific (SS) emission factors to achieve greater accuracy. For the Transport sub-category, a Tier 1 method was used. CH_4 and N_2O emissions from these sources were estimated using Tier 1 and Tier 2 methods. Fugitive Emissions: Recognizing the importance of methane emissions from coal mining, a Tier 2 method with country-specific (CS) data was used for estimating CH_4 from Solid Fuels. Emissions from Oil and Natural Gas systems were estimated using a Tier 1 approach.

2. Industrial Processes and Product Use (IPPU)

Methodologies in the IPPU sector are tailored to the specific chemical and physical processes involved: Mineral and Chemical Industry: GHG emissionsof CO_2, CH_4, and N_2O are estimated using a mix of Tier 1 and Tier 2 methods. A notable feature is the use of country-specific (CS) emission factors for CO_2 in the chemical industry, reflecting the unique production processes within the country. Metal Industry: For fluorinated gases (F-gases), a combination of Tier 1 methods with both default (D) and country-specific (CS) emission factors were used for PFCs. A Tier 2 approach was used for SF_6 emissions. Product Uses as Substitutes for ODS: GHG emissionsof HFCs were estimated using a combination of Tier 1 and Tier 2 methods, with default and country-specific data, demonstrating a robust approach to this complex category.

3. Agriculture

India has made significant strides in developing country-specific methodologies for the agriculture sector, which is vital to the national economy and a key source of non-CO_2 emissions: Enteric fermentation: As one of the major key category, CH_4 emissions from cattle, buffalo, sheep, goat, horses, mules & ass, Mithun & yak and swine are calculated using a combination of both Tier 1 and 2 methods. Rice Cultivation: CH_4 emissions from this sector are calculated using a Tier 2 method with country-specific (CS) emission factors. This moves beyond default values

to more accurately represent local cultivation practices, soil types, and water management regimes. Agricultural Soils: N_2O emissions, a significant component of agricultural emissions, are estimated using a Tier 2 method with country-specific (CS) data. Field Burning of Agricultural Residues: GHG emissions from this source are calculated using a combination of Tier 1 and Tier 2 methods.

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

The LULUCF sector is critical as it includes the only GHG sink category. India has applied sophisticated methods to capture its dynamics: Forest Land: CO_2 removals and emissions are estimated using a Tier 2 method with country-specific data, reflecting a robust capacity to monitor and quantify changes in forest carbon stocks. Cropland and Settlements: CO_2 emissions and removals for these land-use categories are also estimated using a Tier 2 approach. Wetlands: This category is marked as Not Estimated (NE).

5. Waste

Solid Waste Disposal: CH_4 emissions from landfills are estimated using a combination of Tier 1 and Tier 2 methods. Wastewater Treatment and Discharge: CH_4 and N_2O emissions from wastewater are calculated using Tier 2 methods with default IPCC emission factors.

The methodological approach adopted for India's first BTR demonstrates a significant and strategic advancement in its GHG inventory compilation. A key approach in the BTR-1 is the targeted application of higher-tier methodologies (Tier 2 and Tier 3) in sectors of high national importance. This focused effort ensures that the largest and most complex emission sources are quantified with the highest possible accuracy. This customized approach ensures that India's unique national circumstances - from its specific industrial technologies to its diverse agricultural practices are adequately represented in the emission estimates.

Table 1.1: Summary report for methods applied to India's GHG inventory for first BTR

Code	GHG source and sink categories	CO_2		CH_4		N_2O		HFC		PFC		SF_6		NF_3	
		Method	EF	Method	EF	Method	EF	Method	EF	Method	EF	Method	EF	Method	EF
1.	Energy														
1A.	Fuel combustion														
1A1.	Energy industries	T1, T2, T3	D, CS, SS	T1, T2	D	T1, T2	D								
1A2.	Manufacturing industries and construction	T1, T2, T3	D, CS, SS	T1, T2	D	T1, T2	D								
1A3	Transport	T1	D, CS	T1	D	T1	D								
1A4	Other sectors	T1	D	T1	D	T1	D								
1A5	Other (please specify)	T1	D,CS	T1	D,CS	T1	D,CS								
1B.	Fugitive emissions from fuels														
1B1.	Solid fuels	NA	NA	T2	CS	NA	NA								
1B2.	Oil and natural gas and other emissions from energy production	T1	D	T1	D	T1	D								
1C	CO_2 transport and storage	NO	NO												
2	Industrial processes and product use														
2A	Mineral industry	T1, T2	D, CS												
2B	Chemical industry	T1, T2	D, CS	T1	D	T1, T2	D	T1	D, CS	NA	NA	NA	NA	NA	NA
2C	Metal industry	T1	D	T1	D	NA	NA	NA	NA	T1	D, OTH	T1	D	NA	NA
2D	Non-energy products from fuels and solvent use	T1	D	NA	NA	NA	NA								
2E	Electronic industry					NA	NA	NA	NA	T1	D	NE	NE	NE	NE
2F	Product uses as substitutes for ODS							T1	D, CS	NO	NO	NO	NO	NO	NO
2G.	Other product manufacture and use					NE	NE			NE	NE	T1	D	NO	NO

Code	GHG source and sink categories	CO_2		CH_4		N_2O		HFC		PFC		SF_6		NF_3	
		Method	EF	Method	EF	Method	EF	Method	EF	Method	EF	Method	EF	Method	EF
2H.	Other (please specify)	IE	IE	IE	IE	NE	NE	NA	NA	NA	NA	NA	NA	NA	NA
3	Agriculture														
3A.	Enteric fermentation			T1, T2	D, CS										
3B.	Manure management			T1, T2	D, CS	T1, T2	D, CS								
3C	Rice cultivation			T2	CS										
3D	Agricultural soils			NA	NA	T2	CS								
3E	Prescribed burning of savannahs			NO	NO	NO	NO								
3F	Field burning of agricultural residues			T1,T2	D	T1,T2	D								
3G	Liming	NE	NE												
3H	Urea application	T2	D												
3I	Other carbon-containing fertilizers	NO	NO												
3J	Other (please specify)	NA	NA	NA	NA	NA	NA								
4.	Land use, land-use change, and forestry														
4A	Forest land	T2	CS	T2	D, CS	T2	D, CS								
4B	Cropland	T2	CS	NA	NA	NO	NA								
4C	Grassland	T2	CS	NO	NA	T2	D, CS								
4D	Wetlands	NE	NE	NE	NE	NE	NE								
4E.	Settlements	T2	CS	NO	NA	NO	NA								
4F	Other land	NA	NA	NA	NA	NA	NA								
4G.	Harvested wood products	T2	D												
4H.	Other (please specify)	NA	NA	NA	NA	NA	NA								

Code	GHG source and sink categories	CO_2		CH_4		N_2O		HFC		PFC		SF_6		NF_3	
		Method	EF	Method	EF	Method	EF	Method	EF	Method	EF	Method	EF	Method	EF
5	Waste														
5A	Solid waste disposal			T1, T2	D										
5B	Biological treatment of solid waste			T1, T2	D	NE	NE								
5C	Incineration and open burning of waste	T2	D	T1, T2	D	NE	NE								
5D	Wastewater treatment and discharge			T1, T2	D, CS	T1	D								
5E	Other (please specify)	NE	NE	NE	NE	NE	NE								
6.	Other (please specify)														
	Memo items														
1D1	International bunkers														
1D1a	Aviation	T1	D	T1	D	T1	D								
1D1b.	Navigation	T1	D	T1	D	T1	D								
1D2	Multilateral operations	C	C	C	C	C	C								
1D3	CO_2 emissions from biomass	NA	NA												
1D4	CO_2 captured	NO	NO												
5F1	Long-term storage of C in waste disposal sites	T1	D												
	Indirect N_2O					NA	NA								
	Indirect CO_2	T1	D												

T1- Tier 1; T2- Tier 2; T3- Tier 3; EF: Emission Factor; SS- Sector Specific; CS- Country Specific; D- IPCC Default, OTH: Other; NO-Not Occurring, NA-Not Applicable, NE-Not Estimated; C-Confidential

1.4. Brief description of key categories

A key category analysis is a fundamental part of a national GHG inventory, allowing for the identification of the emission sources and sinks that have the most significant influence on the country's total GHG emissionsand removals. This analysis is crucial for prioritizing resources to improve the accuracy and completeness of the inventory over time.

In accordance with the 2006 IPCC Guidelines and the Modalities, Procedures, and Guidelines, India has conducted a key category analysis for the inventory year 2022. As per the flexibility provided to developing country Parties that need it in the light of their capacities under paragraph 25 of the MPGs, IPCC Approach 1, Level Assessment, has been used. The analysis was conducted using a threshold of 85%, meaning all categories that cumulatively account for 85% of total national emissions or removals are identified as "key."

The analysis has been performed in two ways: one excluding the Land Use, Land-Use Change and Forestry (LULUCF) sector to focus solely on emission sources, and a second including the LULUCF sector to provide a complete picture of the national GHG balance.

Key Categories Analysis without LULUCF

An analysis of India's 2022 emissions (excluding Land Use, Land-Use Change, and Forestry - LULUCF) identifies 11 key source categories, with the Energy sector emerging as the unequivocal dominant contributor (refer to Table 1.2 and Figure 1.1).

The single most significant source is CO_2 from electricity generation, which alone accounts for 40.73% of total emissions, highlighting the pivotal role of the power sector. The next largest contributor is CO_2 from road transportation at 9.57%. The third-largest source is the agriculture sector, with CH_4 from enteric fermentation accounting for 8.84%.

Significant industrial sources are listed below, reflecting the nation's economic and infrastructural activity. These include CO_2 from other (non-specified industry) at 5.35%, iron and steel production at 4.71%, and cement production at 4.48%.

Other key categories rounding out the top sources are:

- Residential (CO_2): 2.89%
- Rice cultivation (CH_4): 2.88%
- Petroleum refining (CO_2): 2.44%
- Direct N_2O emissions from managed soils: 1.90%
- Non-metallic minerals (CO_2): 1.53%

Collectively, these sources form the core of India's emission profile. The top three categories alone - electricity generation, road transportation, and enteric fermentation—account for nearly 60% of the total emissions, clearly defining the primary focus areas for national climate mitigation strategies.

Key Categories Analysis with LULUCF

When the LULUCF sector is included in the analysis, the overall picture of India's GHG balance becomes more comprehensive. This assessment identifies 12 key categories (refer to Table 1.3).

The most significant change is the introduction of two major carbon sinks. Remarkably, CO_2 removal by "Cropland remaining cropland" is identified as the second-largest key category overall, offsetting 9.90% of emissions. Furthermore, CO_2 removal by "Forest land remaining forest land" is the eighth-largest category, providing another vital carbon sink that offsets 3.80% of emissions.

While the primary emission sources remain largely the same, their relative percentages are adjusted by sinks. CO_2 from electricity generation is still the top emitter, but its share of the net inventory is now 34.74%. The next largest emission sources are CO_2 from road transportation (8.16%) and CH_4 from enteric fermentation (7.54%). The inclusion of the substantial LULUCF sinks is critical for understanding the net national emissions balance. This more robust analysis alters the cumulative contribution of all categories, providing a more complete foundation for climate strategy and inventory improvement.

Table 1.2: Summary of level assessment without LULUCF for 2022 with Approach 1

S. No.	Categories	Gas	CO_2eq (Gg)	%	Cumulative %
1	1.A.1.a.i. Electricity generation	CO_2	1383394	40.73%	40.73%
2	1.A.3.b. Road transportation	CO_2	325039	9.57%	50.30%
3	3.A. Enteric fermentation	CH_4	300170	8.84%	59.14%
4	1.A.2.g.viii. Other (non-specified industry)	CO_2	181728	5.35%	64.49%
5	1.A.2.a. Iron and steel	CO_2	159898	4.71%	69.20%
6	2.A.1. Cement production	CO_2	152265	4.48%	73.68%
7	1.A.4.b. Residential	CO_2	98165	2.89%	76.57%
8	3.C. Rice cultivation	CH_4	97920	2.88%	79.45%
9	1.A.1.b. Petroleum refining	CO_2	82740	2.44%	81.89%
10	3.D.1. Direct N_2O emissions from managed soils	N_2O	64617	1.90%	83.79%
11	1.A.2.f. Non-metallic minerals	CO_2	51898	1.53%	85.32%
		Total	**3396372**		

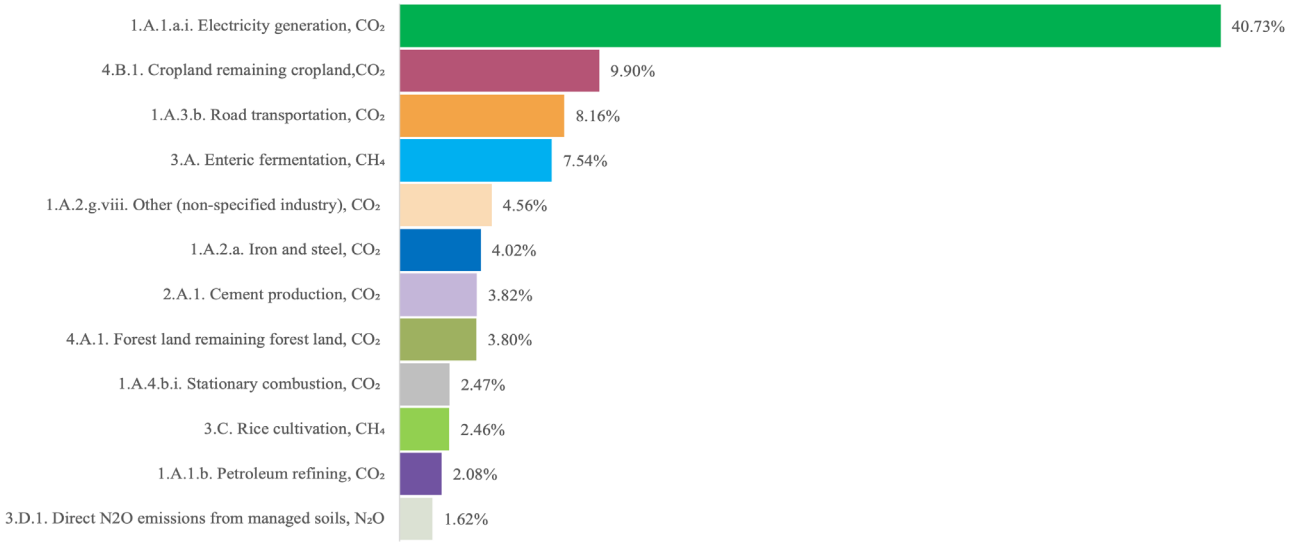


Figure 1.1 Key Categories for 2022 with LULUCF

Table 1.3: Summary of level assessment with LULUCF for 2022 with Approach 1

S. No.	Category	Gas	CO_2eq (Gg)	%	Cumulative %
1	1.A.1.a.i. Electricity generation	CO_2	1383394	34.74%	34.74%
2	4.B.1. Cropland remaining cropland	CO_2 Removal	394333	9.90%	44.64%
3	1.A.3.b. Road transportation	CO_2	325039	8.16%	52.80%
4	3.A. Enteric fermentation	CH_4	300170	7.54%	60.34%
5	1.A.2.g.viii. Other (non-specified industry)	CO_2	181728	4.56%	64.90%
6	1.A.2.a. Iron and steel	CO_2	159898	4.02%	68.92%
7	2.A.1. Cement production	CO_2	152265	3.82%	72.74%
8	4.A.1. Forest land remaining forest land	CO_2 Removal	151342	3.80%	76.54%
9	1.A.4.b.i. Stationary combustion	CO_2	98165	2.47%	79.01%
10	3.C. Rice cultivation	CH_4	97920	2.46%	81.47%
11	1.A.1.b. Petroleum refining	CO_2	82740	2.08%	83.54%
12	3.D.1. Direct N_2O emissions from managed soils	N_2O	64617	1.62%	85.17%
		Total	**3982330**		

In summary, the key category analysis clearly indicates that India's emissions are primarily driven by CO_2 from energy and industrial activities, and CH_4 and N_2O from agriculture. It also powerfully affirms the critical importance of preserving and enhancing India's forest cover as a natural carbon sink. The findings from this analysis will guide the National Inventory Improvement Plan, ensuring that efforts are focused on the most significant categories to enhance the transparency, accuracy, completeness, consistency, and comparability of future inventories.

1.5. Brief general description of QA/QC plan and implementation

This Quality Assurance and Quality Control (QA/QC) Plan outlines the comprehensive framework adopted by India for preparing and verifying its National Greenhouse Gas (GHG) Inventory for 2022. The inventory is submitted as part of India's Biennial Transparency Report (BTR) under the Enhanced Transparency Framework (ETF) of the Paris Agreement. This plan is fully aligned with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, particularly Volume 1, Chapter 6 (Quality Assurance/Quality Control and Verification), as well as the 2019 Refinement to the IPCC Guidelines. The purpose of this QA/QC plan is to ensure that the inventory meets the core principles of transparency, accuracy, consistency, comparability, and completeness (TACCC), and is structured in accordance with India's institutional and data infrastructure.

This QA/QC plan builds upon practices documented in India's previous Biennial Update Reports (BURs), especially BUR4, and incorporates improvements made in response to the UNFCCC International Consultation and Analysis process. It represents a more institutionalized and forward-looking approach tailored to the BTR requirements under Article 13 of the Paris Agreement.

The IPCC (2000) Good Practice Guidance defines Quality Assurance, Quality Control, and Verification as follows:

Quality Control (QC) is a system of routine technical activities to measure and control the quality of the inventory as it is being developed. The QC system is designed to:

(i) Provide routine and consistent checks to ensure data integrity, correctness, and completeness.

(ii) Identify and address errors and omissions.

(iii) Document and archive inventory material and record all QC activities.

QC activities include general methods such as accuracy checks of data acquisition and calculations, and the use of approved, standardized procedures for emission calculations, measurements, uncertainty estimation, archiving, and reporting. Higher-tier QC activities include technical reviews of source categories, activity and emission factor data, and methods.

Quality Assurance (QA) activities include a planned system of review procedures conducted by personnel not directly involved in the inventory compilation/development process. Reviews, preferably by independent third parties, should be conducted upon a finalized inventory following the implementation of QC procedures. Reviews verify that data quality objectives were met, ensure that the inventory represents the best possible estimates of emissions and sinks given the current state of scientific knowledge and data available, and support the effectiveness of the QC program.

Verification refers to the collection of activities and procedures conducted during planning and development, or after the completion of an inventory, that can help establish its reliability for the intended applications of the inventory. For the purposes of this guidance, verification refers specifically to methods external to the inventory that use independent data, including comparisons with inventory estimates made by other bodies or through alternative methods. Verification activities may be constituents of both QA and QC, depending on the methods used and the stage at which independent information is used.

The primary objectives of India's QA/QC system are centered on ensuring and improving transparency, consistency, comparability, completeness, accuracy, and timeliness in national inventories, in alignment with the IPCC 2006 Guidelines and the Enhanced Transparency Framework under the Paris Agreement.

A key objective is to detect and correct any errors or omissions in emission estimates and the underlying activity data. This includes thorough validation of all calculations, data transfers, and assumptions applied during the

estimation process. To support this, the system emphasizes transparency and traceability of all input data sources, emission factors (EFs), and methodological choices. Each emission estimate is supported by clear documentation that enables replication and independent verification.

Maintaining time-series consistency across inventory years is another fundamental goal. The system is designed to ensure that the same methodological approaches are applied across years, unless justified recalculations are required. Equally important is the objective of ensuring the completeness of the inventory. This involves covering all relevant sectors and sub-sectors, as well as the appropriate level of disaggregation of greenhouse gas data based on national circumstances.

Another major objective is to ensure that all recalculations and changes in methods or data are well-documented and justified. This includes maintaining a transparent log of revisions, methodological improvements, and updates to activity data or emission factors.

Institutional capacity building is also an integral objective. The QA/QC plan outlines clear roles, responsibilities, and procedures for all institutions involved in the inventory process, thereby fostering systematic and coordinated engagement across government and research agencies. The plan encourages the inclusion of national-specific scientific studies and data sources to improve the relevance and representativeness of emission estimates.

Finally, the QA/QC system is intended to support a timely and effective response to the findings of the UNFCCC Technical Expert Review process. The structure of the plan enables rapid follow-up on reviewer comments and facilitates improvements in future submissions under the Biennial Transparency Report (BTR) framework.

QA/QC Procedure

India's QA/QC procedures follow a tiered framework as recommended in Table 6.1 of the IPCC 2006 Guidelines (Volume 1), encompassing Tier 1 (general quality control), Tier 2 (enhanced sector-specific quality control), and Tier 3 (independent quality assurance). These procedures are implemented across all inventory sectors according to their significance and contribution to total national emissions.

Tier 1 quality control procedures are applied universally across all sectors. This includes verification of completeness to ensure that all greenhouse gas categories, sub-categories, and gases are accounted for. Activity data is cross-checked using multiple national sources, such as reconciling coal consumption data between the Central Electricity Authority (CEA) and the Ministry of Coal. Units and conversion factors—such as energy units and tons of product—are validated for accuracy. Spreadsheet calculations undergo quality control checks for formula integrity and include embedded QA flags to detect inconsistencies. The correct application of Global Warming Potentials (GWPs), particularly those from the IPCC Fifth Assessment Report (100-year time horizon), is verified. Additionally, the documentation of data sources, assumptions, and responsible contacts is maintained to support transparency and traceability.

Tier 2 quality control is applied to key categories identified through Key Category Analysis (KCA), based on their cumulative emissions contributions and emission trends. For the 2022 inventory, Tier 2 QC was carried out for several high-priority categories. In the Energy sector, this included coal combustion and fugitive emissions. For all the sectors, the key categories identified were subjected to Tier 2 QC

The Tier 3 Quality Assurance (QA) process represents the highest level of independent scrutiny within India's GHG inventory preparation framework. It is designed to provide an impartial, expert-driven validation of the entire inventory before its finalization and submission. This stage is executed by an Independent QA Panel, a specially convened body of senior experts drawn from premier national academic and research institutions, who have no direct involvement in the inventory's compilation.

The panel's mandate is comprehensive, covering a deep-dive assessment of the inventory's scientific integrity, methodological soundness, and compliance with international standards. Its core functions are detailed below.

1. Granular Review of Methodologies and Emission Factors

The panel conducts a rigorous evaluation of the methodologies applied to each source and sink category. This goes beyond a simple check for compliance and involves: Assessing Tier Appropriateness: Verifying that the choice of IPCC Tier (1, 2, or 3) for each category is appropriate, considering its significance in the national emissions profile and the availability of high-quality data. Validating Country-Specific Parameters: Scrutinizing the scientific basis and derivation of all country-specific emission factors and activity data. The panel audits the

justification sheets for these parameters to ensure they are robust, transparent, and accurately reflect national circumstances. Ensuring Completeness: Reviewing the inclusion and exclusion of categories to confirm that all significant sources and sinks are accounted for, in line with the IPCC guidelines.

2. Cross-Sectoral Consistency and Time-Series Analysis

A key function of the Tier 3 panel is to identify and resolve inconsistencies that may not be apparent from a single-sector perspective. This involves: Inter-Sectoral Data Reconciliation: Performing high-level cross-checks of data across sectors. For example, the panel cross-verifies fuel consumption data reported in the Energy sector against fuel use reported under Industrial Processes and Product Use (IPPU) and Agriculture to detect potential double-counting or gaps. Time-Series Coherence: Analyzing the entire time series of emissions for consistency. The panel investigates any unexpected fluctuations or abrupt changes in emission trends, ensuring they are attributable to real-world changes in activity data (e.g., economic shifts, policy implementation) rather than methodological errors or inconsistent data application.

3. Verification of Recalculations and Uncertainty Analysis

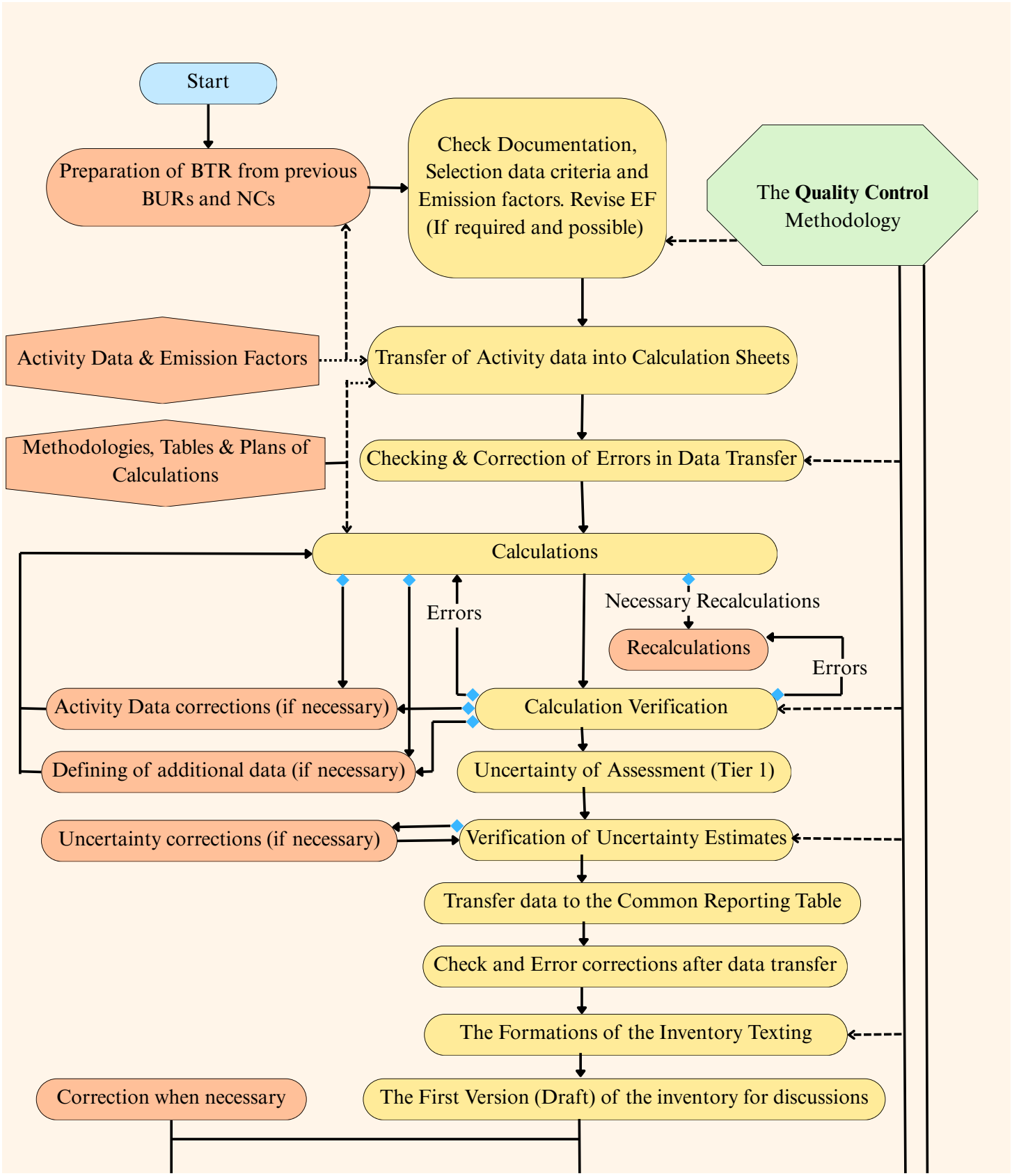
The panel ensures that the inventory is both accurate in its current state and comparable over time. Audit of Recalculations: The panel meticulously reviews any recalculations performed for previously submitted inventories. It verifies that these recalculations are justified (e.g., due to changes in methodology or refined activity data) and have been applied consistently across the relevant time series. Evaluation of Uncertainty Quantification: The panel assesses the robustness of the uncertainty analysis. For key categories where advanced (Tier 2/3) methods are used, this includes evaluating the design and implementation of uncertainty models, such as Monte Carlo simulations, to ensure the statistical validity of the reported uncertainty ranges.

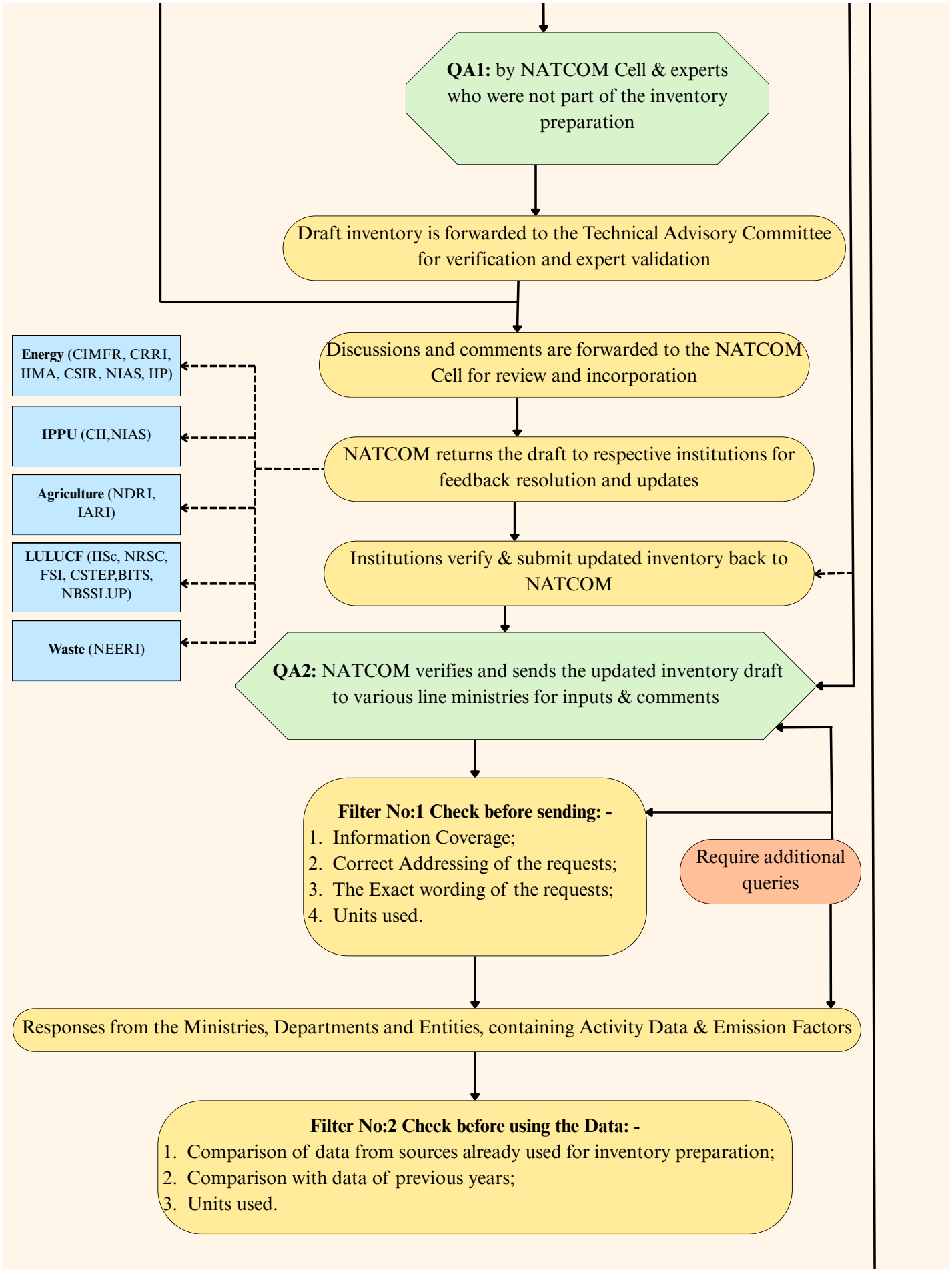
4. Institutional Accountability and Process Integrity

The Tier 3 review serves as a critical mechanism for institutional learning and accountability. Review of Responses to External Feedback: The panel examines India's documented responses to reviews from previous UNFCCC Technical Expert Reviews (TERs), ensuring that past recommendations have been appropriately addressed or that justifications have been provided for not doing so. Verifying Data Traceability: A core task is to audit the data trail, confirming that all activity data and emission factors are clearly sourced and traceable back to their original official or scientific publications. This ensures the entire inventory is replicable and transparent.

Deliverables and Feedback Loop: Upon completing its comprehensive review, the Independent QA Panel prepares a consolidated memo and submits it to the NATCOM Cell. This memo formally documents the panel's findings, highlighting areas of excellence and providing specific, actionable recommendations for any identified issues.

The NATCOM Cell is then responsible for creating a corresponding action-taken report that documents how each panel recommendation was addressed. This transparent response, which includes clear justifications for accepted or rejected recommendations, closes the QA/QC loop and ensures that the Tier 3 review process contributes directly to the continuous improvement of India's national GHG inventory.


Start
Preparation of BTR from previous BURs and NCs
Check Documentation, Selection data criteria and Emission factors. Revise EF (If required and possible)
The Quality Control Methodology
Activity Data & Emission Factors
Transfer of Activity data into Calculation Sheets
Methodologies, Tables & Plans of Calculations
Checking & Correction of Errors in Data Transfer
Calculations
Errors
Necessary Recalculations
Recalculations
Errors
Activity Data corrections (if necessary)
Calculation Verification
Defining of additional data (if necessary)
Uncertainty of Assessment (Tier 1)
Uncertainty corrections (if necessary)
Verification of Uncertainty Estimates
Transfer data to the Common Reporting Table
Check and Error corrections after data transfer
The Formations of the Inventory Texting
Correction when necessary
The First Version (Draft) of the inventory for discussions


QA1: by NATCOM Cell & experts who were not part of the inventory preparation
Draft inventory is forwarded to the Technical Advisory Committee for verification and expert validation
Discussions and comments are forwarded to the NATCOM Cell for review and incorporation
NATCOM returns the draft to respective institutions for feedback resolution and updates
Institutions verify & submit updated inventory back to NATCOM
QA2: NATCOM verifies and sends the updated inventory draft to various line ministries for inputs & comments
Energy (CIMFR, CRRI, IIMA, CSIR, NIAS, IIP)
IPPU (CII,NIAS)
Agriculture (NDRI, IARI)
LULUCF (IISc, NRSC, FSI, CSTEP,BITS, NBSSLUP)
Waste (NEERI)
Filter No:1 Check before sending: -
1. Information Coverage;
2. Correct Addressing of the requests;
3. The Exact wording of the requests;
4. Units used.
Require additional queries
Responses from the Ministries, Departments and Entities, containing Activity Data & Emission Factors
Filter No:2 Check before using the Data: -
1. Comparison of data from sources already used for inventory preparation;
2. Comparison with data of previous years;
3. Units used.

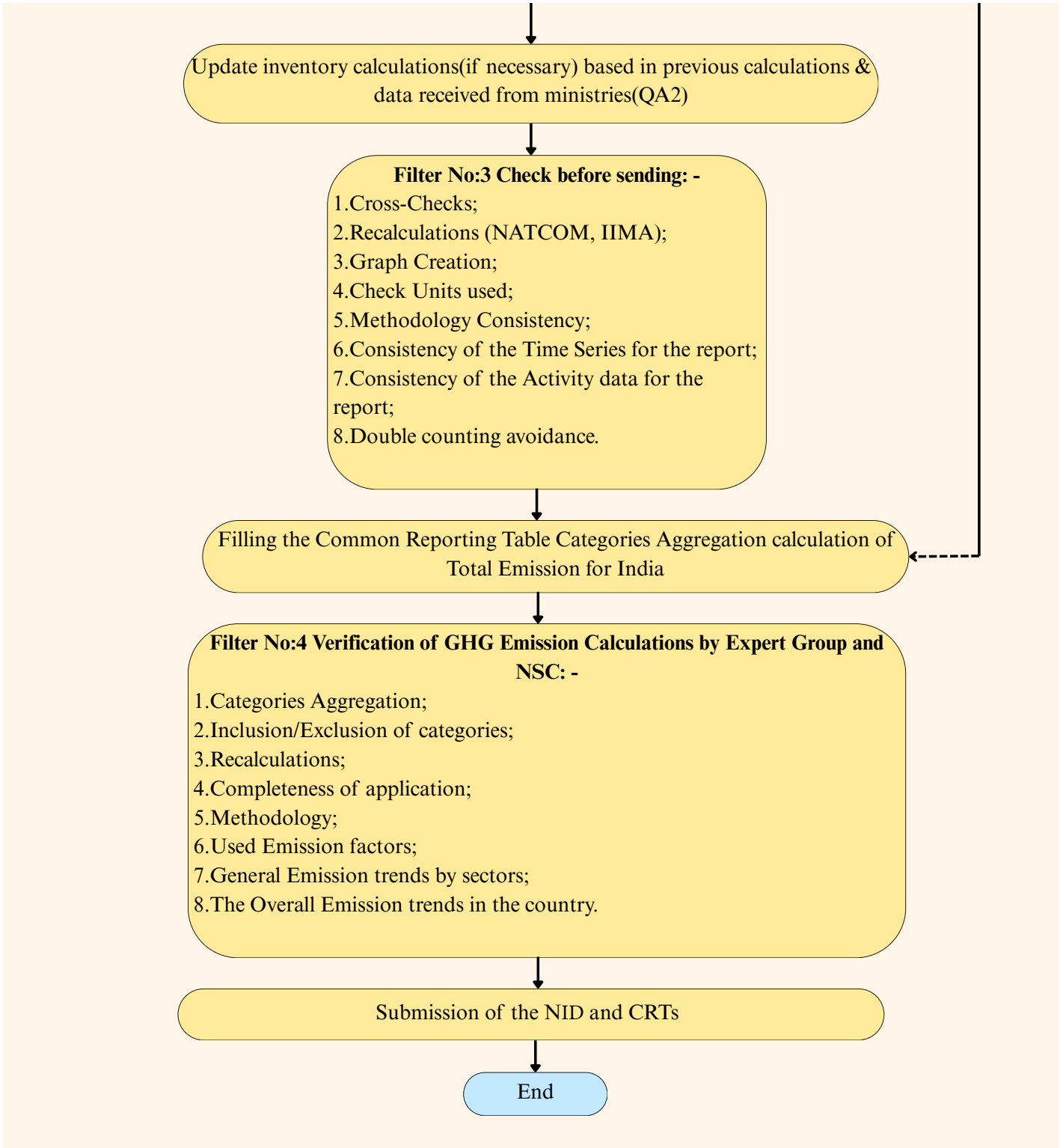


Figure 1.2: QA/QC plan and process for the BTR

1.6. General uncertainty assessment, including data pertaining to the overall uncertainty of inventory totals

A robust uncertainty assessment is central to ensuring the scientific integrity, transparency, and usefulness of India's national greenhouse gas inventory, in accordance with the Modalities, Procedures, and Guidelines of the Enhanced Transparency Framework. The assessment provides a detailed uncertainty assessment for each inventory category, including uncertainty (%) figures for activity data, emission factors, category totals, and their respective contributions to overall inventory uncertainty. Energy Sector: Most subcategories (e.g., fuel combustion, energy industries) report uncertainty for both activity data and emission factors, with uncertainties generally ranging from 2% to 15%, reflecting the use of national energy statistics and well-established methodologies. Agriculture Sector: Categories such as rice cultivation, enteric fermentation, and manure management have higher uncertainties (often 15%–30%), largely due to variability in agricultural practices, data gaps, and reliance on Tier 2 emission factors. Industrial Processes and Waste: Uncertainties here vary widely (typically 5%–20%), depending on whether national emission factors or default IPCC values are used, and the quality of industry reporting. Land Use, Land-Use Change and Forestry (LULUCF): Uncertainty estimates for forest land and other land categories incorporate values between 10% and 35%, reflecting remote sensing limitations, differences in forest management, and ecological diversity. The combined uncertainty for national GHG inventory totals is summarized at the annexure of the report. The uncertainty has been calculated using approach 1.

This uncertainty assessment of the national greenhouse gas (GHG) inventory for the 2022 Biennial Transparency Report reveals a total uncertainty of 8.10% in the inventory and a Trend Uncertainty of 8.41% from 2005 to 2022. The analysis identifies the agriculture sector as the primary driver of overall inventory uncertainty, with methane (CH_4) emissions from rice cultivation and enteric fermentation as the most significant contributors to the total variance. Following agriculture, CO_2 removals from the 'Cropland remaining Cropland' category within LULUCF and CO_2 emissions from cement production within IPPU also represent key sources of uncertainty. Notably, the largest single source of emissions - CO_2 from electricity production - contributes proportionally less to the total uncertainty, indicating a higher confidence in its estimation.

Table 1.4: Overall GHG Inventory Uncertainty in India

Sl. No.	IPCC Category	Category Number, Name	Gas	2005 emissions or removals (Gg CO_2 equivalent)	2022 emissions or removals (Gg CO_2 equivalent)	Activity Data Uncertainty (%)	Emission Factor Uncertainty (%)	Combined Uncertainty (%)	Contribution to Variance by Category in Year T	Type A sensitivity	Type B sensitivity	Uncertainty in Trend in National Emissions introduced by Emission Factor /Estimation parameter uncertainty (%)	Uncertainty in Trend in National Emissions introduced by Activity data Uncertainty (%)	Uncertainty introduced into the Trend in Total National Emissions (%)
1	Energy	1.A.1.a.i. Electricity generation	CO_2	685418	1383394	5.00%	7.51%	9.02%	0.000981	0.078127	61.12%	0.82922%	4.32214%	0.19369%
2	LULUCF	4.B.1. Cropland remaining cropland	CO_2 Removal	198081	394333	9.93%	22.62%	24.70%	0.000598	0.020217	17.42%	0.64673%	2.44678%	0.06405%
3	Energy	1.A.3.b. Road transportation	CO_2	104817	325039	5.00%	6.80%	8.44%	0.000047	0.062098	14.36%	0.59717%	1.01552%	0.01388%
4	Agriculture	3.A. Enteric fermentation	CH_4	276658	300170	15.00%	24.50%	28.73%	0.000469	0.082359	13.26%	2.85360%	2.81347%	0.16059%
5	Energy	1.A.2.g.viii. Other (nonspecified industry)	CO_2	68920	181728	5.00%	7.51%	9.02%	0.000017	0.026705	8.03%	0.28344%	0.56777%	0.00403%
6	Energy	1.A.2.a. Iron and steel	CO_2	90421	159898	5.00%	7.51%	9.02%	0.000013	0.000352	7.06%	0.00373%	0.49957%	0.00250%
7	IPPU	2.A.1. Cement production	CO_2	96201	152265	2.00%	3.00%	3.61%	0.000002	0.007512	6.73%	0.03187%	0.19029%	0.00037%
8	LULUCF	4.A.1. Forest land remaining forest land	CO_2 Removal	22000	151342	7.01%	6.51%	9.57%	0.000013	0.049760	6.69%	0.45812%	0.66292%	0.00649%
9	Energy	1.A.4.b.i. Stationary combustion	CO_2	77256	98165	11.00%	22.00%	24.60%	0.000037	0.016683	4.34%	0.51906%	0.67473%	0.00725%
10	Agriculture	3.C. Rice cultivation	CH_4	88405	97920	10.00%	29.60%	31.24%	0.000059	0.025455	4.33%	1.06558%	0.61186%	0.01510%

Sl. No.	IPCC Category	Category Number, Name	Gas	2005 emissions or removals (Gg CO_2 equivalent)	2022 emissions or removals (Gg CO_2 equivalent)	Activity Data Uncertainty (%)	Emission Factor Uncertainty (%)	Combined Uncertainty (%)	Contribution to Variance by Category in Year T	Type A sensitivity	Type B sensitivity	Uncertainty in Trend in National Emissions introduced by Emission Factor /Estimation parameter uncertainty (%)	Uncertainty in Trend in National Emissions introduced by Activity data Uncertainty (%)	Uncertainty introduced into the Trend in Total National Emissions (%)
11	Energy	1.A.1.b. Petroleum refining	CO_2	25617	82740	5.00%	5.00%	7.07%	0.000002	0.016640	3.66%	0.11766%	0.25851%	0.00081%
12	Agriculture	3.D.1. Direct N_2O emissions from managed soils	N_2O	43060	64617	7.20%	19.00%	20.32%	0.000011	0.004926	2.86%	0.13235%	0.29071%	0.00102%
13	Energy	1.A.2.f. Non-metallic minerals	CO_2	38555	51898	5.00%	9.30%	10.56%	0.000002	0.007043	2.29%	0.09261%	0.16215%	0.00035%
14	Energy	1.A.4.a.i. Stationary combustion	CO_2	25818	37059	11.00%	22.00%	24.60%	0.000005	0.003698	1.64%	0.11505%	0.25472%	0.00078%
15	Waste	5.D.2. Industrial wastewater	CH_4	18933	28137	40.00%	30.00%	50.00%	0.000012	0.002287	1.24%	0.09703%	0.70327%	0.00504%
16	IPPU	2.B.8.b. Ethylene	CO_2	5704	24871	10.00%	10.00%	14.14%	0.000001	0.006554	1.10%	0.09269%	0.15541%	0.00033%
17	LULUCF	4.G.1. Solid wood	CO_2 Removal	13235	22851	8.00%	56.78%	57.34%	0.000011	0.000193	1.01%	0.01551%	0.11423%	0.00013%
18	IPPU	2.A.2. Lime production	CO_2	26768	22609	2.00%	2.00%	2.83%	0.000000	0.010820	1.00%	0.03060%	0.02826%	0.00002%
19	Waste	5.D.1. Domestic wastewater	CH_4	20638	21857	30.00%	20.00%	36.06%	0.000004	0.006387	0.97%	0.18064%	0.40973%	0.00201%
20	Energy	1.B.1.a.ii. Surface mines	CH_4	8901	21830	1.00%	50.00%	50.01%	0.000008	0.002725	0.96%	0.19267%	0.01364%	0.00037%
Total				**2263247**	**3982330**				**0.002401**					**0.006554**
Total Uncertainties									**4.90%**			**Trend Uncertainty**		**8.10%**

1.7. General assessment of completeness

This section provides an assessment of completeness, in line with the non-mandatory provision under paragraph 30 of the MPGs. It serves to transparently report any sources and sinks from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories that have been excluded from the current national inventory, along with the reasons for their exclusion.

As per paragraph 32 of the MPGs, flexibility is provided to developing country Parties that need it, in light of their capacities for reporting source/sink categories. India is committed to preparing the most complete inventory possible and uses this section to document existing gaps and outline a clear path toward their inclusion in future submissions.

Figure 1.1 provides a detailed list of methods and emission factors used for estimating GHG emissions across all the sectors and sub-sectors. A source or sink is designated as "NE" (Not Estimated). Sources that are included but aggregated elsewhere are designated as "IE" (Included Elsewhere), and this is noted in the relevant sectoral chapter.

1.8. Metrics

This section delineates the metrics employed to aggregate greenhouse gas emissions and removals, in alignment with the Modalities, Procedures, and Guidelines for the enhanced transparency framework under the Paris Agreement (Decision 18/CMA.1), particularly provision 37. The application of standardized, globally accepted metrics is essential to ensuring the comparability and clarity of national GHG inventories. This facilitates a uniform evaluation of each gas's contribution to global warming, expressed in a standardized unit: carbon dioxide equivalent (CO_2 eq).

The primary metric used in this National Inventory Document for aggregating GHG emissionsand removals is the Global Warming Potential (GWP). GWP is an index that measures the total radiative forcing (the warming effect on the atmosphere) of a unit mass of a given GHG cumulatively over a specified time horizon, relative to that of carbon dioxide. CO_2 is used as the reference gas and is assigned a GWP of 1. By converting emissions of various GHGs to CO_2 equivalents, policymakers and the public can more easily compare the climate impacts of different gases and sectors.

For this inventory, India has used the 100-year time-horizon GWP values from the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5), as mandated by the UNFCCC for the Biennial Transparency Reports. The 100-year time horizon is the standard for international reporting, as it provides a balanced view of the long-term climate effects of both short-lived and long-lived GHGs.

The calculation of CO_2 equivalent emissions is performed as follows:

CO_2eq (Gas) = Mass of Gas Emitted (in metric tons) × GWP_{100} (Gas)

The following table presents the 100-year GWP values from the IPCC AR5 used in this inventory. The selection of these values ensures consistency, transparency, and comparability with the inventories of other nations.

Table 1.5: Global warming potential used in the inventory, values for a 100-year time-horizon

Name of Gases	Chemical formula	Global warming potential (GWP)
Carbon dioxide	CO_2	1
Methane	CH_4	28
Nitrous oxide	N_2O	265
HFC-23	CHF_3	12,400
HFC-32	CH_2F_2	677
HFC-125	CHF_2CF_3	3,170
HFC-134a	CH_2FCF_3	1,300
HFC-143a	CH_3CF_3	4,800
HFC-152a	CH_3CHF_2	138

Name of Gases	Chemical formula	Global warming potential (GWP)
HFC-227ea	CF_3CHFCF_3	3,350
HFC-236fa	$CF_3CH_2CF_3$	8,060
HFC-245fa	$CH_2FCF_2CHF_2$	858
HFC-365mfc	$CH_3CF_2CH_2CF_3$	804
HFC-43-10mee	$CF_3CHFCHFCF_2CF_3$	1,650
Sulphur hexafluoride	SF_6	23,500
PFC-14	CF_4	6,630
PFC-116	C_2F_6	11,100

Source: IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

To ensure the quality and integrity of this inventory, the source of all GWP values and the time horizon are clearly stated. This ensures that all calculations are replicable and transparent. The same GWP values from AR5 have been applied consistently across all relevant sectors and for all years of the reported time series. This is critical for accurate trend analysis and for comparing the relative contribution of different sources and gases over time. All reported GHGs have been converted to CO_2 eq using the appropriate GWP values. The application of these metrics relies on accurate and complete estimates of the mass of each individual GHG emitted or removed, which are detailed in the respective sectoral chapters of this document.

1.9. Summary of any flexibility applied

In accordance with provisions 4-6 of the MPG for the enhanced transparency framework, this section provides a transparent summary of the flexibility provisions applied in preparing this National Inventory Document. India, as a developing country, has transitioned to this new reporting system and has exercised specific flexibilities in its reporting, acknowledging its capacity constraints and national circumstances. The application of these flexibilities aligns with the principle of common but differentiated responsibilities and respective capabilities (CBDR-RC) and reaffirms India's commitment to progressively enhancing the transparency, accuracy, and completeness of its climate reporting over time.

These flexibilities are clearly identified and justified, consistent with the MPGs. India's commitment to progressively enhance its climate reporting is evident in the self-determined timelines for improvement associated with each availed flexibility. Moving forward, India aims to further enhance its reporting capabilities, gradually reducing its reliance on these flexibilities as its data collection systems and institutional capacities strengthen. This strategic approach ensures adherence to international reporting standards while acknowledging and addressing national development priorities and resource limitations. Continued international support, including financial assistance and capacity-building, will be crucial to facilitating India's ongoing efforts to improve the comprehensiveness and accuracy of its climate reporting.

The following table details each instance in which flexibility has been applied, the specific capacity constraints that justify its use, and the planned actions to address these constraints in the future.

Table 1.6: Summary of the flexibility provisions applied

MPG Para	Area	Description of the application of flexibility	Clarification of the capacity constraint	Time frame for improvement
25	GHG Inventory	India has availed the flexibility to identify key categories using a threshold no lower than 85 % in place of the 95 % threshold defined in the IPCC guidelines	Unavailability of important data/ information at granular level, lack of adequate funding and technical expertise.	10 years
57	GHG Inventory	India has availed the flexibility in reporting time-series calculation of greenhouse gas inventory for four years – 2005, 2020, 2021, and 2022	Unavailability of data for certain time periods and financial constraints to carry out estimations for all these years, following the BTR requirements due to institutional capacities, technical constraints and data governance frameworks.	10 years

CHAPTER-2

TRENDS IN GREENHOUSE GAS EMISSIONS AND REMOVALS

TRENDS IN GREENHOUSE GAS EMISSIONS AND REMOVALS

2.1. Description of emission and removal trends for aggregated GHG emissions and removals

This section describes trends in India's aggregated greenhouse gas emissions and removals from 2005, 2020, 2021, and 2022 (the latest year). The analysis of these trends is fundamental to understanding the nation's progress, the impact of key national circumstances, and the effectiveness of climate policies over time.

Overall Emission and Removal Trends: 2005, 2020-2022

India's GHG emission trajectory from 2005 to 2022 reflects a nation undergoing significant economic development, industrialization, and population growth. This has been coupled with a strong and consistent commitment to enhancing its carbon sinks through dedicated forestry policies. Total GHG emissions, excluding the Land Use, Land-Use Change and Forestry (LULUCF) sector, grew by approximately 69.71% between 2005 and 2022, rising from 20,01,288 $GgCO_2eq$ to 33,96,372 $GgCO_2eq$.

Concurrently, and demonstrating the success of national policies such as the National Afforestation Programme and the Green India Mission, the LULUCF sector has functioned as a vital and growing carbon sink. GHG removals from the sector increased by approximately 177.56 % over the same period, from -2,06,020 $GgCO_2eq$ in 2005 to -5,71,823 $GgCO_2eq$ in 2022. As a result of these parallel trends, India's net national emissions (including LULUCF) increased by 57.33 % over the period, from 17,95,268 $GgCO_2eq$ in 2005 to 28,24,549 $GgCO_2eq$ in 2022.

While the aggregated data shows a clear trend, a deeper analysis reveals crucial context. The trend is dominated by CO_2 emissions from the energy sector, which has fueled India's development. Trends in CH_4 and N_2O, primarily from the agriculture sector, have shown more moderate growth rates over the same period. It is critical to view these trends in the light of India's national circumstances. Despite the absolute increase in emissions, India's GHG emissionsper capita have consistently remained far below the global average. Furthermore, the emissions intensity of India's GDP (emissions per unit of economic output) has shown a significant and steady decline. This demonstrates a progressive decoupling of economic growth from GHG emissionsand reflects the successful implementation of a wide array of policies focused on energy efficiency, renewable energy deployment, and low-carbon technologies. This positive trend in reducing emissions intensity is a cornerstone of India's climate strategy.

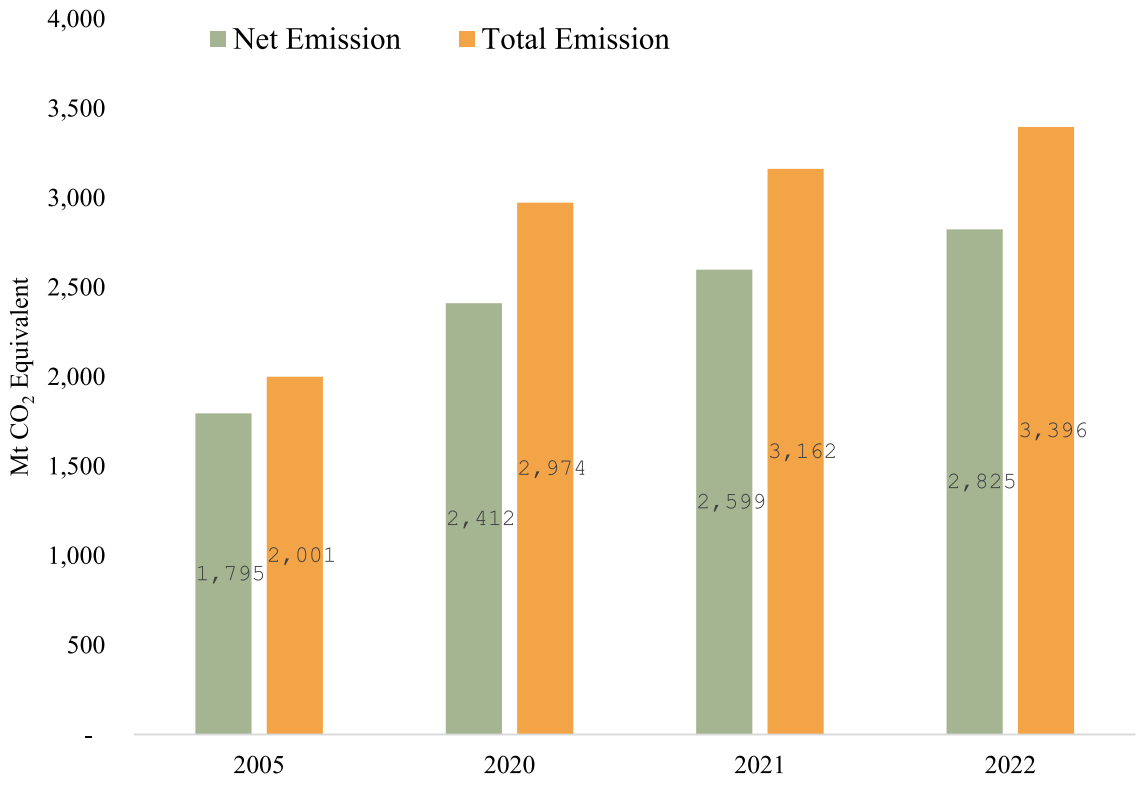


Figure 2.1: Summary of GHG emissions in 2005, 2020, 2021 and 2022 in Mt CO_2 eq

Table 2.1: Sector-wise GHG emissions summary for 2005, 2020, 2021 and 2022 in Gg CO_2 eq

Sectors	Total Gg CO_2 Equivalent				% Change (2005-2022)
	2005	2020	2021	2022	
Net Emission	**17,95,268**	**24,11,849**	**25,98,902**	**28,24,549**	**57.33%**
Total Emission	**20,01,288**	**29,74,093**	**31,62,473**	**33,96,372**	**69.71%**
1. Energy	12,48,692	21,28,202	22,90,174	24,92,069	99.57%
2. Industrial Processes and Product Use (IPPU)	2,47,092	2,55,512	2,79,869	3,01,023	21.83%
3. Agriculture	4,43,443	4,98,256	5,02,579	5,09,439	14.88%
4. Land Use, Land-Use Change and Forestry (LULUCF)	(-) 2,06,020	(-) 5,62,243	(-) 5,63,571	(-) 5,71,823	(-) 177.56%
5. Waste	62,061	92,124	89,851	93,842	51.21%

The above Table 2.1 presents a comprehensive sector-wise summary of Greenhouse Gas (GHG) emissions for India in gigagrams of CO_2 equivalent ($GgCO_2eq$) for the years 2005, 2020, 2021, and 2022. The table details emissions across five key sectors: Energy, Industrial Processes and Product Use (IPPU), Agriculture, Land Use, Land-Use Change and Forestry (LULUCF), and Waste. The Energy sector consistently remains the dominant contributor, with emissions rising from 1,248,691 $GgCO_2eq$ in 2005 to 2,492,069 $GgCO_2eq$ in 2022, marking a 99.57% change. The IPPU sector shows an increase, from 247,092 $GgCO_2eq$ in 2005 to 301,023 $GgCO_2eq$ in 2022, an increase of 21.83%. In contrast, the agriculture sector experienced a comparatively modest growth in emissions, from 443,443 $GgCO_2eq$ in 2005 to 509,439 $GgCO_2eq$ in 2022, a 14.88% increase. The LULUCF sector, which acts as a net sink for GHGs, showed an increased removal of CO_2 equivalent, moving from 206,020 $GgCO_2eq$ in 2005 to 571,823 $GgCO_2eq$ in 2022, indicating an enhanced carbon sequestration capacity with a 177.56% change. Finally, the Waste sector demonstrated an increase in emissions from 62,061 $GgCO_2eq$ in 2005 to 93,842 $GgCO_2eq$ in 2022, a 51.21% change. The overall net emission for India increased by 57.33 % from 17,95,268$GgCO_2eq$ in 2005 to 28,24,549 $GgCO_2eq$ in 2022.

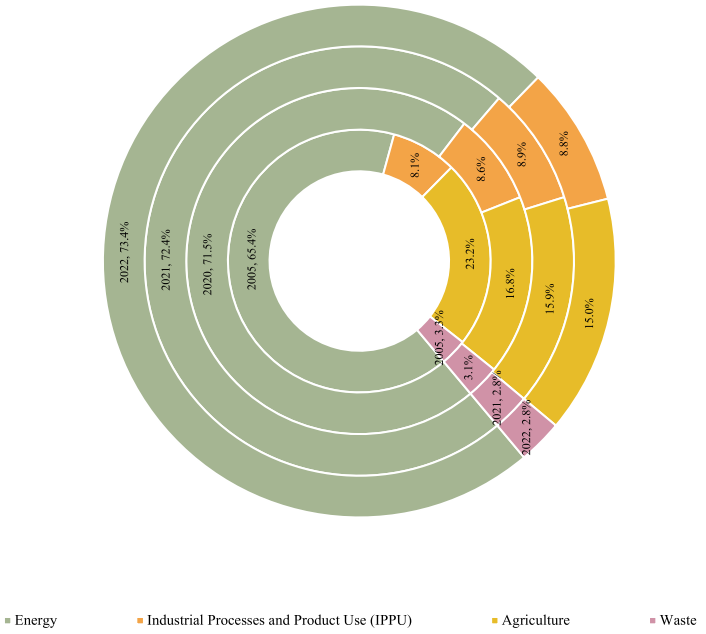


Figure 2.2: Sector-wise percentage share of emissions during 2005, 2020-2022

2.2. Description of emission and removal trends by sector and by gas

This section disaggregates the national GHG emission and removal trends described in Section 2.1 to provide a more detailed analysis of the trends by sector and by individual greenhouse gas. Understanding these underlying trends is essential for identifying the primary drivers of India's emissions profile and for formulating effective, targeted climate policies. The analysis covers the period from 2005, and 2020 to 2022.

Table 2.2, collectively titled “Summary of India's GHG emissionsand Removals in 2022 (Gg)”, offers a detailed breakdown of greenhouse gas emissions and removals for the year 2022 across various source and sink categories. The reported gases include Carbon Dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O), Hydrofluorocarbons (HFC), Perfluorocarbons (PFC), and Sulphur Hexafluoride (SF_6), with total CO_2 equivalent presented for each category. India's total net emissions in 2022 were 2,824,549 $GgCO_2$ equivalent, resulting from total emissions of 3,396,372 $GgCO_2$ equivalent and CO_2 removals of 578,891 Gg.

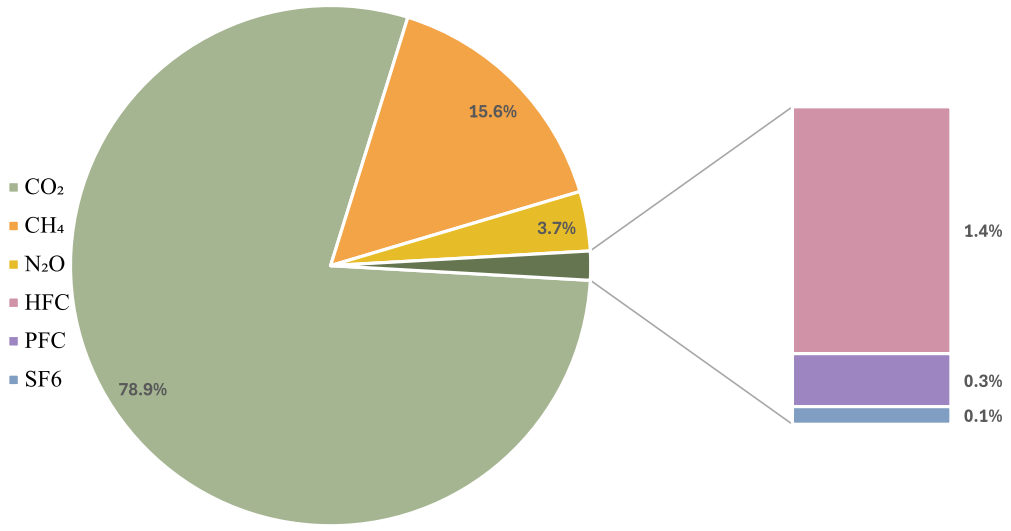


Figure 2.3: Gas-wise total GHG emissions in 2022

The Energy sector is, by far, the largest and fastest-growing contributor to India's GHG emissions, accounting for the majority of the national total. Within this sector, Fuel Combustion Activities, particularly Energy Industries (1,482,506 $GgCO_2eq$, 59%) and Manufacturing Industries and Construction (435,670 $GgCO_2eq$, 17%), are the primary sources. Fugitive Emissions from Fuels also contribute, mainly from Solid Fuels and Oil & Natural Gas.

The IPPU sector contributed 301,023 $GgCO_2$ equivalent in 2022. Emissions from the IPPU sector have shown a strong correlation with industrial production and infrastructure development. Mineral Industry (175,231 $GgCO_2eq$), Chemical Industry (68,235 $GgCO_2eq$), and Metal Industry (27,580 $GgCO_2eq$) are key sub-sectors within IPPU. Significant emissions from Product Uses as substitutes for Ozone Depleting Substances (ODS) are also noted, largely from refrigeration and air conditioning (25,397 Gg CO_2eq).

The agriculture sector's total emissions amounted to 5,09,439 $GgCO_2$ equivalent. Enteric Fermentation, predominantly from cattle, and Rice Cultivation, especially irrigated rice, are the largest sources within this sector. Manure Management and Agricultural Soils (with direct and indirect N_2O emissions) also contribute significantly. Field Burning of Agricultural Residues and Urea Application are other identified sources.

The Land Use, Land-Use Change and Forestry (LULUCF) sector acted as a significant carbon sink, removing a net of -5,71,823 $GgCO_2$ equivalent. Forest land remaining forest land contributed to substantial removals, while Cropland also showed considerable carbon sequestration. Grassland, Wetlands, and Settlements also played a role in removals. Harvested wood products further contributed to carbon removal. The LULUCF sector represents a success story in India's environmental efforts. The trend in this sector is a consistent and growing net sink for CO_2. The primary driver for this positive trend is the sustained implementation of national policies focused on conservation, afforestation, and reforestation. These efforts have led to a steady increase in the nation's forest and tree cover, enhancing the capacity of the land to absorb and store carbon.

The trend in the Waste sector is driven by population growth and increasing urbanization. The Waste sector accounted for 93,842 $GgCO_2$ equivalent. Solid Waste Disposal, with significant contributions from unmanaged waste disposal sites, is the largest emission source in this sector. Wastewater Treatment and Discharge, encompassing both domestic and industrial wastewater, also contributes to a considerable amount of emissions. The trend is gradually being influenced by improved waste management practices in many urban areas, including waste segregation, composting, and waste-to-energy projects, which are helping to curb the growth rate of emissions from this sector.

Table 2.2: Summary of India's GHG emissionsand Removals during 2005. 2020-2022 in Gg CO_2 eq.

Summary of India's GHG emissionsand Removals in $GgCO_2$ eq.				
Source/Sink Categories	**2005**	**2020**	**2021**	**2022**
Net Emission	1795268	2411849	2598902	2824549
Total Emission	2001288	2974093	3162473	3396372
1. Energy	1248692	2128202	2290174	2492069
1.A. Fuel combustion activities (sectoral approach)	1217819	2093143	2253088	2452172
1.B. Fugitive emissions from fuels	30873	35059	37086	39897
2. Industrial Processes and Product Use (IPPU)	247092	255512	279869	301023
2.A. Mineral industry	123176	152270	164200	175231
2.B. Chemical industry	84041	61925	67424	68235
2.C. Metal industry	36843	25060	27002	27580
2.D. Non-energy products from fuels and solvent use	1249	2546	2756	2456
2.E. Electronics industry	1	0	0	0
2.F. Product uses as substitutes for ODS	1033	11746	16649	25397
2.G. Other product manufacture and use	749	1965	1839	2124
3. Agriculture	443443	498256	502579	509439
3.A. Enteric fermentation	276658	296843	298436	300170
3.B. Manure management	12582	13025	13058	13099
3.C. Rice cultivation	88405	90300	95253	97920

Summary of India's GHG emissionsand Removals in $GgCO_2$ eq.				
Source/Sink Categories	**2005**	**2020**	**2021**	**2022**
3.D. Agricultural soils	52975	80729	78584	80052
3.F. Field burning of agricultural residues	8037	9748	9665	10451
3.H. Urea application	4786	7611	7583	7746
4. Land Use, Land-Use Change and Forestry (LULUCF)	-206020	-562243	-563571	-571823
4.A. Forest land	-21061	-148108	-147946	-149896
4.B. Cropland	-198081	-386142	-387198	-394333
4.C. Grassland	26281	6944	6329	5622
4.E. Settlements	749	-8952	-9056	-9507
4.G. Harvested wood products (Approach A/B/C)	-13909	-25986	-25700	-23709
5. Waste	62061	92124	89851	93842
5.A. Solid waste disposal	10800	25523	26581	27523
5.B. Biological treatment of solid waste	0	169	199	209
5.C. Incineration and open burning of waste	712	479	489	498
5.D. Wastewater treatment and discharge	50549	65953	62582	65611

Table 2.3: Summary of India's GHG emissionsand Removals in 2022 (Gg)

Source/Sink Categories	CO_2	CO_2 Removal	CH_4	N_2O	HFCs	PFCs	SF_6	Total CO_2 Equivalent
Net Emission	**2682727**	**578891**	**19037**	**476**	**20.3**	**1.32**	**0.09**	**2824549**
Total Emission	**2678327**		**18992**	**470**	**20.3**	**1.32**	**0.09**	**3396372**
1. Energy	2434229		1476	62.28				2492069
1.A. Fuel combustion activities (sectoral approach)	2431992		131	62.26				2452172
1.A.1. Energy industries	1475934		17.09	23				1482506
1.A.2. Manufacturing industries and construction	432947		39.86	6.07				435670
1.A.3. Transport	359044		70.53	32.12				369532
1.A.4. Other sectors	146297		3.24	0.93				146635
1.A.5. Other	17771		0.72	0.14				17829
1.B. Fugitive emissions from fuels	2237		1345	0.02				39897
1.B.1. Solid fuels			931					26065
1.B.2. Oil and natural gas and other emissions from energy production	2237		414	0.02				13832
1.C. CO_2 Transport and storage	NO		NO	NO				NO
1.C.1. Transport of CO_2	NO		NO	NO				NO
1.C.2. Injection and storage	NO		NO	NO				NO
1.C.3. Other	NO		NO	NO				NO
1.D. Memo items								
1.D.1. International bunkers	7716		0.29	0.21				7780
1.D.2. Multilateral operations	NO	NO	NO					NO
1.D.3. CO_2 emissions from biomass	805332							805332

Source/Sink Categories	CO_2	CO_2 Removal	CH_4	N_2O	HFCs	PFCs	SF_6	Total CO_2 Equivalent
1.D.4. CO_2 captured	NO		NO	NO				NO
2. Industrial Processes and Product Use (IPPU)	235854		36.89	9.51	20.3	1.32	0.09	301023
2.A. Mineral industry	175231							175231
2.A.1. Cement production	152265							152265
2.A.2. Lime production	22609							22609
2.A.3. Glass production	331							331
2.A.4. Other process uses of carbonates	27							27
2.B. Chemical industry	40797		36.79	9.51	3.08			68235
2.B.1. Ammonia production	12428	NA	NA					12428
2.B.2. Nitric acid production				8.39				2224
2.B.3. Adipic acid production	NE							NE
2.B.4. Caprolactam, glyoxal and glyoxylic acid production	NO			1.12				296
2.B.5. Carbide production	96		NO					96
2.B.6. Titanium dioxide production	66							66
2.B.7. Soda ash production	1029							1029
2.B.8. Petrochemical and carbon black production	27178		36.79					28208
2.B.9. Fluorochemical production					3.08	NO	NO	23888
2.B.10. Other	NE		NE	NO	NO	NO	NO	NE,NO
2.C. Metal industry	17370		0.1	NO	NO	1.32	0.004	27580
2.C.1. Iron and steel production	IE		IE					IE
2.C.2. Ferroalloys production	10013		0.1					10016
2.C.3. Aluminium production	6908					1.32		17017
2.C.4. Magnesium production	309				NO	NO	0.004	407
2.C.5. Lead production	102							102
2.C.6. Zinc production	38							38
2.C.7. Other	NO		NO	NO	NO	NO	NO	NO
2.D. Non-energy products from fuels and solvent use	2456		NA	NA				2456
2.D.1. Lubricant use	2323		NA	NA				2323
2.D.2. Paraffin wax use	133		NA	NA				133
2.D.3. Other	NE		NE	NE				NE, NO
2.E. Electronics industry				NO	NO, NE	NE	NE	NE, NO
2.E.1. Integrated circuit or semiconductor				NO	NO	NO	NO	NO
2.E.2. TFT flat panel display				NO	NO	NO	NO	NO
2.E.3. Photovoltaics					NO	NO	NO	NO
2.E.4. Heat transfer fluid					NO	NE	NO	NO,NE
2.E.5. Other				NO	NE	NO	NO	NO, NE

Source/Sink Categories	CO_2	CO_2 Removal	CH_4	N_2O	HFCs	PFCs	SF_6	Total CO_2 Equivalent
2.F. Product uses as substitutes for ODS					17.22	NO	NO	25397
2.F.1. Refrigeration and air conditioning					8.07	NO	NO	15172
2.F.2. Foam blowing agents					2.15	NO	NO	1076
2.F.3. Fire protection					0.47	NO	NO	1634
2.F.4. Aerosols					3.93	NO	NO	4131
2.F.5. Solvents					0.001	NO	NO	2.06
2.F.6. Other applications					2.6	NO	NO	3382
2.G. Other product manufacture and use	NA		NA	NA, NE	NO	NO	0.09	2124
2.G.1. Electrical equipment					NO	NO	0.09	2124
2.G.2. SF6 and PFCs from other product use						NE	NE	NE
2.G.3. N_2O from product uses				NE				NE
2.G.4. Other	NA		NA	NA	NO	NE	NE	NA,NE,NO
2.H. Other	IE, NE, NA		NA, IE	NA, NE	NO	NO	NO	IE, NE, NA, NO
2.H.1. Pulp and paper	IE		IE	NE	NO	NO	NO	IE, NE, NO
2.H.2. Food and beverages industry	NE		IE	NE				NE, IE
2.H.3. Other *(please specify)*	NA		NA	NA	NO	NO	NO	NA, NO
3. Agriculture	7746		14703	339.68				509439
3.A. Enteric fermentation			10720					300170
3.A.1. Cattle			6025					168696
3.A.2. Sheep			321					8982
3.A.3. Swine			8.44					236
3.A.4. Other livestock			4366					122256
3.B. Manure management			186	29.82				13099
3.B.1. Cattle			102	18.5				7763
3.B.2. Sheep			2.74	0.13				112
3.B.3. Swine			3.19	2.22				677
3.B.4. Other livestock			77.44	8.98				4547
3.B.5. Indirect N_2O emissions				NA				NA
3.C. Rice cultivation			3497					97920
3.C.1. Irrigated			2552					71448
3.C.2. Rain-fed			770					21573
3.C.3. Deep water			175					4899
3.C.4. Other *(please specify)*			NO					NO
3.D. Agricultural soils			NA	302.08				80052
3.D.1. Direct N_2O emissions from managed soils				243.84				64617
3.D.2. Indirect N_2O Emissions from managed soils				58.25				15436

Source/Sink Categories	CO_2	CO_2 Removal	CH_4	N_2O	HFCs	PFCs	SF_6	Total CO_2 Equivalent
3.E. Prescribed burning of savannahs			NO	NO				NO
3.E.1. Forest land *(specify ecological zone)*			NO	NO				NO
3.E.2. Grassland *(specify ecological zone)*			NO	NO				NO
3.F. Field burning of agricultural residues			300	7.77				10451
3.F.1. Cereals			217	5.62				7564
3.F.2. Pulses			NO	NO				NO
3.F.3. Tubers and roots			NO	NO				NO
3.F.4. Sugar cane			47	1.23				1648
3.F.5. Other			36	0.92				1239
3.G. Liming	NE							NE
3.G.1. Limestone $CaCO_3$	NE							NE
3.G.2. Dolomite $CaMg(CO_3)_2$	NE							NE
3.H. Urea application	7746							7746
3.I. Other carbon-containing fertilizers	NA							NA
3.J. Other *(please specify)*	NA		NA	NA				NA
4. Land Use, Land-Use Change and Forestry (LULUCF)	4400	578891	45	5.34				-571823
4.A. Forest land		151342	45	0.72				-149896
4.A.1. Forest land remaining forest land		151342	45	0.72				-149896
4.A.2. Land converted to forest land	NE	NE	NE	NE				NE
4.B. Cropland		394333	IE,NA	IE,NA				-394333
4.B.1. Cropland remaining cropland		394333	IE	IE				-394333
4.B.2. Land converted to cropland	NE	NE	NA	NA				NE,NA
4.C. Grassland	4400		NE	4.61				5622
4.C.1. Grassland remaining grassland	4400		NE	4.61				5622
4.C.2. Land converted to grassland	NE		NE	NE				NE
4.D. Wetlands		NE	NE	NE				NE
4.D.1. Wetlands remaining wetlands		NE	NO	NE				NE,NO
4.D.2. Land converted to wetlands		NE	NA	NE				NE,NA
4.E. Settlements		9507	NE	NE				-9507
4.E.1. Settlements remaining settlements		9507	NO	NE				-9507
4.E.2. Land converted to settlements		NE	NA	NE				NE,NA
4.F. Other land		NE	NE	NE				NE
4.F.1. Other land remaining other land								

Source/Sink Categories	CO_2	CO_2 Removal	CH_4	N_2O	HFCs	PFCs	SF_6	Total CO_2 Equivalent
4.F.2. Land converted to other land		NE	NA,NE	NE				NE, NA
4.G. Harvested wood products (Approach A/B/C)		23709						-23709
4.G.1. Solid wood		22851						-22851
4.G.2. Paper and paperboard		858						-858
4.G.3. Other *(please specify)*		NE						NE
4.H. Other *(please specify)*								
5. Waste	498.33		2776	58.93				93842
5.A. Solid waste disposal			983					27523
5.A.1. Managed waste disposal sites			135					3767
5.A.2. Unmanaged waste disposal sites			681					19062
5.A.3. Uncategorized waste disposal sites			168					4694
5.B. Biological treatment of solid waste			7.46	NE, NO				209
5.B.1. Composting			7.46	NE, NO				209
5.B.2. Anaerobic digestion at biogas facilities			0.00	NE, NO				NO
5.C. Incineration and open burning of waste	498		NE, NO, IE	NE, NO, IE				498
5.C.1. Waste incineration	179		NE, NO, IE	NE, NO, IE				179
5.C.2. Open burning of waste	319		NE, NO	NE, NO				319
5.D. Wastewater treatment and discharge			1785	58.93				65611
5.D.1. Domestic wastewater			781	58.93				37474
5.D.2. Industrial wastewater			1005	NE				28137
5.D.3. Other			NA	NO				NO
5.E. Other *(please specify)*	NE	NE	NE	NE				NE

CHAPTER-3

ENERGY

ENERGY

3.1. Overview of the sector (e.g. quantitative overview and description, including trends and methodological tiers by category) and background information

The Energy Sector is the single most significant component of India's national greenhouse gas inventory. In the latest inventory year, 2022, this sector was responsible for 73% of the country's total GHG emissions(excluding LULUCF). This dominance underscores the foundational role of energy in driving India's economy, supporting industrial growth, and improving the quality of life for its citizens.

The sector encompasses emissions from two primary activities: *Fuel Combustion:* This is the largest source, including emissions from burning fossil fuels for electricity and heat production, in manufacturing industries and construction, for transportation (road, rail, aviation, etc.), and in residential and commercial buildings. *Fugitive Emissions:* These are emissions released during the extraction, processing, storage, and transport of fossil fuels, such as methane released from coal mines and natural gas infrastructure.

The key category analysis for 2022 confirms the sector's pre-eminence. The analysis identifies CO_2 from Electricity and Heat Production as the single largest key category in the entire national inventory. Other key categories in this sector include CO_2 from non-specified industry, CO_2 from Iron and Steel, CO_2 from Road Transportation, and CO_2 from Other sector. These categories account for a substantial share of total national GHG emissions, underscoring that power generation, industrial production, and transportation are the primary areas of focus for both inventory reporting and mitigation efforts.

The Energy sector's emissions trend has been one of consistent growth from 2005 to 2022, a trajectory that mirrors India's economic development. This growth is fundamentally linked to the expansion of energy infrastructure to meet the demands of a growing population and a modernizing economy. The most significant driver of this trend has been the increased combustion of coal, primarily for electricity generation. However, the period has also seen a significant increase in the consumption of petroleum products, largely for the transport sector.

In the more recent time series and more strategically important, the long-term trend is increasingly being influenced by a massive policy-driven shift towards renewable energy. While the absolute emissions from the sector are still growing to meet India's development needs, the growth rate is being moderated by this clean energy transition. This demonstrates a clear and progressive decoupling of economic growth from energy sector emissions.

Methodological Tiers

The GHG inventory for the Energy sector is compiled using the methodological approaches outlined in the 2006 IPCC Guidelines. A mix of Tier 1, Tier 2, and Tier 3 methods is applied, consistent with data availability and the significance of the source category, to ensure the highest possible accuracy.

Fuel Combustion Activities (e.g., Electricity Generation, Manufacturing): For the most significant key categories, a mixture of Tier 2 and Tier 3 approaches is predominantly used. This involves combining detailed, high-quality activity data (e.g., tons of coal consumed by power plants) with country-specific emission factors that reflect the unique characteristics of the fuels used in India. This provides a more accurate estimate than using global default values. For less significant fuel combustion sources, a Tier 1 approach may be applied.

Mobile Combustion (Transport): For the road transport category, a Tier 1 approach is generally used, combining detailed national statistics on fuel sold with a set of default emission factors.

Fugitive Emissions: For fugitive emissions from coal mining and natural gas systems, a combination of Tier 1 and Tier 2 methodologies is employed. Tier 2 methods are used where detailed, facility-level data on methane leakage is available, while the IPCC's Tier 1 default emission factors are applied for other parts of the sector where such specific data is not yet available.

This tiered approach ensures that the Energy sector inventory is as accurate as practicable and directs future improvement efforts toward developing country-specific parameters for the remaining Tier 1 categories.

Emission Profile

The table provides India's GHG emissions from the Energy Sector, measured in $GgCO_2$ equivalent, for 2005, 2020, 2021, and 2022. The total emissions from the Energy sector have significantly increased from 1,248,691 $GgCO_2$ equivalent in 2005 to 2,492,069 $GgCO_2$ equivalent in 2022.

Fuel Combustion Activities, under category 1.A, represent the largest source of emissions within the Energy sector. These emissions rose from 1,217,819 $GgCO_2$ equivalent in 2005 to 2,452,172 $GgCO_2$ equivalent in 2022. The largest sub-category here is Energy Industries (1.A.1), primarily driven by Public Electricity and Heat Production (1.A.1.a), which alone accounted for 1,389,591 $GgCO_2$ equivalent in 2022, up from 688,310 $GgCO_2$ equivalent in 2005. Petroleum Refining (1.A.1.b) also showed an increase from 25,642 $GgCO_2$ equivalent in 2005 to 82,819 $GgCO_2$ equivalent in 2022.

Manufacturing Industries and Construction (1.A.2) are another substantial contributor, with emissions increasing from 227,384 $GgCO_2$ equivalent in 2005 to 435,670 $GgCO_2$ equivalent in 2022. Within this, Iron and Steel (1.A.2.a) and Non-metallic Minerals (1.A.2.f) are prominent sub-sectors.

Transport (1.A.3) emissions have also risen considerably, from 131,193 $GgCO_2$ equivalent in 2005 to 369,532 $GgCO_2$ equivalent in 2022. Road Transportation (1.A.3.b) is the dominant sub-category here, growing from 107,140 $GgCO_2$ equivalent in 2005 to 334,223 $GgCO_2$ equivalent in 2022, with significant contributions from cars, light-duty trucks, heavy-duty trucks and buses, and motorcycles. Aviation sector emissions, comparatively smaller, have increased 2.5 times from 6,763 Gg CO_2 Equivalent in 2005 to 16,616 Gg CO_2 Equivalent in 2022. The navigation emissions are even less but have doubled from 1,768 Gg CO_2 Equivalent in 2005 to 3,571 Gg CO_2 Equivalent in 2022. Almost 98% of railway routes are now electrified. Consequently, GHG emissions from railways have decreased from 6,116 Gg CO_2 equivalent in 2005 to 4,330 Gg CO_2 Equivalent in 2022 due to the direct use of fossil fuel in this sector.

Other Sectors (1.A.4), including Commercial/Institutional (1.A.4.a) and Residential (1.A.4.b) consumption, also showed increased emissions. Residential emissions, for instance, increased from 77,465 $GgCO_2$ equivalent in 2005 to 98,323 $GgCO_2$ equivalent in 2022.

Fugitive Emissions from Fuels (1.B) represent another source, with emissions rising from 30,873 $GgCO_2$ equivalent in 2005 to 39,897 $GgCO_2$ equivalent in 2022. This category includes emissions from Solid Fuels —predominantly Coal Mining and Handling —and from Oil and Natural Gas systems, with notable contributions from natural gas production, transmission, and distribution, as well as flaring and venting activities. International Bunkers (1.D.1), comprising aviation and navigation, are reported as Memo Items, with emissions increasing from 3,425 $GgCO_2$ equivalent in 2005 to 7,780 $GgCO_2$ equivalent in 2022. Table 3.1 shows GHG emissions from all energy sector categories during 2005, 2020 to 2022 in $GgCO_2e$.

Table 3.1: Summary of India's GHG emissions from the Energy Sector in $GgCO_2e$

Summary of India's GHG emissions from the Energy Sector	Total Gg CO_2 Equivalent			
Source/Sink Categories	2005	2020	2021	2022
1. Energy	1248692	2128202	2290174	2492069
1.A. Fuel combustion activities (sectoral approach)	1217819	2093143	2253088	2452172
1.A.1. Energy industries	715553	1257253	1348803	1482506
1.A.1.a. Public electricity and heat production	688310	1166558	1257424	1389591
1.A.1.a.i. Electricity generation	688310	1166558	1257424	1389591
1.A.1.a.ii. Combined heat and power generation	0	0	0	0
1.A.1.a.iii. Heat plants	0	0	0	0
1.A.1.b. Petroleum refining	25642	82056	80145	82819
1.A.1.c. Manufacture of solid fuels and other energy industries	1600	8639	11234	10097
1.A.1.c.i. Manufacture of solid fuels	1600	8639	11234	10097
1.A.1.c.ii. Oil and gas extraction	0	0	0	0
1.A.1.c.iii. Other energy industries	0	0	0	0
1.A.2. Manufacturing industries and construction	227384	388744	434597	435670
1.A.2.a. Iron and steel	91070	151204	157596	161050
1.A.2.b. Non-ferrous metals	2509	2319	5451	4101
1.A.2.c. Chemicals	14945	6331	5622	5034
1.A.2.d. Pulp, paper and print	5419	2571	3924	3479
1.A.2.e. Food processing, beverages and tobacco	0	0	0	0
1.A.2.f. Non-metallic minerals	38795	50329	51307	52106
1.A.2.g. Other	74645	175989	210697	209900
1.A.2.g.i. Manufacturing of machinery	683	3103	3060	1449
1.A.2.g.ii. Manufacturing of transport equipment	0	0	0	0
1.A.2.g.iii. Mining (excluding fuels) and quarrying	2099	5483	5414	4128
1.A.2.g.iv. Wood and wood products	0	0	0	0
1.A.2.g.v. Construction	0	19296	19773	19178
1.A.2.g.vi. Textile and leather	2533	635	2041	2286
1.A.2.g.vii. Off-road vehicles and other machinery	0	0	0	0
1.A.2.g.viii. Other (non-specified industry)	69330	147473	180409	182859
1.A.3. Transport	131193	303917	324390	369532
1.A.3.a. Domestic aviation	6763	11949	11923	16616
1.A.3.b. Road transportation	107140	277573	297752	334223
1.A.3.b.i. Cars	43531	85486	91356	100975
1.A.3.b.ii. Light duty trucks	12860	53155	56325	66467
1.A.3.b.iii. Heavy duty trucks and buses	33936	91150	97348	109321
1.A.3.b.iv. Motorcycles	16813	47782	52722	57460
1.A.3.b.v. Other (please specify)	0	0	0	0
1.A.3.c. Railways	6116	4031	4050	4330
1.A.3.d. Domestic navigation	1768	3182	3032	3571
1.A.3.e. Other transportation	9406	7181	7633	10792
1.A.3.e.i. Pipeline transport	403	943	972	2959
1.A.3.e.ii. Other (please specify)	9004	6238	6661	7833
1.A.4. Other sectors	109731	128217	130286	146635

Summary of India's GHG emissions from the Energy Sector	Total Gg CO_2 Equivalent			
Source/Sink Categories	2005	2020	2021	2022
1.A.4.a. Commercial/institutional	25880	23236	27318	37138
1.A.4.a.i. Stationary combustion	25880	23236	27318	37138
1.A.4.a.ii. Off-road vehicles and other machinery	0	0	0	0
1.A.4.b. Residential	77465	93879	92005	98323
1.A.4.b.i. Stationary combustion	77465	93879	92005	98323
1.A.4.b.ii. Off-road vehicles and other machinery	0	0	0	0
1.A.4.c. Agriculture/forestry/fishing	6386	11102	10963	11174
1.A.4.c.i. Stationary	2247	2635	2441	1760
1.A.4.c.ii. Off-road vehicles and other machinery	0	0	0	0
1.A.4.c.iii. Fishing	4139	8467	8522	9413
1.A.5. Other	33958	15008	15012	17829
1.A.5.a. Stationary	15710	15008	15012	17829
1.A.5.b. Others	18248	0	0	0
1.B. Fugitive emissions from fuels	30873	35059	37086	39897
1.B.1. Solid fuels	18344	22278	23370	26065
1.B.1.a. Coal mining and handling	18344	22278	23370	26065
1.B.1.a.i. Underground mines	9442	4203	4037	4236
1.B.1.a.i.1. Mining activities	7777	3399	3266	3428
1.B.1.a.i.2. Post-mining activities	1666	804	772	808
1.B.1.a.i.3. Abandoned underground mines (number of mines)	0	0	0	0
1.B.1.a.i.4. Flaring of drained methane or conversion of methane to CO_2	0	0	0	0
1.B.1.a.i.5. Other (please specify)	0	0	0	0
1.B.1.a.ii. Surface mines	8901	18076	19333	21830
1.B.1.a.ii.1. Mining activities	7897	16037	17152	19368
1.B.1.a.ii.2. Post-mining activities	1004	2039	2180	2462
1.B.1.a.ii.3. Other (please specify)	0	0	0	0
1.B.1.b. Fuel transformation	0	0	0	0
1.B.1.b.i. Charcoal and biochar production	0	0	0	0
1.B.1.b.ii. Coke production	0	0	0	0
1.B.1.b.iii. Coal to liquids	0	0	0	0
1.B.1.b.iv. Gas to liquids	0	0	0	0
1.B.1.b.v. Other (please specify)	0	0	0	0
1.B.1.c. Other	0	0	0	0
1.B.2. Oil and natural gas and other emissions from energy production	12529	12781	13716	13832
1.B.2.a. Oil	942	1341	1336	1390
1.B.2.a.i. Exploration	0	0	0	0
1.B.2.a.ii. Production and upgrading	427	369	355	350
1.B.2.a.iii. Transport	23	17	18	19
1.B.2.a.iv. Refining/storage	493	955	963	1021
1.B.2.a.v. Distribution of oil products	0	0	0	0
1.B.2.a.vi. Other	0	0	0	0

Summary of India's GHG emissions from the Energy Sector	Total Gg CO_2 Equivalent			
Source/Sink Categories	2005	2020	2021	2022
1.B.2.a.vi.1. Abandoned wells	0	0	0	0
1.B.2.a.vi.2. Other (please specify)	0	0	0	0
1.B.2.b. Natural gas	7873	8254	8844	8823
1.B.2.b.i. Exploration	0	0	0	0
1.B.2.b.ii. Production and gathering	1401	1404	1563	1582
1.B.2.b.iii. Processing	80	73	82	86
1.B.2.b.iv. Transmission and storage	2053	1747	2007	2155
1.B.2.b.v. Distribution	4340	5030	5192	4999
1.B.2.b.vi. Other	0	0	0	0
1.B.2.b.vi.1. Gas post-meter	0	0	0	0
1.B.2.b.vi.2. Abandoned wells	0	0	0	0
1.B.2.b.vi.3. Other (please specify)	0	0	0	0
1.B.2.c. Venting and flaring	3714	3186	3536	3619
1.B.2.c.i. Venting	1595	1238	1627	1922
1.B.2.c.i.1. Oil	0	0	0	0
1.B.2.c.i.2. Gas	0	0	0	0
1.B.2.c.i.3. Combined	1595	1238	1627	1922
1.B.2.c.ii. Flaring	2119	1947	1909	1697
1.B.2.c.ii.1. Oil	0	0	0	0
1.B.2.c.ii.2. Gas	0	0	0	0
1.B.2.c.ii.3. Combined	2119	1947	1909	1697
1.B.2.d. Other	0	0	0	0
1.C. CO_2 Transport and storage	0	0	0	0
1.C.1. Transport of CO_2	0	0	0	0
1.C.1.a. Pipelines	0	0	0	0
1.C.1.b. Ships	0	0	0	0
1.C.1.c. Other (please specify)	0	0	0	0
1.C.2. Injection and storage	0	0	0	0
1.C.2.a. Injection	0	0	0	0
1.C.2.b. Storage	0	0	0	0
1.C.3. Other	0	0	0	0
1.D. Memo items				
1.D.1. International bunkers	3425	4979	5096	7780
1.D.1.a. Aviation	3338	3219	2952	4950
1.D.1.b.Navigation	87	1759	2144	2830
1.D.2. Multilateral operations	0	0	0	0
1.D.3. CO_2 emissions from biomass	740832	797908	801611	805332
1.D.4. CO_2 captured	0	0	0	0
1.D.4.a. For domestic storage	0	0	0	0
1.D.4.b. For storage in other countries	0	0	0	0

3.2. Fuel combustion (CRT 1.A)

This section details GHG emissions from fuel combustion activities, which constitute the largest single component of the Energy Sector's emissions. The estimations are based on methodologies from the 2006 IPCC Guidelines and utilize a combination of country-specific and IPCC default parameters to ensure the highest possible accuracy and transparency. Emissions from this category increased from 1,217,819 $GgCO_2$ equivalent in 2005 to 2,452,172 $GgCO_2$ equivalent in 2022, representing a 101.36% change over the period. In 2022, this category accounted for 98.40% of the total emissions from the Energy sector. India has acknowledged that challenges in data availability and funding have led to the use of Tier I methodology for certain significant sub-sectors, such as road transport, which contributes significantly to the national inventory. Despite these constraints, India has committed to improving data availability and applying higher-tier methodologies to key sectors within the next 10 years.

3.2.1. Comparison of the sectoral approach with the reference approach

The bar chart illustrates the percentage difference between the sectoral and reference approaches for GHG emissionsin $GgCO_2$ for the years 2005, 2020, 2021, and 2022. The difference was 2.01% in 2005, increasing to 11.70% in 2020. It then slightly decreased to 11.37% in 2021 and further to 11.10% in 2022. The accompanying table provides the specific $GgCO_2$ values for both the Reference and Sectoral approaches for these years, showing, for instance, that in 2022, the Reference emission was 2,704,409 $GgCO_2$ while the Sectoral emission was 2,434,229 $GgCO_2$. This comparison is related to a non-mandatory provision as per paragraph 36 of the MPGs.

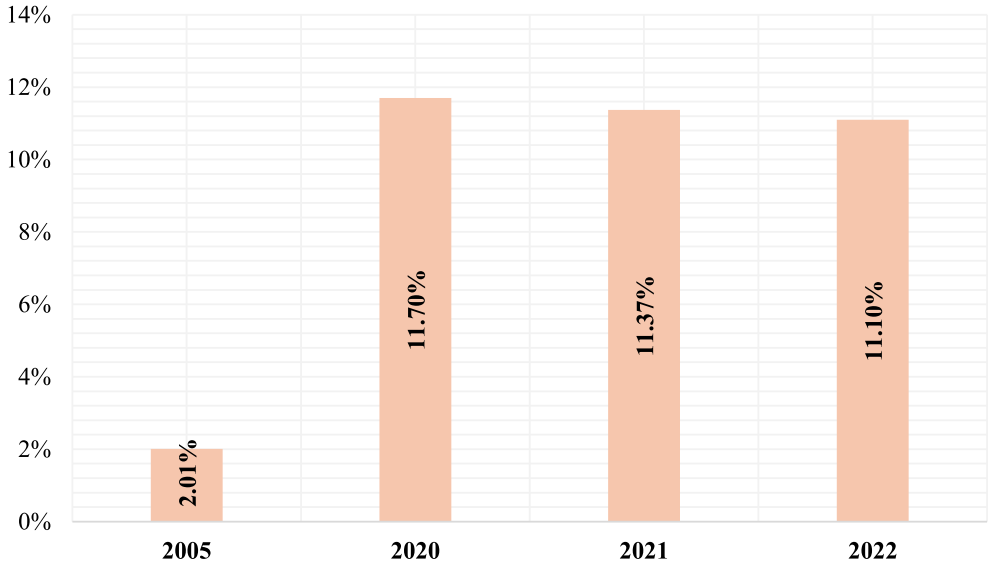


Figure 3.1: Percentage difference between CO_2 emission with the Sectoral approach and the Reference approach

3.2.2. International bunker fuels

In accordance with IPCC Guidelines and paragraph 53 of the MPGs, emissions from fuels used for international transport (aviation and navigation) are calculated and reported separately as a memo item. These emissions are not included in the national totals, but their estimation and reporting are crucial for global transparency. Total emissions from Memo items, entirely attributed to international bunkers, increased from 3,425 $GgCO_2$ equivalent in 2005 to 7,780 $GgCO_2$ equivalent in 2022, representing a 127% change. Within International bunkers, Aviation (1.D.1.a) emissions rose from 3,338 $GgCO_2$ equivalent in 2005 to 4,950 $GgCO_2$ equivalent in 2022, a 48% increase. Navigation (1.D.1.b) emissions saw a more increase, from 87 $GgCO_2$ equivalent in 2005 to 2,830 $GgCO_2$ equivalent in 2022, a remarkable 3143% change.

3.2.2.1. Category description

This section covers GHG emissions from fuels sold within India for use in international aviation and maritime navigation.

International Aviation (1.D.1.a): This category includes emissions from flights departing from India and arriving in a different country. The primary fuel consumed is Aviation Turbine Fuel (ATF).

International Navigation (Shipping) (1.D.1.b): This includes emissions from water-borne navigation of all vessels engaged in international transport. The main fuels used are Fuel Oil and Marine Gas Oil.

3.2.2.2. Methodological issues

The estimation of emissions from international bunker fuels follows the Tier 1 method as outlined in the 2006 IPCC Guidelines.

Activity Data: The core activity data is the amount of fuel sold for international transport. This data is sourced from official national statistics provided by the Ministry of Petroleum and Natural Gas (MoPNG) and the Petroleum Planning and Analysis Cell (PPAC). For international aviation, the total consumption of Aviation Turbine Fuel (ATF) is used, with the domestic portion (accounted for in section 1.A.3.a) subtracted to determine the international share. For international navigation, data on the sales of fuel oil, HSD and LDO for international shipping are used directly.

Table 3.2: International bunker fuels consumption in 2005, 2020-2022

Activity data for international bunker fuels in TJ				
Category	**2005**	**2020**	**2021**	**2022**
1.D.1.a. international aviation (aviation bunkers)				
Jet kerosene	46327.05	44687.63	40971.11	68707.80
1.D.1.b. international navigation (marine bunkers)				
Residual fuel oil	755.48	20038.4	25573.2	34138
Gas/diesel oil	192.43	2591.91	1958.74	2179.53
Other Liquid Fuels (Diesel oil/ Light diesel Oil (LDO))	184.90	NO	NO	NO

Emission Factors: As country-specific emission factors for fuels used in international transport are not currently available, IPCC default emission factors for CO_2, CH_4, and N_2O have been used for all estimations.

3.2.2.3. Uncertainty assessment

A quantitative uncertainty assessment has not been performed separately for this memo item. However, the primary sources of uncertainty lie in the disaggregation of fuel sales data between domestic and international transport and the use of IPCC default emission factors, which may not perfectly reflect the characteristics of the fuels supplied in India.

3.2.2.4. QA/QC and verification

The activity data used for bunker fuel estimations undergoes the same rigorous quality control as the rest of the Energy Sector inventory. Data is sourced from official, audited government publications from the MoPNG and PPAC, ensuring a high degree of reliability and transparency. These figures are cross-checked with other available national energy statistics to ensure consistency.

3.2.2.5. Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

3.2.2.6. Planned improvements

India is committed to the continuous improvement of its inventory. Future efforts may focus on exploring methodologies to further refine the disaggregation of fuel sales data between domestic and international transport to enhance the accuracy of the estimates for this memo item.

3.2.3. Feedstocks and non-energy use of fuels

In line with the 2006 IPCC Guidelines and the non-mandatory provision under paragraph 54 of the MPGs, this section accounts for fossil fuels that are used as raw materials (feedstocks) for manufacturing processes or in other non-energy applications. The carbon contained in these fuels is not emitted as CO_2 during their use; instead, it is stored or "sequestered" within the products created. Examples of such uses include:

- Naphtha, natural gas, or LPG used as feedstock in the chemical and petrochemical industries to produce plastics, synthetic rubber, and other organic chemicals.
- Natural gas used to produce ammonia for fertilizers.
- Bitumen used for paving roads.
- Lubricants used to reduce friction in machinery.

The purpose of accounting for these fuel quantities is to ensure a complete and transparent national energy and carbon balance. The carbon from these fuels is subtracted from the national energy consumption totals to avoid overestimating emissions from fuel combustion. This quantity is reported as a memo item and is not included in the Energy sector's emission totals.

Activity Data: Collecting data on the quantities of fuels delivered to industries for use as feedstocks or for other non-energy purposes. This data is sourced from official national statistics provided by the Ministry of Petroleum and Natural Gas (MoPNG), the Petroleum Planning and Analysis Cell (PPAC), and the Ministry of Statistics and Programme Implementation (MoSPI).

Carbon Content: Applying appropriate carbon content factors to the quantities of each fuel type to calculate the total amount of carbon stored. Any subsequent emissions that occur during the life cycle of the products made from these feedstocks (e.g., during product use or disposal) are accounted for in other relevant sectors of the inventory, such as Industrial Processes and Product Use (IPPU) or the Waste sector. This ensures that the carbon is tracked accurately throughout the economy without double-counting.

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

This category includes emissions from fuel combustion in electricity generation, petroleum refining, and the manufacturing of solid fuels. It is the most significant source category within the entire national inventory with accounting 59% of energy sector in 2022. The primary activity data used is fuel consumption, which is considered the most reliable metric in the Indian context. Data is primarily sourced from official government publications, with preference given to documents from the respective line ministries such as the Ministry of Coal (MoC), Ministry of Petroleum and Natural Gas (MoPNG), Ministry of Statistics and Programme Implementation (MoSPI), and the Central Electricity Authority (CEA). Where only financial year data is available, it has been reconciled to a calendar year basis. For solid fuels (coking coal, non-coking coal, and lignite), country-specific (CS) and sector-specific emission factors have been applied, reflecting a Tier 2/Tier 3 approach. This is particularly notable for non-coking coal used in electricity generation. For liquid and gaseous fuels, IPCC default (D) emission factors have been used, corresponding to a Tier 1 approach. These country- and sector-specific factors are under continuous review for future improvement.

3.2.4.1. Public electricity and heat production (1.A.1.a.)

This is the largest sub-category and includes emissions from utility-scale electricity generation, captive power plants, and combined heat and power generation. Emissions from both indigenous and imported coal are accounted for in detail. The oxidation factor used for coal and lignite combustion in this sub-category is 0.97. Emissions from this category significantly increased from 688,310 $GgCO_2$ equivalent in 2005 to 1,389,591 $GgCO_2$ equivalent in 2022. This represents a substantial 102% change over the period of 2005 to 2022. In 2022, this category accounted for 56% of the total emissions within its sector.

3.2.4.1.1 Electricity generation (1.A.1.a.i.)

Category description

This category covers emissions from electricity generation in utility-scale power plants, which form the backbone of India's power supply. It is the single largest source of GHG emissionsin the India's national inventory. While this section specifically addresses utility electricity generation (1.A.1.a.i), the reported figures also encompass emissions from Captive Power Plants, including both Combined Heat and Power (CHP) generation (1.A.1.a.ii) and Heat Plants (1.A.1.a.iii). A further disaggregation of captive power into CHP and heat-only plants is not currently possible due to limitations in the available data. The inventory for this category is comprehensive, accounting for all major fuels. It includes detailed accounting of imported non-coking coal, as well as consumption of coking coal and coal middling used in both utility and captive power plants.

Emissions from this category were 688,310 $GgCO_2$ equivalent in 2005, increasing to 1,166,558 $GgCO_2$ equivalent in 2020, 1,257,424 $GgCO_2$ equivalent in 2021, and 1,389,591 $GgCO_2$ equivalent in 2022. This represents a 102% change in emissions from 2005 to 2022. In 2022, electricity generation accounted for 56% of the total emissions within its sector.

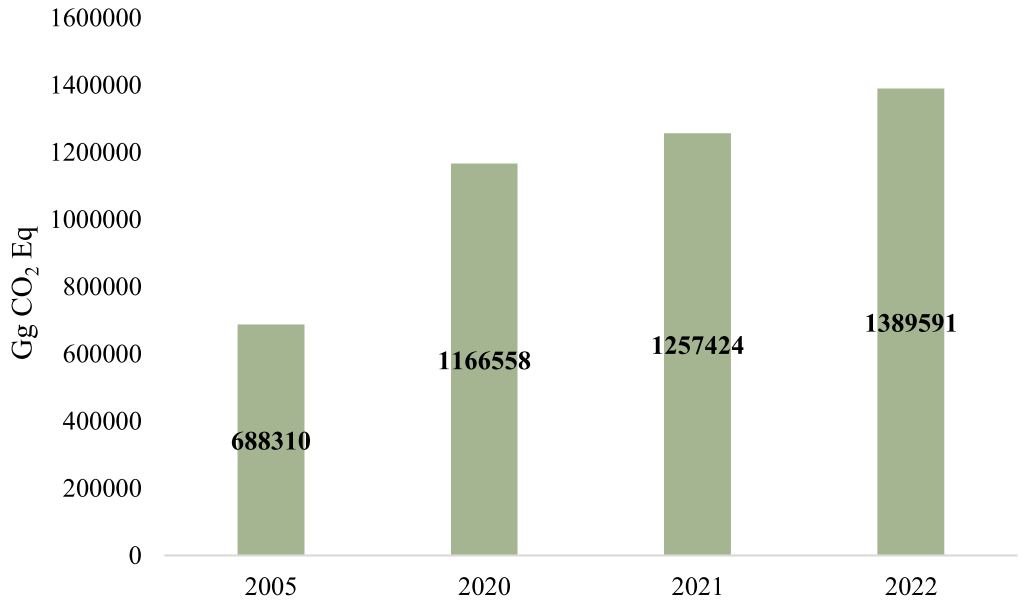


Figure 3.2: GHG emissions from Electricity generation (1.A.1.a.i.) in 2005, 2020-2022

Methodological issues

The estimation of GHG emissionsfor this category is robust, relying on high-quality national data and a combination of methodological tiers to ensure accuracy.

Activity Data: Data on fuel consumption is sourced from a range of official government publications, ensuring reliability and transparency. The primary data sources include the Coal Directory of India, the Annual Report of the Ministry of Coal, Energy Statistics from the MoSPI, and various detailed reports from the CEA, the MoPNG. Emissions from biomass fuel consumption under this category are reported as NE due to non unavailability of the data.

Table 3.3: Activity data for electricity generation in TJ for 2005, 2020-2022

Fuel Consumption (TJ)	2005	2020	2021	2022
1.A.1.a.i. Electricity generation	**74,48,558**	**1,25,44,097**	**1,34,99,828**	**1,48,80,492**
Liquid fuels	1,92,814	45,279	34,824	36,576
Solid fuels	66,04,467	1,20,79,717	1,30,60,542	1,44,96,991
Gaseous fuels	6,51,277	4,19,100	4,04,463	3,46,925
Biomass	NE	NE	NE	NE

Emission Factors and Tier Level: The choice of emission factors reflects a commitment to using the most accurate data available: For non-coking coal, which is the primary fuel for power generation, India-specific sector-specific emission factors have been used. This represents a higher-tier (Tier 2/3) approach. For coking coal and lignite, country-specific emission factors are applied. For all liquid and gaseous fuels consumed in this sector, IPCC default emission factors are used (Tier 1). A country-specific oxidation factor of 0.97 is applied for all coal and lignite combustion to accurately reflect the portion of carbon that is oxidized during combustion.

Flexibility applied

Detailed information on the specific provisions and the justification for the applied flexibility is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

A quantitative uncertainty analysis for this category was conducted using the Tier 1 approach from the 2006 IPCC Guidelines. For each category and gas, a detailed analysis is conducted for the starting and latest reporting years, highlighting the main contributors to overall uncertainty.

Time-series consistency is a cornerstone of the inventory process. For the reported years, consistent methodologies and data sources have been applied to the greatest extent possible to ensure that trends reflect actual changes in emissions.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking the consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Efforts will be made to improve data collection to enable more detailed disaggregation of emissions. Future research programs will be explored to develop country-specific emission factors for various liquid and gaseous fuels used in the power sector, which will reduce reliance on IPCC default values.

3.2.4.1.2 Combined heat and power generation (1.A.1.a.ii.)

Category description

Combined Heat and Power (CHP) generation, also known as cogeneration, represents a highly efficient approach to energy production where both electricity and useful thermal energy (heat) are produced simultaneously from a single fuel source. This integrated process significantly enhances fuel efficiency compared to the separate generation of heat and power, thereby reducing overall greenhouse gas emissions. A disaggregation of captive power into CHP and heat-only plants is not currently possible due to limitations in the available data. India has used the 'IE' notation key for this category for current inventory reporting.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible. These plans include initiatives to improve the resolution of activity data, such as establishing direct data reporting mechanisms from all significant CHP facilities.

3.2.4.1.3 Heat plants (1.A.1.a.iii.)

Category description

Heat plants, often referred to as boilers or heating plants, are facilities dedicated solely to the generation of useful thermal energy (heat) for various applications, including industrial processes, district heating, and commercial or residential heating. Unlike Combined Heat and Power (CHP) plants, these facilities do not simultaneously produce electricity. India has used the 'IE' notation key for this category for current inventory reporting.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible. Future initiatives include efforts to collect more disaggregated and robust activity data, particularly from decentralized or smaller heat generation units, through targeted surveys or improved statistical collection mechanisms.

3.2.4.2. Petroleum refining (1.A.1.b.)

Category description

This covers CO_2 emissions from the combustion of refinery gas and other fuels used within petroleum refineries. The data is sourced from MoPNG statistics and PPAC information. It does not include evaporative (fugitive) emissions, which are accounted for elsewhere. Emissions from the category increased from 25,642 $GgCO_2$ equivalent in 2005 to 82,819 $GgCO_2$ equivalent in 2022, representing a 223% change over this period. In 2022, petroleum refining accounted for 3.32% of the total emissions within the Energy sector.

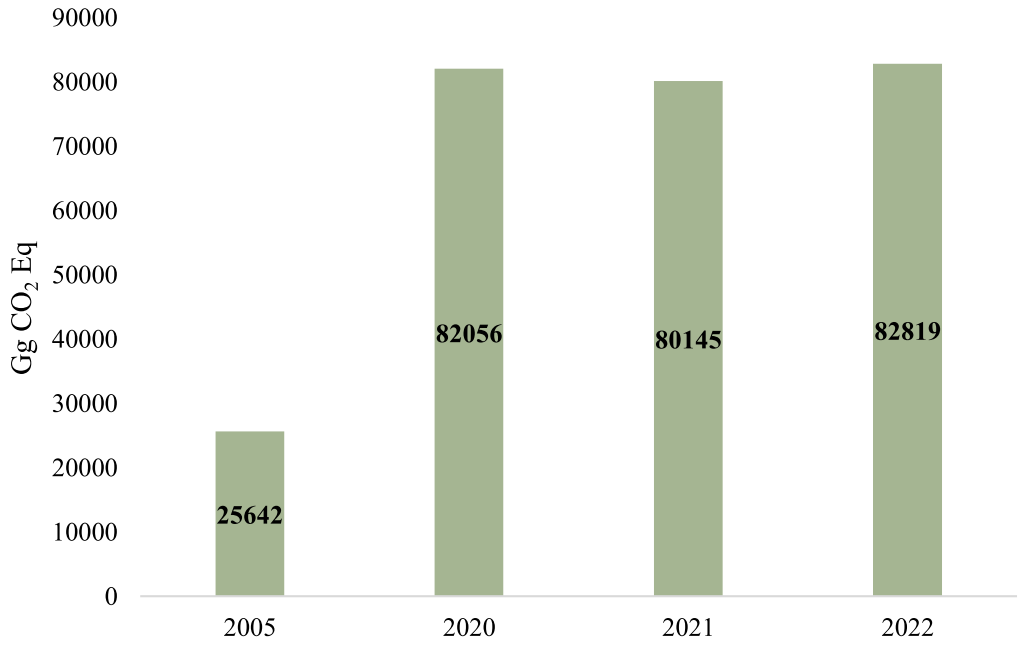


Figure 3.3: GHG emissions from Petroleum refining (1.A.1.b.) in 2005, 2020-2022

Methodological issues

India has employed a Tier 1 methodology for this category, in accordance with the 2006 IPCC Guidelines for National GHG Inventories. The Tier 1 approach is characterized by its reliance on aggregated national fuel consumption data for the petroleum refining sector and default emission factors.

Table 3.4 Activity data for Petroleum refining in TJ for 2005, 2020-2022

Consumption (TJ)	2005	2020	2021	2022
1.A.1.b. Petroleum refining	4,45,005	14,31,398	13,96,427	14,41,258
Liquid fuels	4,45,005	11,43,945	11,78,942	12,85,862
Solid fuels	NO	NO	NO	NO
Gaseous fuels	NO	2,87,453	2,17,485	1,55,396

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

A quantitative uncertainty analysis for this category was conducted using the Tier 1 approach from the 2006 IPCC Guidelines. For each category and gas, a detailed analysis is conducted for the starting and latest reporting years, highlighting the main contributors to overall uncertainty.

Time-series consistency is a cornerstone of the inventory process. For the reported years, consistent methodologies and data sources have been applied to the greatest extent possible to ensure that trends reflect actual changes in emissions.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking the consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

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

Category description and background

This category primarily covers emissions from coke-making plants that are not part of integrated steel plants. It excludes emissions from fuel combusted for coal mining or gas production, as these are considered insignificant. Emissions from "1.A.1.c. Manufacture of solid fuels and other energy industries" are reported under "1.A. Fuel combustion activities (sectoral approach)" within the Energy sector. These emissions show an increase from 1,600 $GgCO_2$ equivalent in 2005 to 10,097 $GgCO_2$ equivalent in 2022, marking a 531% change over this period. In 2022, this category constituted 0.41% of the total emissions within the Energy sector. It is noted that for "1.A.1.c.i. Manufacture of solid fuels," the emissions mirror the parent category, indicating that this sub-category is the primary, if not sole, contributor to emissions under "1.A.1.c.". Sub-categories like "1.A.1.c.ii. Oil and gas extraction" and "1.A.1.c.iii. Other energy industries" show included elsewhere (liquid and gaseous fuels) for all reported years.

3.2.4.3.1 Manufacture of solid fuels (1.A.1.c.i.)

Category description

This category primarily encompasses activities related to the transformation of primary solid fuels into secondary solid fuels or other energy products. This typically includes processes such as briquetting of coal or peat, coke production, and other solid fuel processing activities where fuel combustion is integral to the manufacturing process. Emissions from this category arise predominantly from the combustion of fuels to provide heat and power for these industrial operations, contributing to the national greenhouse gas inventory under IPCC Source Category 1.A.1.c.i. This section details the methodology, data requirements, and best practices for estimating these emissions, with a specific focus on the Tier 2 approach utilized by India.

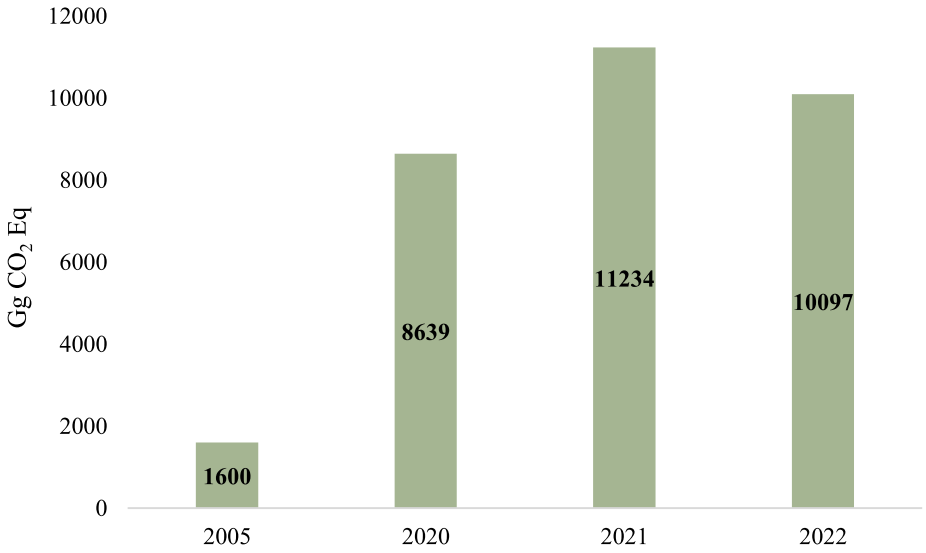


Figure 3.4: GHG emissions from Manufacture of solid fuels (1.A.1.c.i.) in 2005, 2020-2022

Methodological issues

India has employed a Tier 2 methodology for CO_2, CH_4, and N_2O for this category, in accordance with the 2006 IPCC Guidelines. This approach leverages country-specific data and factors, offering a more refined estimation than Tier 1. The Tier 2 approach for this category is chosen because it allows for the use of more specific emission factors that reflect national fuel characteristics and industrial practices, leading to more accurate emission estimates.

Table 3.5 Activity data for Manufacture of Solid Fuels in TJ for 2005, 2020-2022

Consumption (TJ)	2005	2020	2021	2022
1.A.1.c.i. Manufacture of solid fuels	1,04,427	6,31,859	7,03,961	6,99,385
Liquid fuels	NO	NO	NO	NO
Solid fuels	1,04,427	6,31,859	7,03,961	6,99,385
Gaseous fuels	NO	NO	NO	NO

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 (“Information on Flexibility”) of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

A quantitative uncertainty analysis for this category was conducted using the Tier 1 approach from the 2006 IPCC Guidelines. For each category and gas, a detailed analysis is conducted for the starting and latest reporting years, highlighting the main contributors to overall uncertainty.

Time-series consistency is a cornerstone of the inventory process. For the reported years, consistent methodologies and data sources have been applied to the greatest extent possible to ensure that trends reflect actual changes in emissions.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking the consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

3.2.4.3.2 Oil and gas extraction (1.A.1.c.ii.)

Category description

This category encompasses GHG emissionsarising from fossil fuel extraction activities, specifically the upstream operations of crude oil and natural gas production within India. It includes emissions from both onshore and offshore fields, operated by public sector undertakings and private/joint venture entities. The scope covers exploration, drilling, production, and initial processing stages prior to transmission or refining. India has used the 'IE' notation key for this category for current inventory reporting, as Oil and gas extraction cannot be disaggregated from the Other Manufacturing category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

3.2.4.3.3 Other energy industries (1.A.1.c.iii.)

Category description

This category captures GHG emissions from energy-related activities not classified under electricity generation, petroleum refining, or oil and gas extraction. It includes emissions from the manufacture of solid fuels, charcoal production, biomass-based energy systems, and other transformation processes such as coal gasification, coke production, and liquefied petroleum gas (LPG) bottling. India has used 'IE' notation key for this category for current inventory reporting as Other energy industries cannot be disaggregated from Other Manufacturing.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

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

Category description and background

This category includes emissions from the combustion of fuels across a wide range of industries critical to India's economy. Similar to the Energy Industries category, activity data on fuel consumption is sourced from official publications from the MoPNG, Ministry of Coal, MoSPI, and PPAC. A Tier 2 approach is applied for solid fuels used in most major manufacturing industries, utilizing country-specific emission factors. For example, the non-coking coal consumed in the iron and steel industry uses the emission factor developed specifically for the electricity sector. For liquid and gaseous fuels, a Tier 1 approach using IPCC default values is employed.

Emissions from "1.A.2. Manufacturing Industries and Construction" within the Energy sector showed increase from 227,384 $GgCO_2$ equivalent in 2005 to 435,670 $GgCO_2$ equivalent in 2022, representing a 92 % change. In 2022, this category accounted for 17.48% of the total emissions within the Energy sector.

Key sub-sectors contributing to these emissions include:

- **1.A.2.a. Iron and steel:** GHG emissionsrose from 91,070 $GgCO_2$ equivalent in 2005 to 161,050 $GgCO_2$ equivalent in 2022, a 77% increase.
- **1.A.2.f. Non-metallic minerals:** GHG emissionsincreased from 38,795 $GgCO_2$ equivalent in 2005 to 52,106 $GgCO_2$ equivalent in 2022, a 34% increase.
- **1.A.2.g. Other (non-specified industry):** This sub-category saw a substantial increase from 69,330 $GgCO_2$ equivalent in 2005 to 182,859 $GgCO_2$ equivalent in 2022, representing a 164% change, and making up 7% of the sector's share in 2022.

Conversely, some sub-categories experienced a decrease in emissions:

- **1.A.2.c. Chemicals:** GHG emissionsdecreased by 66% from 14,945 $GgCO_2$ equivalent in 2005 to 5,034 $GgCO_2$ equivalent in 2022.
- **1.A.2.d. Pulp, paper, and print:** GHG emissionsdecreased by 36% from 5,419 $GgCO_2$ equivalent in 2005 to 3,479 $GgCO_2$ equivalent in 2022.
- **1.A.2.g.vi. Textile and leather:** GHG emissionsdecreased by 10% from 2,533 $GgCO_2$ equivalent in 2005 to 2,286 $GgCO_2$ equivalent in 2022.

Several sub-categories, including "1.A.2.e. Food processing, beverages and tobacco," "1.A.2.g.ii. Manufacturing of transport equipment," and "1.A.2.g.iv. Wood and wood products," reported not occurring (NO) and included elsewhere (IE) across all years. The table shows summary of GHG emissionsfor 1.A.2. for 2005 and 2020 to 2022.

Table 3.6: Summary of India's GHG emissionsfor 1.A.2. in $GgCO_2e$

Source/Sink Categories	Total Gg CO_2 Equivalent			
	2005	2020	2021	2022
1. Energy	**1248691**	**2128202**	**2290160**	**2492069**
1.A. Fuel combustion activities (sectoral approach)	**1217819**	**2093143**	**2253088**	**2452172**
1.A.2. Manufacturing industries and construction	227384	388744	434597	435670
1.A.2.a. Iron and steel	91070	151204	157596	161050
1.A.2.b. Non-ferrous metals	2509	2319	5451	4101
1.A.2.c. Chemicals	14945	6331	5622	5034
1.A.2.d. Pulp, paper, and print	5419	2571	3924	3479
1.A.2.e. Food processing, beverages, and tobacco	NO, IE	NO, IE	NO, IE	NO, IE
1.A.2.f. Non-metallic minerals	38795	50329	51307	52106
1.A.2.g. Other	74645	175989	210697	209900
1.A.2.g.i. Manufacturing of machinery	683	3104	3060	1449

Source/Sink Categories	Total Gg CO_2 Equivalent			
	2005	2020	2021	2022
1.A.2.g.ii. Manufacturing of transport equipment	NO, IE	NO, IE	NO, IE	NO, IE
1.A.2.g.iii. Mining (excluding fuels) and quarrying	2099	5483	5414	4128
1.A.2.g.iv. Wood and wood products	NO, IE	NO, IE	NO, IE	NO, IE
1.A.2.g.v. Construction	NO	19296	19773	19178
1.A.2.g.vi. Textile and leather	2533	635	2041	2286
1.A.2.g.vii. Off-road vehicles and other machinery	NO, IE	NO, IE	NO, IE	NO, IE
1.A.2.g.viii. Other (non-specified industry)	69330	147473	180409	182859

3.2.5.1. Iron and Steel (1.A.2.a)

Category description

This is a major key category that includes integrated steel plants and sponge iron industries. The estimation accounts for various fuel types, including indigenous and imported coking coal, non-coking coal (for boilers and sponge iron), and coke oven coke. The Iron and Steel industry is a cornerstone of industrial development, involving complex processes that convert iron ore into various forms of steel. This sector is characterized by significant energy consumption, primarily through the combustion of fossil fuels and the use of process-related reductants, leading to substantial GHG emissions. Activities covered under this category typically include blast furnaces, basic oxygen furnaces, electric arc furnaces, and other associated processes like rolling and finishing, along with the Sponge Iron industry, which has been specifically included in this group for India's inventory. This section details the methodology, data requirements, and best practices for estimating emissions from the Iron and Steel sector, incorporating India's unique approach. Emissions rose from 91,070 GgCO_2 equivalent in 2005 to 161,050 GgCO_2 equivalent in 2022, a 77% increase.

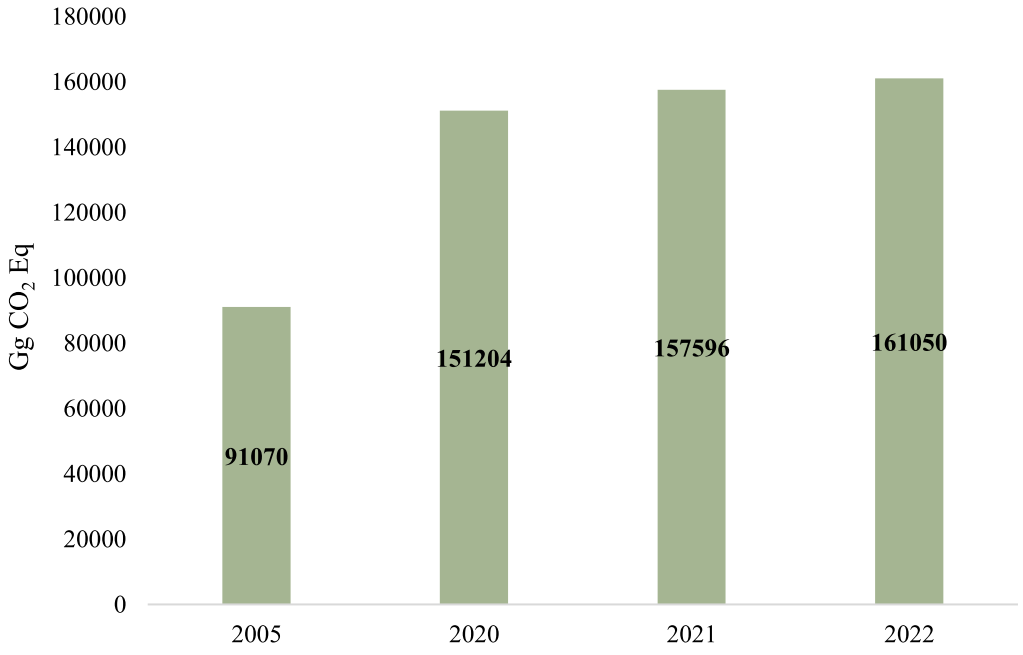


Figure 3.5: GHG emissions from Iron and steel (1.A.2.a.) in 2005, 2020-2022

Methodological issues

Emissions from the Iron and Steel sector arise from both fuel combustion to provide heat and power for operations and from process emissions. This section focuses on the fuel combustion emissions. The estimation methodology adheres to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

For India's inventory, the methodology for the Iron and Steel sector is detailed as follows, reflecting specific national practices and data considerations:

Sponge Iron Industry Inclusion: The Sponge Iron industry has also been explicitly included in this group, ensuring a comprehensive capture of emissions from iron production processes.

Coal Consumption Data: Challenges in obtaining coal consumption data directly from consumer end sources have led to the adoption of estimation methods.

Non-Coking Coal: The accounting of non-coking coal in the Iron and Steel sector is comprehensive, encompassing boiler coal consumption, coal for the sponge iron industry, and direct feed coal to the Iron & Steel sector. Due to this comprehensive accounting, boiler coal in iron & steel has explicitly not been included in the 'Electricity sector' when considering captive power plants, avoiding double-counting. Furthermore, Middling of both coking and non-coking coal washeries and CDI (Coal Dust Injection) coal have been accounted in detail under the head of non-coking coal consumption. For estimating emissions from non-coking coal, the electricity-sector specific emission factors were used, indicating a cross-sectoral application of robust factors.

Coking Coal: Coking coal consumption is meticulously aggregated, including indigenous and imported coking coals for integrated steel plants, coking coal consumption in the sponge iron industry, and coking coal used as direct feed for metallurgical purposes. This holistic approach ensures all coking coal inputs are captured. Washed coal delivery and imports have been accounted for in detail.

Coke Oven Coke: Coke oven coke consumption has been estimated rationally, and appropriate Net Calorific Values (NCV) and Carbon Emission Factors (CEF) were used, indicating a reliance on national or specific industry data for these parameters.

Table 3.7: Activity data for Iron and steel in TJ for 2005, 2020-2022

Consumption (TJ)	2005	2020	2021	2022
1.A.2.a. Iron and steel	9,87,671	16,31,678	16,95,024	17,29,841
Liquid fuels	47,921	47,879	49,520	46,205
Solid fuels	9,39,750	15,60,926	16,39,572	16,83,599
Gaseous fuels	NO	22,873	5,932	37

Flexibility applied

India's approach, particularly the inclusion of the sponge iron industry and the need for estimations for certain coal consumption data, reflects a pragmatic application of flexibility. While aiming for comprehensive coverage, the adoption of estimation methods for coal consumption when consumer-end data is unavailable highlights a capacity constraint that justifies flexibility, especially for the years 2005, 2020 to 2022. This flexibility ensures that the inventory is as complete as possible given the existing data governance frameworks and technical constraints in this complex industrial sector.

Uncertainty assessment and time-series consistency

A comprehensive uncertainty assessment for emissions from the Iron and Steel sector rigorously quantifies uncertainties arising from activity data (especially for estimated coal consumption), the applicability of emission factors (including the electricity-sector specific factors for non-coking coal), and the representativeness of NCV and CEF for coke oven coke. Particular attention is given to understanding the impact of data estimation methods on overall uncertainty.

To ensure robust time-series consistency, the detailed methodology outlined for India's Iron and Steel sector, including the specific accounting for various coal types, coke, and the sponge iron industry, is applied consistently across all historical years.

QA/QC and verification

The QA and QC procedures for emissions from this category are highly stringent, reflecting the complexity and significance of this industry. Level 1 QC activities include meticulous checks on all fuel consumption data, including the estimated coal consumption, ensuring consistency with national industrial production statistics. The application of electricity-sector specific emission factors for non-coking coal and the derived NCV/CEF

for coke oven coke are meticulously verified, along with the accuracy of CO_2, CH_4, and N_2O calculations. Level 2 QC involves independent expert review of the specific methodologies employed, particularly for the inclusion of the sponge iron industry and the estimation approaches, as well as the completeness of emission source coverage within the sector.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

3.2.5.2. Non-ferrous metals (1.A.2.b.)

Category description

The Non-ferrous metals sector encompasses the production of metals like aluminum, copper, zinc, lead, and others that do not contain iron in significant amounts. These industries are highly energy-intensive, primarily relying on the combustion of fossil fuels for various processes such as smelting, refining, and casting. Emissions from this category are a significant component of the national greenhouse gas inventory. This section details the methodology, data requirements, and best practices for estimating emissions from the non-ferrous metals sector. In the India's GHG emission inventory, this category primarily includes emissions from the aluminium industry. The emissions from this category fluctuated, starting at 2,509 $GgCO_2$ equivalent in 2005, decreasing to 2,319 $GgCO_2$ equivalent in 2020, then rising to 5,452 $GgCO_2$ equivalent in 2021, and finally settling at 4,101 $GgCO_2$ equivalent in 2022. Overall, there was a 63.42% increase in emissions from 2005 to 2022.

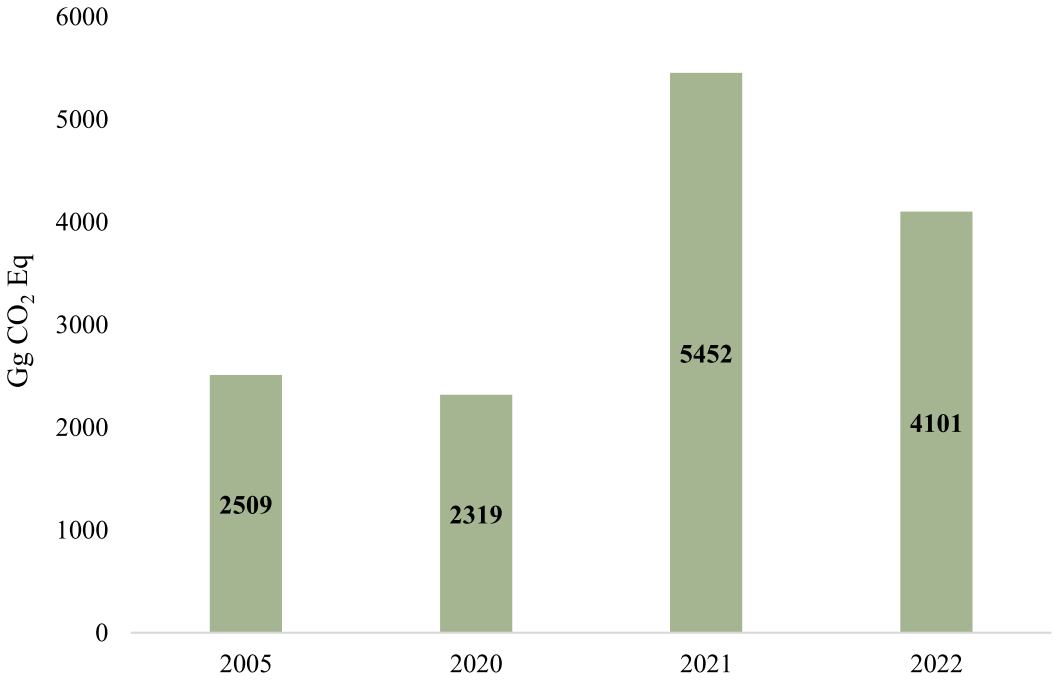


Figure 3.6: GHG emissions from Non-ferrous metals (1.A.2.b.) in 2005, 2020-2022

Methodological issues

Emissions from the non-ferrous metals industry primarily arise from the combustion of fuels (e.g., natural gas, coal, fuel oil, electricity from fossil fuels if not accounted for elsewhere) to generate heat and power for a diverse range of operations. It is important to distinguish these fuel combustion emissions from process emissions (e.g., PFCs from aluminum smelting, SF_6 from magnesium production), which are typically reported under the Industrial Processes and Product Use (IPPU) sector. This section focuses solely on fuel combustion emissions.

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

A comprehensive uncertainty assessment for emissions from the Non-Ferrous Metals sector identifies and quantifies uncertainties associated with activity data (e.g., accuracy of fuel consumption by specific metal type), the representativeness of emission factors (particularly for non-CO_2 gases, which can vary with technology), and the completeness of source coverage.

QA/QC and verification

The QA and QC procedures for emissions from the Non-Ferrous Metals (1.A.2.b.) sector are rigorously implemented. Level 1 QC activities include meticulous checks on the consistency and completeness of fuel consumption data from various non-ferrous metal industries. The correct application of emission factors and the accuracy of CO_2, CH_4, and N_2O calculations are thoroughly verified. Level 2 QC involves independent expert review of the methodologies applied, assessing the representativeness of national data or selected default factors, and evaluating the completeness of emission source coverage across the diverse non-ferrous metal production processes.

Verification measures for this category often include cross-referencing fuel consumption and production data with national industrial statistics and major non-ferrous metal industry associations.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

3.2.5.3. Chemicals (1.A.2.c.)

Category description

This includes emissions from the broader chemical industry, including fertilizer production. Emissions decreased from 14,945 $GgCO_2$ equivalent in 2005 to 5,034 $GgCO_2$ equivalent in 2022. This represents a significant decrease of 66% over this period. In 2022, emissions from the Chemicals sub-sector accounted for 0.20% of the total emissions in the Energy sector.

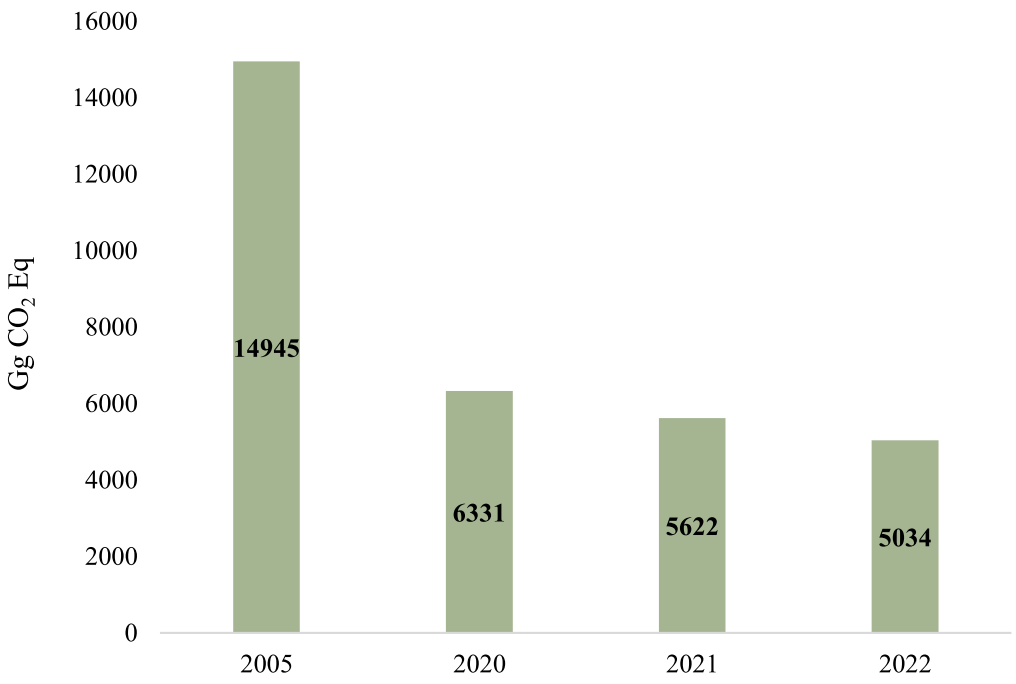


Figure 3.7 GHG emissions from Chemicals (1.A.2.c.) in 2005, 2020-2022

Methodological issues

Emissions from the chemicals industry primarily arise from the combustion of fuels (e.g., natural gas, naphtha, fuel oil, coal, process off-gases, waste fuels) in boilers, furnaces, reformers, and other combustion units. For this inventory, a Tier 2 for CO_2 and Tier 1 for CH_4 and N_2O approach is applied, or a combination of tiers depending on the sub-category (e.g., Tier 2 for major bulk chemicals like fertilizers, Tier 1 for more diverse, smaller chemical manufacturers).

Table 3.8: Activity data for chemicals in TJ for 2005, 2020-2022

Consumption (TJ)	2005	2020	2021	2022
1.A.2.c. Chemicals	**1,75,287**	**73,269**	**65,612**	**58,164**
Liquid fuels	1,04,097	31,081	31,058	28,747
Solid fuels	71,191	42,187	34,554	29,417

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

A comprehensive uncertainty assessment for emissions from the Chemicals sector rigorously identifies and quantifies uncertainties associated with activity data (e.g., accuracy of fuel consumption by specific chemical process, especially for internally generated fuels like process off-gases), the representativeness of emission factors (particularly for non-CO_2 gases, which can vary significantly with combustion conditions and fuel types), and the completeness of source coverage across the diverse industry. Significant efforts are made to understand where the largest uncertainties lie, guiding future improvement efforts.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking the consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process

but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

3.2.5.4. 3.2.5.4 Pulp, paper, and print (1.A.2.d.)

Category description

The Pulp, Paper, and Print sector encompasses the manufacturing processes involved in producing pulp from wood or other fibers, converting pulp into various paper products, and the subsequent printing activities. These industries are typically energy-intensive, primarily relying on the combustion of fossil fuels and, increasingly, biomass and recovered wastes (like black liquor in pulp mills) to generate heat, steam, and electricity for their operations. This reports emissions from the paper and pulp industries only. Emissions from the category decreased from 5,419 $GgCO_2$ equivalent in 2005 to 3,479 $GgCO_2$ equivalent in 2022, representing a 36% change. In 2022, this sub-category accounted for 0.14% of the total emissions within the Energy sector.

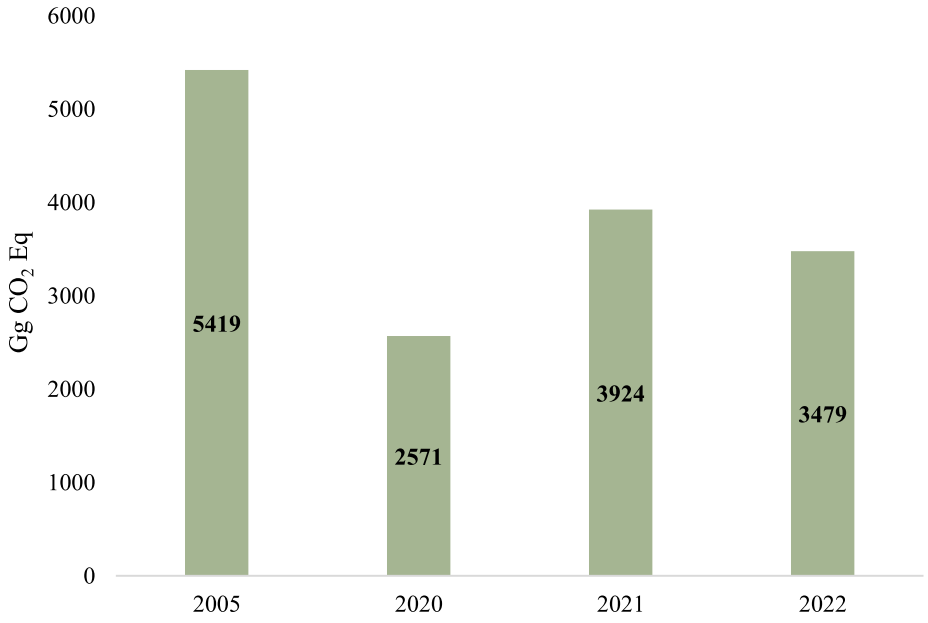


Figure 3.8: GHG emissions from Pulp, paper and print (1.A.2.d.) in 2005, 2020-2022

Methodological issues

For this inventory, a Tier 2 for CO_2 and Tier 1 for CH_4 and N_2O is applied, or a combination of tiers depending on the sub-category (e.g., Tier 2 for major integrated pulp and paper mills, Tier 1 for smaller print operations).

Table 3.9: Activity data for Pulp, paper and print in TJ for 2005, 2020-2022

Consumption (TJ)	2005	2020	2021	2022
1.A.2.d. Pulp, paper and print				
Solid fuels	55,923	25,963	38,780	34,709

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

A quantitative uncertainty analysis for this category was conducted using the Tier 1 approach from the 2006 IPCC Guidelines. For each category and gas, a detailed analysis is conducted for the starting and latest reporting years, highlighting the main contributors to overall uncertainty.

Time-series consistency is a cornerstone of the inventory process. For the reported years, consistent methodologies and data sources have been applied to the greatest extent possible to ensure that trends reflect actual changes in emissions.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

3.2.5.5. Food processing, beverages, and tobacco (1.A.2.e.)

Category description

The Food Processing, Beverages, and Tobacco category encompasses a wide range of industrial activities involved in transforming agricultural products into food items, producing alcoholic and non-alcoholic beverages, and manufacturing tobacco products. These industries primarily rely on the combustion of various fuels to generate heat, steam, and power for processes such as cooking, drying, distillation, pasteurization, and refrigeration. India has used the 'IE' notation key for this category for current inventory reporting. The data for consumption of fuels under this category have been reported under 1.A.2.g.viii (Other) due to the unavailability of disaggregated data.

Planned Improvements

Planned improvements for estimating emissions from this category are targeted at continuously enhancing the accuracy, granularity, and methodological sophistication of this category. Future initiatives include focused efforts to improve the collection of highly disaggregated activity data, ideally distinguishing fuel consumption by specific sub-industries (e.g., sugar, dairy, brewing) and separating fossil from biogenic fuel use more precisely.

3.2.5.6. Non-metallic minerals (1.A.2.f.)

Category description

This category is dominated by emissions from the cement and brick manufacturing industries. Pet coke consumption in cement plants is also accounted for. Emissions from this category saw an increase in emissions from 38,795 $GgCO_2$ equivalent in 2005 to 52,106 $GgCO_2$ equivalent in 2022. This represents a 34% change over the period. In 2022, the category contributed 2% to the total emissions within the Energy sector.

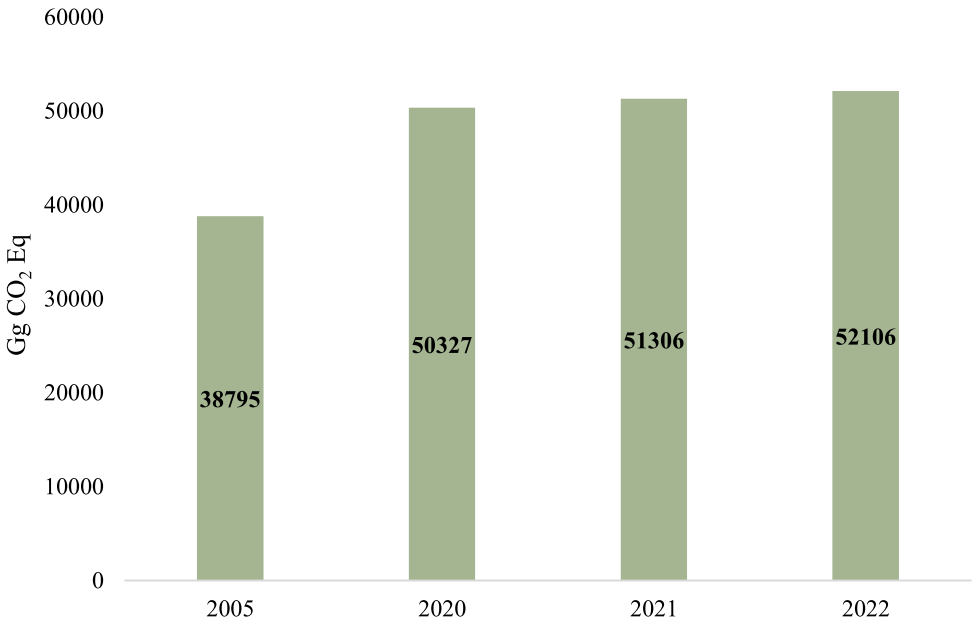


Figure 3.9: GHG emissions from Non-metallic minerals (1.A.2.f.) in 2005, 2020-2022

Methodological issues

Emissions from the non-metallic minerals industry primarily arise from the combustion of fuels (e.g., coal, petcoke, natural gas, fuel oil, waste-derived fuels like tires or municipal solid waste) to generate the high temperatures required for processes like clinker production, glass melting, and ceramic firing. Tier 1 approach uses aggregated national fuel consumption data for the entire non-metallic minerals sector and applies default IPCC emission factors for each fuel type.

Table 3.10 Activity data for Non-metallic minerals in TJ for 2005, 2020-2022

Consumption (TJ)	2005	2020	2021	2022
1.A.2.f. Non-metallic minerals	**4,00,823**	**5,18,862**	**5,27,782**	**5,35,742**
Liquid fuels	72,464	3,60,823	3,60,105	3,55,943
Solid fuels	3,28,359	1,58,039	1,67,678	1,79,799

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 (“Information on Flexibility”) of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

A comprehensive uncertainty assessment for emissions from the Non-Metallic Minerals sector rigorously identifies and quantifies uncertainties associated with activity data (e.g., accurate quantification of diverse fuels, including alternative fuels whose composition can vary), the representativeness of emission factors (particularly for non-CO_2 gases, which are highly sensitive to combustion conditions in kilns and furnaces), and the completeness of source coverage across this broad industry. Specific attention is paid to the challenging aspect of characterizing the fossil and biogenic carbon content of waste-derived fuels and their contribution to overall uncertainty.

QA/QC and verification

The QA and QC procedures for emissions from the Non-Metallic Minerals (1.A.2.f.) category are meticulously implemented to ensure accuracy and reliability. Level 1 QC activities include thorough checks on the consistency and completeness of fuel consumption data across various sub-industries, with particular attention to the proper accounting and characterization of alternative fuels (e.g., derived from wastes). The application of emission

factors and the accuracy of CO_2, CH_4, and N_2O calculations are thoroughly verified. Level 2 QC involves independent expert review of the methodologies applied, assessing the representativeness of national data or selected default factors, and evaluating the completeness of emission source coverage across the diverse processes in this sector.

Verification measures for this category often include cross-referencing fuel consumption and production data with national industrial statistics, industry associations, and major manufacturers.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

3.2.5.7. Other (1.A.2.g.)

Category description and background

This includes several other industries such as textiles and leather, machinery manufacturing, and a "Non-specific Industry" category that captures fuel consumption not attributable to other specific sectors. This category shows a notable increase in emissions. Total $GgCO_2$ equivalent emissions for this category rose from 74,645 in 2005 to 209,900 in 2022, representing 181% increase. In 2022, this category constituted 8.42% of the total emissions within the Energy sector.

3.2.5.7.1 Manufacturing of machinery (1.A.2.g.i.)

Category description

This category includes the production of a wide array of machinery for various industries, including industrial machinery, agricultural machinery, construction equipment, and other specialized machinery. While not typically as energy-intensive as primary metals or chemical production, these manufacturing processes still require significant energy for operations such as machining, assembly, welding, heat treatment, painting, and testing. Emissions from this category arise primarily from the combustion of fuels to generate heat and power for these activities. In 2022, the category had 1449 $GgCO_2$ equivalent of emissions, which is an increase of 112% from 2005.

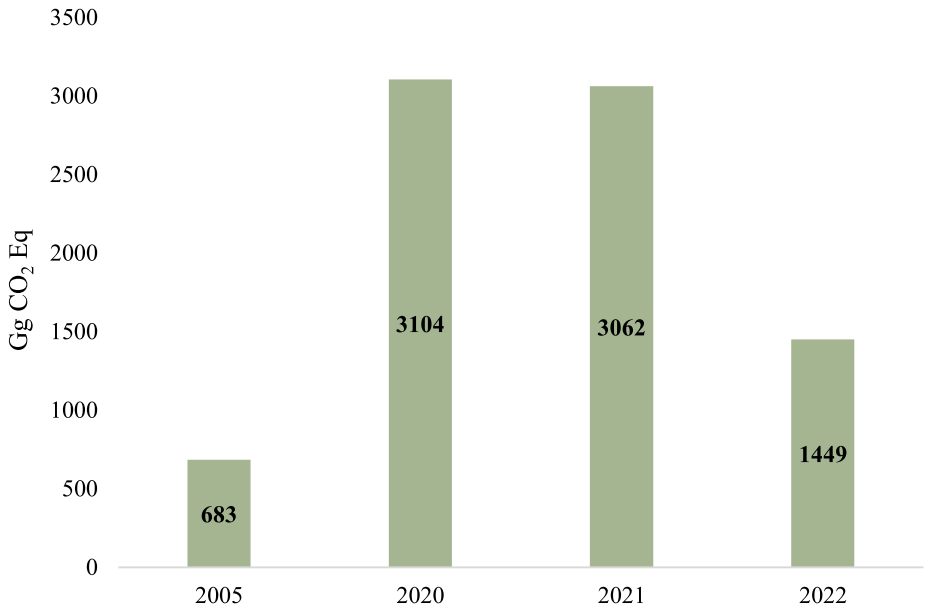


Figure 3.10: GHG emissions from Manufacturing of machinery (1.A.2.g.i.) in 2005, 2020-2022

Methodological issues

Emissions from the manufacturing of machinery primarily arise from the combustion of various fuels (e.g., electricity from the grid, natural gas, fuel oil, LPG, diesel for on-site power or specific processes) in boilers, furnaces, and other combustion equipment. This approach uses aggregated national fuel consumption data for the entire machinery manufacturing sub-sector and applies default IPCC emission factors.

Table 3.11: Activity data for Manufacturing of machinery in TJ for 2005, 2020-2022

Consumption (TJ)	2005	2020	2021	2022
1.A.2.g.i. Manufacturing of machinery				
Liquid fuels	9,214	41,785	41,165	19,473

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 (“Information on Flexibility”) of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

A comprehensive uncertainty assessment for emissions from the Manufacturing of Machinery sub-sector identifies and quantifies uncertainties associated with activity data (e.g., accurate quantification of fuel consumption from a highly diverse and sometimes fragmented industry). The representativeness of emission factors (particularly for non-CO_2 gases, which can vary with fuel type and combustion technology) and the completeness of source coverage across this broad sub-sector are also key considerations. To ensure robust time-series consistency, the chosen methodologies and emission factors for the Manufacturing of Machinery sub-sector are applied uniformly across all reported years.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India’s first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

3.2.5.7.2 Manufacturing of transport equipment (1.A.2.g.ii.)

Category description

This category includes the production of a wide range of vehicles and equipment for transportation, such as automobiles, trucks, buses, motorcycles, railway rolling stock, aircraft, and ships. These manufacturing processes require energy for activities like metal forming, welding, painting, assembly, engine testing, and other specialized operations. India has used ‘IE’ notation key for this category for current inventory reporting as Manufacturing of transport equipment cannot be disaggregated from Other Manufacturing. Therefore, the data for consumption of fuels under this category have been reported under 1.A.2.g.viii (Other) due to the unavailability of disaggregated data.

Planned Improvements

Planned improvements for estimating emissions from this category are targeted at continuously enhancing the accuracy, granularity, and methodological sophistication of this category. Future initiatives include focused efforts to improve the collection of more disaggregated activity data, ideally distinguishing fuel consumption by specific vehicle types (e.g., automobiles, aircraft, ships) or key manufacturing processes.

3.2.5.7.3 Mining (excluding fuels) and quarrying (1.A.2.g.iii.)

Category description

This category encompasses the extraction of a wide range of non-fuel minerals (e.g., metallic ores, industrial minerals like limestone, gypsum, phosphates, and construction minerals like sand, gravel, and stone). These operations are energy-intensive, require energy for excavation, drilling, blasting, crushing, grinding, material handling, and transportation within the mine/quarry site. Emissions from this category arise primarily from the combustion of fuels to power machinery and equipment used in these activities. This section details the methodology, data requirements, and best practices for estimating fuel combustion emissions from mining (excluding fuels) and quarrying. Emissions from this source increased from 2,099 $GgCO_2$ equivalent in 2005 to 4,128 $GgCO_2$ equivalent in 2022, representing a 97% change. In 2022, this subcategory accounted for 0.17% of total emissions in the Energy sector.

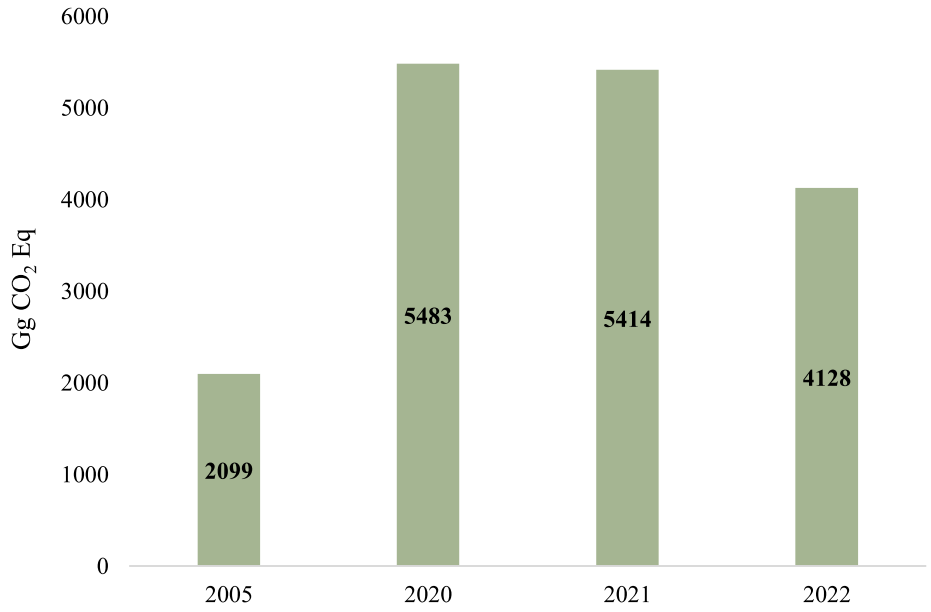


Figure 3.11: GHG emissions from Mining (excluding fuels) and quarrying (1.A.2.g.iii.) in 2005, 2020-2022

Methodological issues

Emissions from mining (excluding fuels) and quarrying primarily arise from the combustion of various fuels (e.g., diesel for heavy machinery, electricity from grid or on-site generation, natural gas, LPG) in mobile equipment (e.g., excavators, haul trucks, drills), stationary equipment (e.g., crushers, conveyors), and for heating and lighting facilities. Given the diverse nature of operations —from large-scale open-pit mines to numerous small quarries —the choice of methodology tier often depends on the availability of disaggregated data and the significance of emissions.

Table 3.12: Activity data for Mining (excluding fuels) and quarrying in TJ for 2005, 2020-2022

Consumption (TJ)	2005	2020	2021	2022
1.A.2.g.iii. Mining (excluding fuels) and quarrying				
Liquid fuels	28,240	73,632	72,673	55,395

Flexibility applied

g its time-series reporting in future BTRs as national data governance frameworks mature and institutional capacities are strengthened in alignment with BTR requirements

Uncertainty assessment and time-series consistency

A comprehensive uncertainty assessment for emissions from the Mining (excluding fuels) and Quarrying sector identifies and quantifies uncertainties associated with activity data (e.g., accurate quantification of fuel consumption from a highly diverse and sometimes fragmented industry, especially for off-road mobile equipment). The representativeness of emission factors (particularly for non-CO_2 gases from heavy-duty diesel engines) and the completeness of source coverage across this broad sector are also key considerations. To ensure robust time-series consistency, the chosen methodologies and emission factors for the Mining (excluding fuels) and Quarrying sector are applied uniformly across all reported years.

QA/QC and verification

The QA and QC procedures for emissions from this category are meticulously implemented to ensure accuracy and reliability. Level 1 QC activities include thorough checks on the consistency and completeness of fuel consumption data across various sub-segments, including diesel for mobile sources. The application of emission factors and the accuracy of CO_2, CH_4, and N_2O calculations are thoroughly verified. Level 2 QC involves independent expert review of the methodologies applied, assessing the representativeness of national data or selected default factors, and evaluating the completeness of emission source coverage across the diverse processes in this sector. Verification measures for this category often include cross-referencing aggregated fuel consumption data with national industrial statistics or production data for key non-fuel minerals.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

3.2.5.7.4 Wood and wood products (1.A.2.g.iv.)

Category description

This category covers GHG emissions from industrial activities related to wood processing and product manufacturing, excluding emissions from forestry operations and biomass combustion for energy. It includes emissions from sawmills, plywood and veneer production, particleboard and fibreboard manufacturing, furniture and joinery units, and paper and pulp mills where wood is used as a raw material. India has used 'IE' notation key for this category for current inventory reporting as Wood and wood products cannot be disaggregated from Other Manufacturing. The data for consumption of fuels under this category have been reported under 1.A.2.g.viii (Other) due to the unavailability of disaggregated data.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

3.2.5.7.5 Construction (1.A.2.g.v.)

Category description

This category encompasses a broad range of activities related to the erection, maintenance, and repair of buildings, infrastructure (roads, bridges, railways), and other construction projects. This category is characterized by the extensive use of heavy machinery, equipment, and on-site processes that require significant energy. Emissions

from this category (1.A.2.g.v.) arise primarily from the combustion of fuels to power construction machinery, on-site generators, and for various heating and drying processes. This section details the methodology, data requirements, and best practices for estimating fuel combustion emissions from the construction sector. India is reporting emissions from the construction sector as a separate category, with data sourced from MoSPI's Energy Statistics. For the year 2005, the data for consumption of fuels under this category have been reported under 1.A.2.g.viii (Other) due to the unavailability of disaggregated data.

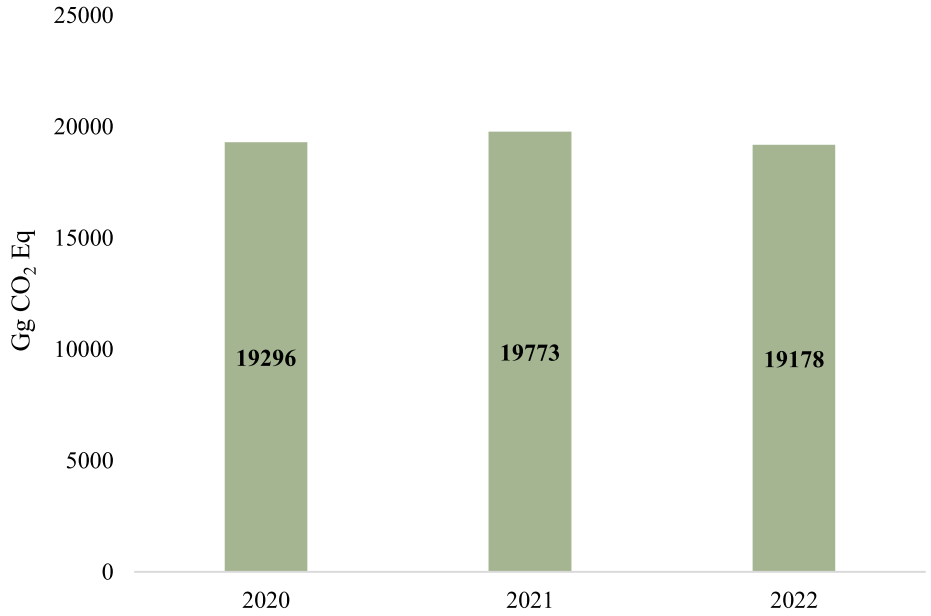


Figure 3.12: GHG emissions from Construction (1.A.2.g.v.) in 2020-2022

Methodological issues

Emissions from the construction sector primarily arise from the combustion of various fuels (e.g., diesel for heavy-duty off-road vehicles, electricity from grid or on-site generation, LPG, heating oil) in:

- Mobile combustion sources: Excavators, bulldozers, loaders, cranes, concrete mixers, pavers, drilling rigs, and other construction vehicles.
- Stationary combustion sources (on-site): Generators for power, heaters for curing concrete or drying materials, asphalt plants (if integrated into construction site operations and not already covered under manufacturing).

Table 3.13: Activity data for Construction in TJ for 2005, 2020-2022

Consumption (TJ)	2005	2020	2021	2022
1.A.2.g.v. Construction	**IE**	**2,10,554**	**2,12,596**	**2,02,096**
Liquid fuels	IE	50,726	43,126	21,632
Solid fuels	IE	1,59,828	1,69,470	1,80,464

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

A comprehensive uncertainty assessment for emissions from the Construction sector identifies and quantifies uncertainties associated with activity data (e.g., accurate quantification of fuel consumption from a highly dispersed and dynamic sector, especially for off-road mobile equipment). The representativeness of emission factors (particularly for non-CO_2 gases from a diverse fleet of construction machinery) and the completeness of source coverage across numerous construction sites are key considerations. To ensure robust time-series

consistency, the chosen methodologies and emission factors for the Construction sector are applied uniformly across all reported years.

QA/QC and verification

The QA and QC procedures for emissions from this category are meticulously implemented to ensure accuracy and reliability. Level 1 QC activities include thorough checks on the consistency and completeness of fuel consumption data, with particular attention to distinguishing between on-road and off-road fuel use. The application of emission factors and the accuracy of CO_2, CH_4, and N_2O calculations are thoroughly verified. Level 2 QC involves independent expert review of the methodologies applied, assessing the representativeness of national data or selected default factors, and evaluating the completeness of emission source coverage across the diverse activities in this sector.

Verification measures for this category often include cross-referencing aggregated fuel consumption data with national energy statistics, economic indicators for the construction sector, and, where possible, data from major construction projects or equipment rental companies.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible. Capacity-building for inventory compilers will prioritize specialized training in off-road mobile combustion emission estimation and data collection techniques relevant to the construction sector, ensuring continuous improvement and alignment with the highest standards of the ETF.

3.2.5.7.6 Textile and leather (1.A.2.g.vi.)

Category description

This category encompasses a wide range of industrial activities involved in the processing of fibers into yarns and fabrics, the manufacturing of clothing and other textile products, and the tanning and finishing of leather to produce various leather goods. These industries are typically energy-intensive, requiring significant energy for processes such as spinning, weaving, dyeing, finishing, drying, and tanning. Emissions from this category arise primarily from the combustion of fuels to generate heat, steam, and power for these activities. These emissions decreased from 2,533 $GgCO_2$ equivalent in 2005 to 2,286 $GgCO_2$ equivalent in 2022, representing a 10% decrease. In 2022, this sub-category accounted for 0.09% of the total emissions within the Energy sector.

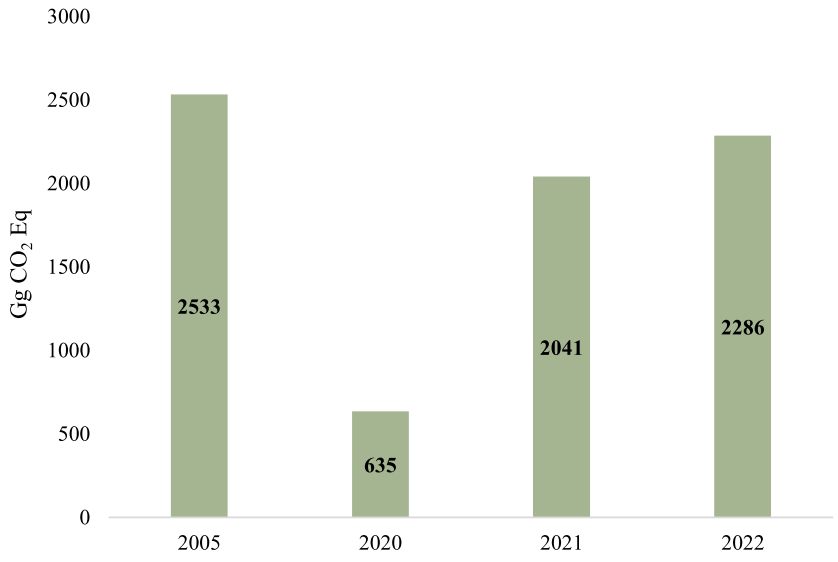


Figure 3.13: GHG emissions from Textile and leather (1.A.2.g.vi.) in 2005, 2020-2022

Methodological issues

Emissions from the textile and leather industries primarily arise from the combustion of various fuels (e.g., coal, natural gas, fuel oil, LPG, biomass, electricity from grid) in boilers for steam generation (critical for dyeing and finishing), ovens for drying, and other combustion units.

Table 3.14: Activity data for Textile and leather in TJ for 2005, 2020-2022

Consumption (TJ)	2005	2020	2021	2022
1.A.2.g.vi. Textile and leather	**26,662**	**6,878**	**19,971**	**22,048**
Liquid fuels	8,617	2,611	2,340	1,517
Solid fuels	18,046	4,268	17,631	20,531

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

A comprehensive uncertainty assessment for emissions from the Textile and Leather sector identifies and quantifies uncertainties associated with activity data (e.g., accurate quantification of fuel consumption from a highly diverse and sometimes fragmented industry, including biomass use). The representativeness of emission factors (particularly for non-CO_2 gases, which can vary with fuel type and combustion technology) and the completeness of source coverage across this broad sector are also key considerations. Specific attention is paid to distinguishing between fossil and biogenic carbon sources and their respective uncertainties. To ensure robust time-series consistency, the chosen methodologies and emission factors for the Textile and Leather sector are applied uniformly across all reported years.

QA/QC and verification

The QA and QC procedures for emissions from the Textile and Leather category are meticulously implemented to ensure accuracy and reliability. Level 1 QC activities include thorough checks on the consistency and completeness of fuel consumption data across various sub-segments, with particular attention to the proper accounting of both fossil and biogenic fuels. The application of emission factors and the accuracy of CO_2, CH_4, and N_2O calculations are thoroughly verified. Level 2 QC involves independent expert review of the methodologies applied, assessing the representativeness of national data or selected default factors, and evaluating the completeness of emission source coverage across the diverse processes in this sector. Verification measures for this category often include cross-referencing aggregated fuel consumption data with national industrial statistics or production data from major textile and leather manufacturers.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible. Capacity-building for inventory compilers will prioritize specialized training in process analysis, biomass carbon accounting, and advanced emission estimation techniques relevant to this industrial sector, ensuring continuous improvement.

3.2.5.7.7 Off-road vehicles and other machinery (1.A.2.g.vii.)

Category description

This category includes GHG emissions from non-road mobile machinery (NRMM) used in industrial, agricultural, forestry, and construction applications. These vehicles and equipment operate outside public road networks and are typically powered by diesel internal combustion engines. Examples include agricultural tractors, combine harvesters, bulldozers, excavators, cranes, forklifts, and portable generators. The category excludes emissions

from on-road transport and stationary combustion sources. India has used 'IE' notation key for this category for current inventory reporting Off-road vehicles and other machinery cannot be disaggregated from Other Manufacturing. Therefore, the data for consumption of fuels under this category have been reported under 1.A.2.g.viii (Other) due to the unavailability of disaggregated data.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

3.2.5.7.8 Other (non-specified industry) (1.A.2.g.viii.)

Category description

The Other (non-specified industry) category serves as a residual or catch-all for fuel combustion emissions from various manufacturing industries that do not fit into the more specific subcategories under 1.A.2 (e.g., Iron and Steel, Non-ferrous metals, Chemicals, Pulp/Paper/Print, Food/Beverages/Tobacco, Non-metallic minerals, Manufacturing of machinery, Manufacturing of transport equipment, Mining excluding fuels, and Other manufacturing industries such as wood and wood products, electrical and optical equipment). This category shows a increase in emissions from 69,330 $GgCO_2$ equivalent in 2005 to 182,859 $GgCO_2$ equivalent in 2022. This represents a 164% change over the given period. In 2022, this "Other (non-specified industry)" sub-category accounted for 7% of the total emissions within the Energy sector.

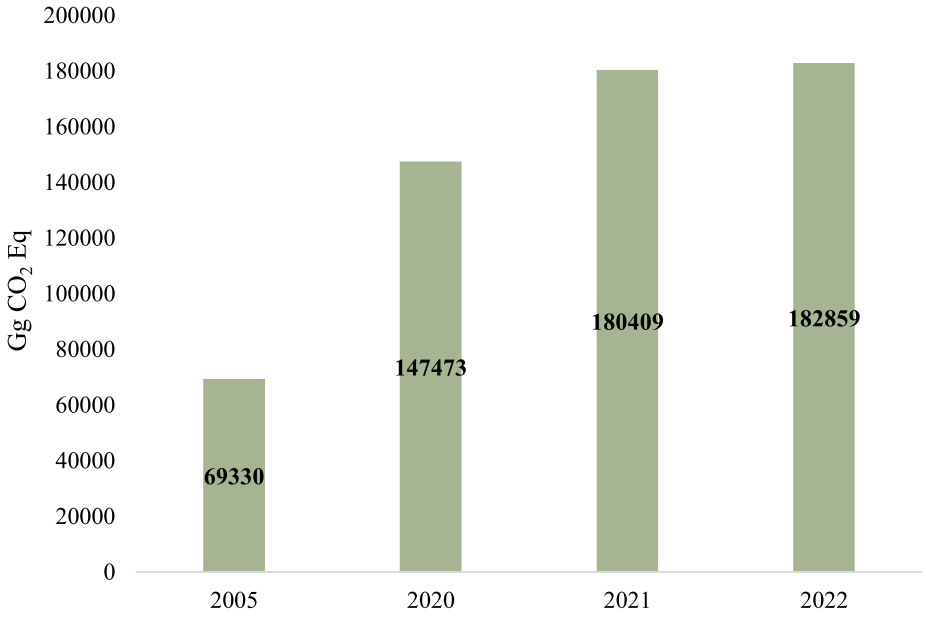


Figure 3.14: GHG emissions from Other (non-specified industry) (1.A.2.g.viii.) in 2005, 2020-2022

Methodological issues

Emissions from Other (non-specified industry) primarily arise from the combustion of various fuels (e.g., natural gas, fuel oil, LPG, coal, electricity from grid) in boilers, furnaces, ovens, and other combustion equipment.

Table 3.15: Activity data for Other (Non-specified Industry) in TJ for 2005, 2020-2022

Consumption (TJ)	2005	2020	2021	2022
1.A.2.g.viii. Other *(Non-specified Industry)*	**7,97,697**	**16,35,285**	**20,39,394**	**20,71,074**
Liquid fuels	1,04,148	1,57,913	1,82,019	1,68,606
Solid fuels	5,57,579	13,13,978	15,63,200	15,84,810
Gaseous fuels	1,35,970	1,63,394	2,94,175	3,17,659

Flexibility applied

Detailed information on the specific provisions and the justification for the applied flexibility is provided in Chapter 7 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

A comprehensive uncertainty assessment for emissions from the Other (non-specified industry) category identifies and quantifies uncertainties primarily associated with the aggregated nature of the activity data (as it's a residual category) and the generic nature of applied emission factors. The completeness of source coverage is also a key consideration, ensuring no significant industrial activities are inadvertently omitted or double-counted. Given the aggregated nature, efforts are made to estimate a reasonable range of uncertainty that reflects the heterogeneity of the included industries. To ensure robust time-series consistency, the methodologies, fuel consumption allocation rules, and emission factors applied to this other category are maintained uniformly across all reported years.

QA/QC and verification

The QA and QC procedures for emissions from the Other (non-specified industry) category are meticulously implemented to ensure accuracy and reliability. Level 1 QC activities include thorough checks on the consistency and completeness of the aggregated fuel consumption data attributed to this residual category and the accurate application of default emission factors. Level 2 QC involves independent expert review to confirm that the other category is properly defined, that no significant sources are inappropriately placed here or omitted, and that the methodology aligns with IPCC guidelines for residual categories. Verification measures for this category typically involve cross-referencing the aggregated fuel consumption data with national energy balances and, if available, broad economic indicators for the manufacturing sector, ensuring that the residual fuel use aligns with general economic trends.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible. Capacity-building for inventory compilers will prioritize training in data disaggregation techniques and the effective use of national statistical data to refine the allocation of fuel consumption across all manufacturing sub-sectors, ensuring continuous improvement.

3.2.6. Transport (1.A.3.)

Category description and background

This category covers greenhouse gas (GHG) emissions from fuel combustion in the transport sector, including road, rail, domestic aviation, inland waterways, and pipeline transport. It excludes international bunker fuels (reported separately) and focuses on domestic transport activities within India's territorial boundaries. The sector is a major contributor to national CO_2 emissions and is closely linked to urbanization, economic growth, and infrastructure development.

Table 3.16: Summary of Transport sector GHG emissionsfor 2005, 2020-2022 in GgCO_2 equivalent

	Total Gg CO_2 Equivalent			
Source/Sink Categories	2005	2020	2021	2022
1.A.3. Transport	131193	303920	324390	369532
1.A.3.a. Domestic aviation	6763	11949	11923	16616
1.A.3.b. Road transportation	107140	277573	297752	334223
1.A.3.b.i. Cars	43531	83041	89925	100975

	Total Gg CO_2 Equivalent			
Source/Sink Categories	2005	2020	2021	2022
1.A.3.b.ii. Light-duty trucks	12860	55927	57944	66467
1.A.3.b.iii. Heavy-duty trucks and buses	33936	90827	97161	109321
1.A.3.b.iv. Motorcycles	16813	47782	52722	57460
1.A.3.b.v. Other *(please specify)*	NO	NO	NO	NO
1.A.3.c. Railways	6116	4031	4050	4330
1.A.3.d. Domestic navigation	1768	3182	3032	3571
1.A.3.e. Other transportation	9406	7181	7633	10792
1.A.3.e.i. Pipeline transport	403	943	972	2959
1.A.3.e.ii. Other *(please specify)*	9004	6238	6661	7833

3.2.6.1. Domestic aviation (1.A.3.a.)

Category description

This category encompasses passenger and freight flights that both take off and land within India. It accounts for direct GHGs such as CO_2, CH_4, and N_2O resulting from the combustion of aviation turbine fuel (ATF) and, to a small extent, aviation gasoline. The emissions from this sector increased from 6,763 $GgCO_2$ equivalent in 2005 to 16,616 $GgCO_2$ equivalent in 2022, representing a 146% change over this period. In 2022, Domestic aviation accounted for 0.67% of the total emissions within the Energy sector.

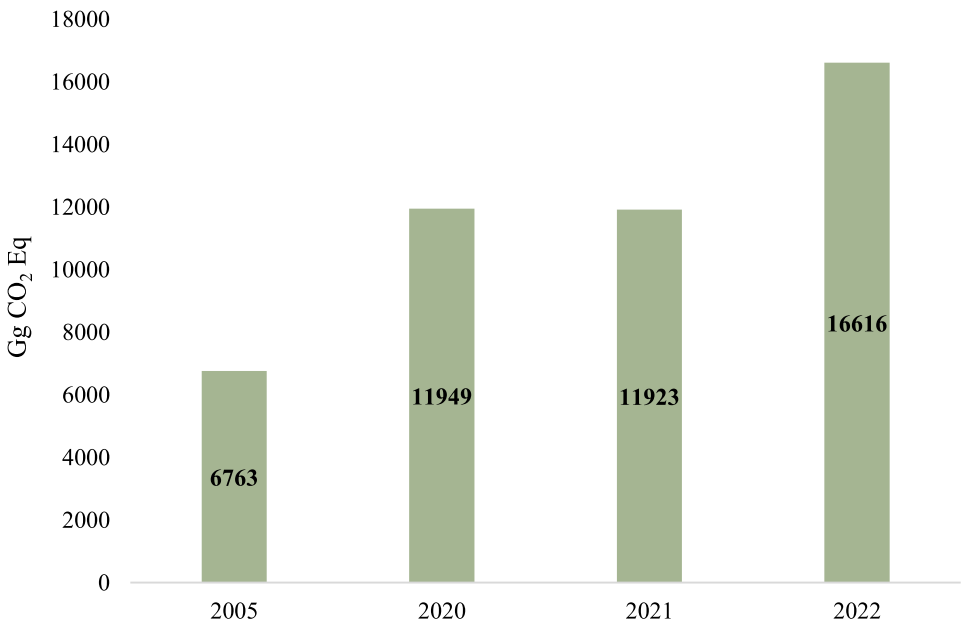


Figure 3.15: GHG emissions from Domestic aviation (1.A.3.a.) in 2005, 2020-2022

Methodological issues

Emissions of CO_2, CH_4, and N_2O are estimated using the Tier 1 method, as per the 2006 IPCC Guidelines (Volume 2, Chapter 3, Page 3.59). The calculation involves converting fuel consumption data from mass to energy units using NCV. Aviation Turbine Fuel (ATF)/Jet Kerosene data is published by the Ministry of Petroleum and Natural Gas. Financial year data (April-March) is converted to calendar year by using one-fourth of the preceding financial year and three-fourths of the current financial year.

Table 3.17: Activity data for Domestic aviation in TJ for 2005, 2020-2022

Consumption (TJ)	2005	2020	2021	2022
1.A.3.a. Domestic aviation	**93,872.52**	**1,65,863.60**	**1,65,497.18**	**2,30,638.56**
Aviation gasoline	NO	63.23	63.23	103.66
Jet kerosene	93,872.52	1,65,800.37	1,65,433.95	2,30,534.90

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

A quantitative uncertainty analysis for this category was conducted using the Tier 1 approach from the 2006 IPCC Guidelines. For each category and gas, a detailed analysis is conducted for the starting and latest reporting years, highlighting the main contributors to overall uncertainty. The same emission calculation method and emission factors are applied for all years (2005, 2020, 2021, 2022).

QA/QC and verification

QA/QC procedures follow Tier 1 general checks from the 2006 IPCC Guidelines (Table 6.1, Annex 6A.1) and Good Practice Guidance (GPG, 2000) (Table 8.1). Cross-checks are performed for transcription errors in activity data, EFs, and NCVs. Units and conversion factors are checked for consistency and correctness.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, (i) collection of more granular and higher-quality activity data such as aircraft types and LTO data to estimate GHG emissions using Tier-2 IPCC approach to capture the variations in GHG emissionsby aircraft types, (ii) incorporation of of country-specific emission factors for aviation fuel and or by aircraft type.

3.2.6.2. Road transportation (1.A.3.b.)

Category description and background

This source category includes CO_2, CH_4, and N_2O emissions from the road transport sector. The road transport sector in India has been divided into five sub-categories as stipulated by IPCC: 1.A.3.b.i. Cars, 1.A.3.b.ii. Light duty trucks, 1.A.3.b.iii. Heavy duty trucks and buses, 1.A.3.b.iv. Motorcycles, and 1.A.3.b.v. Other. The activity for category 1.A.3.b.v. "Other" is not occurring in India, and the notation key 'NO' has been used. The main fuels consumed in the road transport sector are Gasoline, Diesel, LPG, and Natural gas, with bioethanol (blended with Gasoline) being the major biofuel consumed. Emissions from this category increased from 107,140 $GgCO_2$ equivalent in 2005 to 334,223 $GgCO_2$ equivalent in 2022, marking a 212% change. This category accounted for 13% of the total emissions within the Energy sector in 2022.

- **Cars:** GHG emissionsrose from 43,531 $GgCO_2$ equivalent in 2005 to 100,975 $GgCO_2$ equivalent in 2022, an increase of 132%. In 2022, cars contributed 4% to the sector's total emissions.
- **Light duty trucks:** GHG emissionsincreased from 12,860 $GgCO_2$ equivalent in 2005 to 66,467 $GgCO_2$ equivalent in 2022, a 417% change. This sub-category represented 3% of the sector's total emissions in 2022.
- **Heavy duty trucks and buses:** GHG emissionsgrew from 33,936 $GgCO_2$ equivalent in 2005 to 109,321 $GgCO_2$ equivalent in 2022, an increase of 222%. Their share in the sector's total emissions was 4% in 2022.
- **Motorcycles:** GHG emissionsincreased from 16,813 $GgCO_2$ equivalent in 2005 to 57,460 $GgCO_2$ equivalent in 2022.

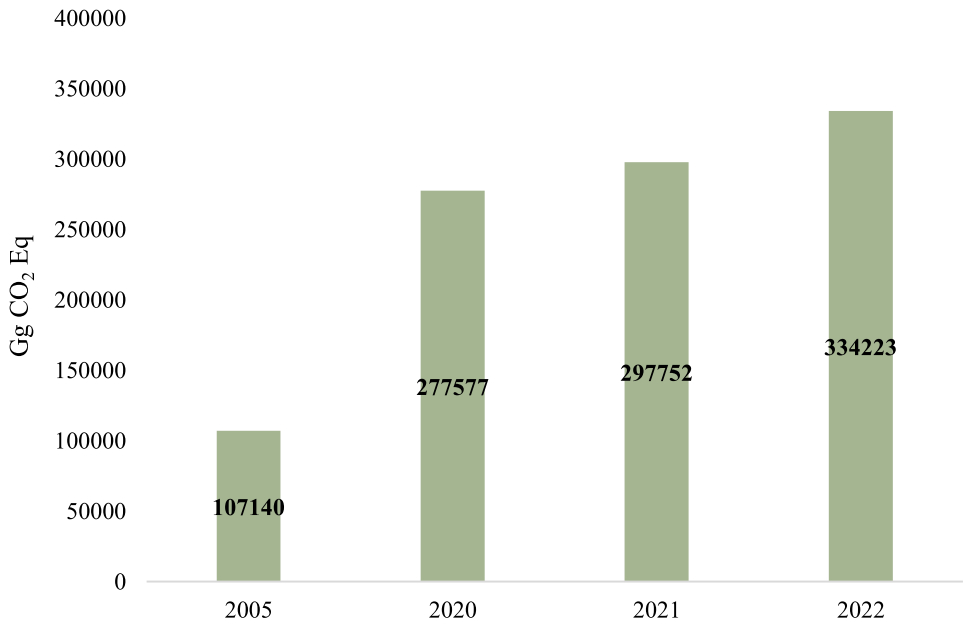


Figure 3.16: GHG emissions from Road transportation (1.A.3.b.) in 2005, 2020-2022

Methodological issues

Emissions from the road transport sector in India are calculated using the Tier 1 method as described in the 2006 IPCC Guidelines (Vol. 2, Chapter 3, Fig. 3.2.2 and Fig. 3.2.3). This approach is adopted primarily because country-specific emission factors for fuels used in India's road transport sector have not yet been developed. For CO_2 emissions from biogenic sources (ethanol, bio-CNG, biodiesel), these are not considered for the national inventory but are provided as memo items. However, CO_2 Equivalent emissions due to CH_4 and N_2O emissions from these biogenic sources are considered. For bioethanol, the NCV and emission factors of bio-gasoline given in IPCC are used. For biodiesel, NCV and CO_2 emission factors are obtained from the US-EPA database, while CH_4 and N_2O emission factors for diesel are also used. For Bio-CNG, which is comparable to CNG, the natural gas IPCC default NCV and emission factor are used.

Activity data are obtained from relevant ministries, agencies, and organizations that control this data. Key entities include: Ministry of Petroleum & Natural Gas (MoPNG): Fuel consumption statistics; Ministry of Road Transport & Highways (MoRTH): Road Transport Vehicle Statistics; Ministry of Statistics and Programme Implementation (MoSPI): Fuel consumption statistics; Petroleum Planning & Analysis Cell (PPAC): Fuel consumption statistics; Natural Gas consumption statistics, and Ready Reckoner reports for natural gas distribution; NITI Aayog: Fuel consumption statistics and SATAT: Bio-CNG production and sale statistics.

Gasoline and Diesel: Activity data are obtained from PPAC petroleum product consumption statistics. Monthly statistics are aggregated for yearly consumption. Ethanol-blended gasoline amounts are obtained by subtracting the blended ethanol. For 2005, the Nielsen 2013 survey was used to calculate gasoline (99.6%) and diesel (62%) consumption in road transport. For 2020, 2021, and 2022, the CRISIL (2020-21) survey by MoPNG and PPAC was used, indicating 99.7% gasoline and 80% diesel consumption in road transport.

Natural Gas: CNG and LNG consumed in road transport are considered. MoPNG annual reports are used for 2005, and PPAC Natural Gas consumption statistics for 2020, 2021, and 2022. Approximately 20% of total natural gas consumed in the CGD sector in India, with 55% of that amount consumed in road transport, is considered based on PPAC Ready Rekoner reports. CNG vehicle statistics from the VAHAN portal are used to allocate consumption to different vehicle types (Cars, 3-wheelers, small goods trucks, buses), with a 0.5 weightage for Petrol-CNG hybrid vehicles. For 2005, Delhi city CNG vehicle statistics from a published article were used due to unavailability of VAHAN portal data.

LPG: Activity data are from MoPNG yearly reports, with auto-LPG mainly consumed by 3-wheelers and allocated to the Cars category (1.A.3.b.i.). No LPG consumption in road transport was observed in 2005.

Biofuels: Bio-ethanol consumption is calculated using reported blending percentages in Gasoline by PPAC. Bio-diesel consumption is obtained from "India's Roadmap for Biofuels Report" by J M BAXI group. Bio-CNG consumption is from SATAT, MoPNG, PPAC reports, and a PWC report (PwC India, 2023).

Table 3.18: Activity data for Road transportation (1.A.3.b.) in TJ for 2005, 2020-2022

Consumption (TJ)	2005	2020	2021	2022
1.A.3.b.i. Cars	**5,87,634**	**12,21,610**	**13,11,597**	**14,47,902**
Gasoline	1,44,912	4,58,616	5,04,751	5,48,739
Diesel oil	4,28,061	5,13,127	5,41,211	6,40,444
Liquefied petroleum gases (LPG)	NO	6,286	5,678	5,331
Gaseous fuels	14,661	2,21,018	2,26,884	2,07,857
Ethanol	NO	22,054	32,456	44,055
Biodiesel	NO	430	428	1,015
Bio-CNG	NO	77	189	460
1.A.3.b.ii. Light duty trucks	**1,71,175**	**7,11,418**	**7,54,712**	**8,89,734**
Diesel oil	1,69,918	6,89,901	7,27,660	8,61,079
Gaseous fuels	1,257	20,931	26,455	28,195
Biodiesel	NO	578	575	397
Bio-CNG	NO	7	22	62
1.A.3.b.iii. Heavy duty trucks and buses	**4,51,465**	**12,13,758**	**12,96,071**	**14,54,505**
Diesel oil	4,49,370	12,06,377	12,88,933	14,48,727
Gaseous fuels	2,094	6,369	6,118	5,276
Ethanol	NO	NO	NO	NO
Biodiesel	NO	1,010	1,015	428
Bio-CNG	NO	2	5	74
1.A.3.b.iv. Motorcycles	**2,33,119**	**6,89,176**	**7,70,236**	**8,49,936**
Gasoline	2,33,119	6,57,554	7,23,702	7,86,770
Ethanol	NO	31,621	46,534	63,166

The main fuels consumed are Gasoline and Diesel, contributing approximately 26% and 73% respectively in 2005, with Natural gas at 1%. By 2022, Gasoline and Diesel consumption were 29% and 64% respectively, with Natural gas at 5% and biofuels at 2% of total energy consumption in the road transport sector. Gasoline is mainly consumed by Cars (40%) and Motorcycles (60%), while Diesel is primarily by Heavy Duty Trucks (50%). Approximately 80% of natural gas is consumed by Cars.

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

The default values of uncertainties given in the 2006 IPCC Guidelines are adopted. A default uncertainty of 5% was assumed for all activity data in the road transport sector. The uncertainty in the emission factor was calculated from the values of Default, Lower, and Upper limits provided in the 2006 IPCC Guidelines for Mobile Combustion. The combined uncertainty in the road transport sector for the years 2005, 2020, 2021, and 2022 were calculated to be 6%, 7.1%, 7.1%, and 6.8%, respectively. The increase in uncertainty from 2005 to 2020 and 2021 can be attributed to the overall increase in natural gas consumption, which has higher uncertainty for emission factors. The same emission factors and emission calculation methods were used for the complete time series (2005, 2020, 2021, and 2022). Activity data for gasoline, diesel, and LPG were obtained from consistent sources like PPAC and MoPNG. Natural gas consumption data were also consistently obtained from MoPNG and PPAC statistics. Consistent time series information is maintained by consistent time-series input data for each category.

QA/QC and verification

The QA and QC procedures for the Road Transportation (1.A.3.b.) sector adhere to the TACCC principles. All QA/QC activities follow Chapter 6 of the 2006 IPCC Guidelines.

- QA/QC activities include data processing, calculations, completeness, and documentation.
- Default emission factors are used, and QA/QC checks are performed accordingly.
- Activity data from officially recognized national bodies (MoPNG, PPAC, NITI AYYOG) are used.
- Assumptions for activity data and emission factor selection are documented as per IPCC 2006 Guidelines.
- All references are cited bibliographically and are traceable.
- Traceable spreadsheets are prepared for each inventory year to avoid transcription errors.
- IPCC Inventory software is used for preparation and cross-checked with Excel-based spreadsheets.
- Units are properly labelled, and conversion factors are carefully applied.
- Consistency of data between categories with similar parameters is checked.
- Detailed inventory estimation reports are stored for review.

For verification, IPCC Inventory software is used to cross-check activity data and GHG emissions. In-house GHG inventory software was also used to cross-check fuel consumption data and related sectoral GHG emissionsin the road transport sector.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Planned improvements for estimating emissions from the Road Transportation (1.A.3.b.) sector aim to address systematic shortcomings observed in activity data and emission factors. As CO_2 from road transport is a key category, the goal is to improve the emission tier of India's road transport sector GHG inventory. Key plans include:

- Developing Country-Specific Emission Factors and Achieving Tier-II: This involves detailed laboratory analysis to obtain precise estimates of NCV and carbon content of fuels (diesel, gasoline, CNG) specific to India's circumstances. This database will provide a comprehensive foundation for informed decision-making and adherence to international reporting standards.

- Refining Activity Data Allocation: Currently, allocation of gasoline and diesel is based on surveys by MoPNG and PPAC. Future improvements will focus on detailed vehicle statistics with Vehicle Kilometres Travelled (VKT) analysis for more accurate allocation. For CNG, detailed surveys on consumption by different vehicle types are required for proper allocation, as current allocation is based on PPAC surveys and vehicle numbers from the VAHAN database.

- Capacity Building Requirements: Dedicated high-accuracy equipment is required for continuous testing, monitoring, and surveying of fuel parameters to obtain precise laboratory determination of NCV/GCV and carbon content. This includes bomb calorimeters for NCV/GCV and CHNSO analysers for carbon content. This will also aid in developing India's country-specific uncertainty and QA/QC protocols for the road transport sector.

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

Category description

This category includes GHG emissions from fuel combustion in railway transport, specifically from diesel-powered locomotives and auxiliary rail equipment operating within India's domestic network. It excludes emissions from electrified rail segments (reported under electricity generation) and international rail movements. The Indian Railways system is one of the largest globally, and while electrification is progressing rapidly, diesel traction remains a significant source of transport-related emissions. As of 2023, 88% of the total Bharat Gaurav Railway Network is electrified (57,067 RKMs). The remaining network primarily runs on High-Speed Diesel Oil (HSDO), with small amounts of non-coking coal and kerosene also reported. This category covers estimates CO_2, CH_4, and N_2O emissions from the combustion of these fuels in Indian Railway Locomotives.

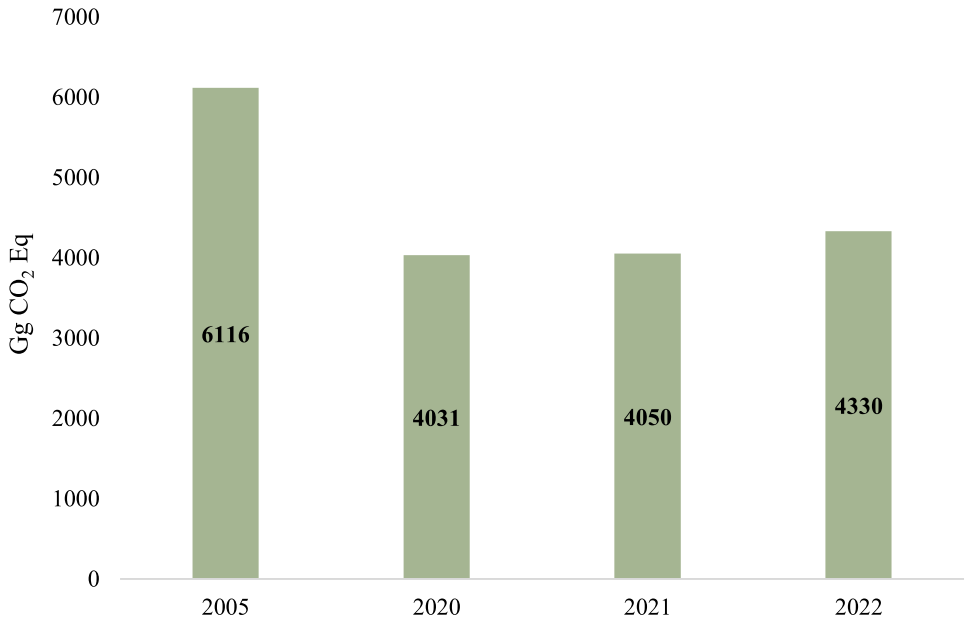


Figure 3.17: GHG emissions from Railways (1.A.3.c.) in 2005, 2020-2022

Methodological issues

Direct GHG emissionsare estimated using the Tier 1 method, based on the IPCC 2006 Guidelines (Vol. 2, Chapter 3, page 3.41, fig 3.4.2). Fuel consumption data, collected by mass, is converted into energy units using NCVs. Default emission factors from the 2006 IPCC Guidelines (Vol. 2, Chapter 3, Table 3.4.2) are used for CO_2, CH_4, and N_2O from the combustion of HSDO, Light Speed Diesel, fuelwood, coal, petrol, and kerosene. NCVs used are also default values from the 2006 IPCC Guidelines (Vol. 2, Chapter 1, Table 1.2). Activity data, including coal, kerosene, and HSDO consumption, are published annually in the Indian Railways Annual Statistical Statements (IRASS). Data reported in financial year format is converted to calendar year and then into energy units.

Table 3.19: Activity data for Railways in TJ for 2005, 2020-2022

Consumption (TJ)	2005	2020	2021	2022
1.A.3.c. Railways	**74,757**	**49,285**	**49,513**	**52,934**
Liquid fuels	74,697	49,280	49,512	52,934
High-speed diesel oil(HSDO)	74,697	49,269	49,498	52,930
kerosene	NO	11	14	4
Solid fuels	60	4.50	0.61	0.02
Coal	60	4.50	0.61	0.02

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

A quantitative uncertainty analysis for this category was conducted using the Tier 1 approach from the 2006 IPCC Guidelines. For each category and gas, a detailed analysis is conducted for the starting and latest reporting years, highlighting the main contributors to overall uncertainty

QA/QC and verification

QA/QC procedures follow Tier 1 general checks from the 2006 IPCC Guidelines (Table 6.1, Annex 6A.1) and Good Practice Guidance (GPG, 2000) (Table 8.1). Transparency is maintained through clear documentation. Activity data from government agencies is reliable. Cross-checks are performed for transcription errors. IPCC Inventory software and Excel spreadsheets are used for preparation and cross-checking. Units and conversion factors are checked. Emission calculations are peer-reviewed.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, use of (i) Incorporation of country-specific emission factors wherever available.

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

Category description

This category includes GHG emissions from fuel combustion in Indian marine vessels and vessels operating within India's inland waterways. It excludes international foreign carriers. It covers passenger ferries, cargo barges, fishing vessels, and support craft engaged in domestic navigation. These emissions arise from main propulsion engines, auxiliary engines, and onboard energy systems. The main fuels used are Fuel Oil (FO), High-Speed Diesel Oil (HSDO), Light Diesel Oil (LDO), and Liquefied Natural Gas (LNG). Compared to 2005, the CO_2 Equivalent emissions increased by 102%, 101%, and 102% respectively in 2022. CO_2 emissions from domestic navigation increased by 80% in 2020, 71% in 2021, and 102% in 2022, compared to 2005. CH_4 emissions were 0.052 Gg in 2005, 0.093 Gg in 2020, 0.089 Gg in 2021, and 0.105 Gg in 2022. N_2O emissions were 0.007 Gg in 2005, 0.013 Gg in 2020, 0.012 Gg in 2021, and 0.014 Gg in 2022.

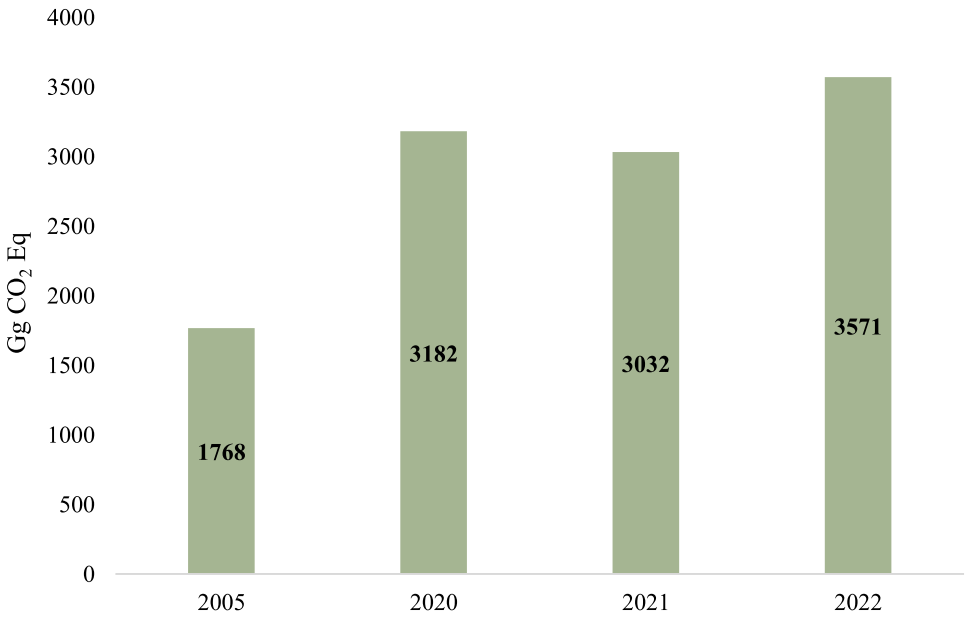


Figure 3.18: GHG emissions from Domestic Navigation (1.A.3.d.) in 2005, 2020-2022

Methodological issues

Direct GHG emissionsare estimated using the Tier 1 method, following the IPCC 2006 Guidelines (Vol. 2, Chapter 3, Page 3.73, Fig 3.6.2). Fuel consumption data is converted to energy units using NCVs. Default emission factors from the 2006 IPCC Guidelines (Vol. 2, Chapter 3, Table 3.6.4) are used for CO_2, CH_4, and N_2O from the combustion of FO, HSDO, LDO, and LNG. NCVs are also default values from the 2006 IPCC Guidelines (Vol. 2, Chapter 1, Table 1.2). Fuel consumption data for FO, HSDO, and LDO are sourced from the Indian Petroleum and Natural Gas Statistics (IPNGS), published annually by the MoPNG. Starting in 2020, LNG consumption has been included in the Ministry of Ports, Shipping and Waterways annual report.

Table 3.20: Activity data for Domestic Navigation in TJ for 2005, 2020-2022

Consumption (TJ)	2005	2020	2021	2022
1.A.3.d. Domestic Navigation	**23,240**	**41,959**	**39,930**	**46,975**
Residual fuel oil	8,910	14,264	14,798	18,212
Gas/diesel oil	12,525	27,288	24,689	28,290
Diesel oil/Light diesel Oil (LDO)	1,804	125	178	241
Gaseous fuels	NO	281	265	231
Biomass	NO	281	265	231

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

A quantitative uncertainty analysis for this category was conducted using the Tier 1 approach from the 2006 IPCC Guidelines. For each category and gas, a detailed analysis is conducted for the starting and latest reporting years, highlighting the main contributors to overall uncertainty.

Time-series consistency is a cornerstone of the inventory process. For the reported years, consistent methodologies and data sources have been applied to the greatest extent possible to ensure that trends reflect actual changes in emissions.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, (i) a comprehensive coverage of fuel use in vessels operating in all the internal waterways, quantification of fuel used separately in fishing vessels, cargo vessels and passenger vessels, (ii) development of country-specific emission factors by type of vessels, (iii) exploration of higher-tier methodologies where feasible, and (iv) capacity-building initiatives for inventory compilers.

3.2.6.5. Other transportation

Category description and background

This category includes GHG emissions from transport modes not explicitly covered under road, rail, domestic aviation, inland waterways. It typically encompasses non-conventional, auxiliary, and specialized transport activities, such as military transport, off-grid logistics operations, emergency response vehicles, and non-commercial mobility systems (e.g., internal factory transport, airport ground vehicles not covered under aviation). These sources are often decentralized and may operate outside standard transport infrastructure.

3.2.6.5.1 Pipeline transport (1.A.3.e.i.)

Category description

This category covers emissions from the combustion of fuels in the transportation of commodities through pipelines, specifically focusing on natural gas pipelines in India. While liquid fuels are also transported via pipelines, the diesel fuel used for these operations has been accounted for under the "Petroleum Refining" (1.A.1.b.) category due to data aggregation. The primary source of emissions in this category is the combustion of natural gas used as fuel in pipeline booster stations.

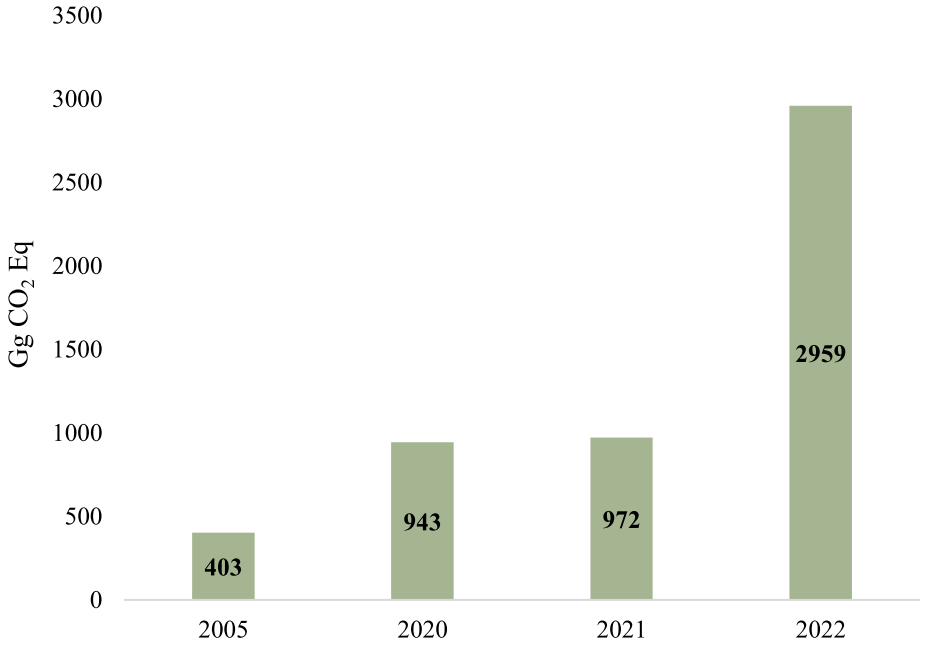


Figure 3.19: GHG emissions from Pipeline transport (1.A.3.e.i.) in 2005, 2020-2022

Methodological issues

Direct GHG emissions from pipeline transport are estimated using the Tier 1 method, as per the IPCC 2006 Guidelines (Volume 2, Chapter 3, page 3.86, Fig 3.8.2). This method uses fuel consumption data converted to energy units via Net Calorific Values (NCVs). Default emission factors from the 2006 IPCC Guidelines (Volume 2, Chapter 3, Table 3.4.2) are used for CO_2, CH_4, and N_2O from natural gas combustion. The NCV for natural gas is also a default value from the 2006 IPCC Guidelines (Volume 2, Chapter 1, Table 1.2). Natural gas consumption data for pipeline transport is sourced from the Petroleum Planning & Analysis Cell (PPAC), under the Ministry of Petroleum & Natural Gas (MoPNG). Data is provided annually.

Table 3.21: Activity data for Pipeline transport in TJ for 2005, 2020-2022

Consumption (TJ)	2005	2020	2021	2022
1.A.3.e.i. Pipeline transport	7,169	16,799	17,301	52,695
Gaseous fuels	7,169	16,799	17,301	52,695

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

Default uncertainty values from the 2006 IPCC Guidelines are adopted. The combined uncertainty for pipeline transport for 2020, 2021, and 2022 was calculated to be 7%. Time-series Consistency: The same emission calculation method and emission factors are applied across the entire time series (2005, 2020, 2021, 2022). Activity data for natural gas consumption is consistently obtained from PPAC.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

3.2.6.5.2 Other (1.A.3.e.ii.)

Category description

The Other category within the transport sector (1.A.3.e.ii.) serves as a residual category to capture any fuel combustion emissions from transport activities that are not explicitly covered by the more specific subcategories of road, rail, domestic aviation, domestic navigation, or pipeline transport. This ensures the completeness of the national greenhouse gas inventory. Such activities could potentially include off-road recreational vehicles, certain industrial mobile machinery not already covered under manufacturing or construction, or other miscellaneous transport activities that do not fall neatly into the primary modes. Emissions from this category show a decrease from 9,004 $GgCO_2$ equivalent in 2005 to 7,833 Gg CO_2 Equivalent in 2022, representing a 13% change over this period. In 2022, this sub-category accounted for 0.31% of the total emissions within the Energy sector.

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

A quantitative uncertainty analysis for this category was conducted using the Tier 1 approach from the 2006 IPCC Guidelines. For each category and gas, a detailed analysis is conducted for the starting and latest reporting years, highlighting the main contributors to overall uncertainty.

Time-series consistency is a cornerstone of the inventory process. For the reported years, consistent methodologies and data sources have been applied to the greatest extent possible to ensure that trends reflect actual changes in emissions.

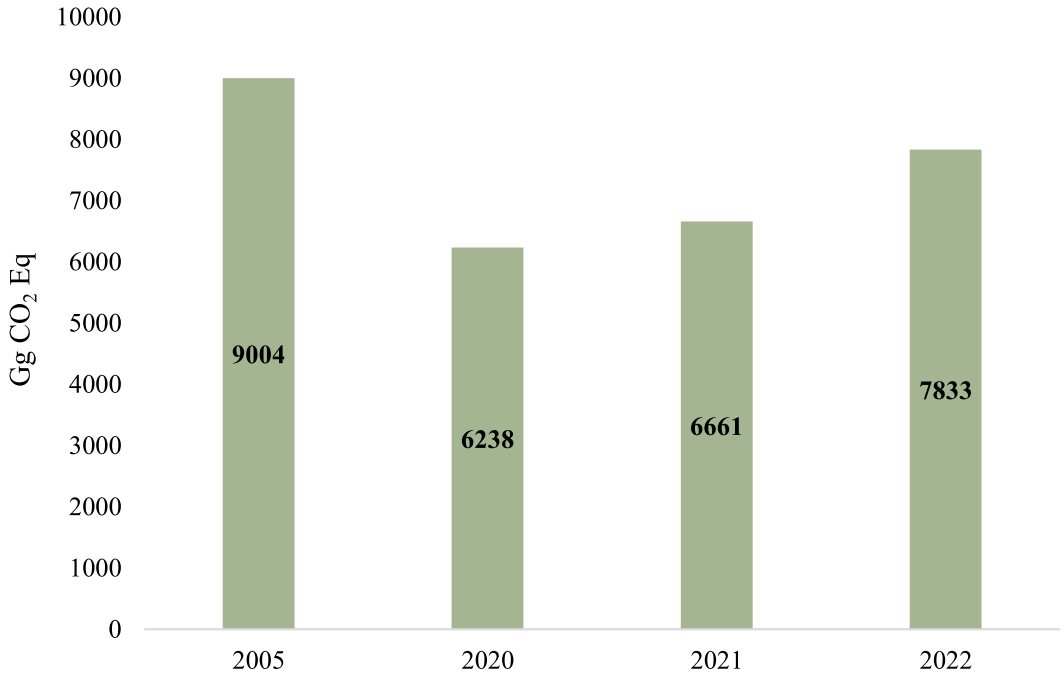


Figure 3.20: GHG emissions from Other (1.A.3.e.ii.) in 2005, 2020-2022

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

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

Category description and background

This category encompasses greenhouse gas emissions from fuel combustion in residential, commercial, institutional, and agricultural sectors, excluding emissions already captured under energy industries, manufacturing, and transport. These sectors are characterized by decentralized energy use, often involving biomass, kerosene, LPG, diesel, and electricity for cooking, heating, lighting, and machinery operations. The category reflects India's diverse socio-economic landscape, with energy consumption patterns varying widely across urban, rural, and peri-urban regions. Emissions from this category increased from 109,731 $GgCO_2$ equivalent in 2005 to 146,635 $GgCO_2$ equivalent in 2022, representing a 34% change. In 2022, this category accounted for around 6% of the total emissions within the Energy sector.

3.2.7.1. Commercial/institutional (1.A.4.a.)

Category description and background

This category encompasses fuel combustion activities in the commercial and institutional sectors. These sectors include a wide range of facilities such as offices, public administration buildings, schools, universities, hospitals, hotels, retail establishments, and other service-oriented entities. Emissions primarily arise from the combustion of various fuels to generate heat for space heating, water heating, cooking, and to produce electricity for lighting, air conditioning, and other electrical appliances on-site. This category is distinct from manufacturing industries or residential energy use. Emissions increased from 25,880 $GgCO_2$ equivalent in 2005 to 37,138 $GgCO_2$ equivalent in 2022, a 43.50% change.

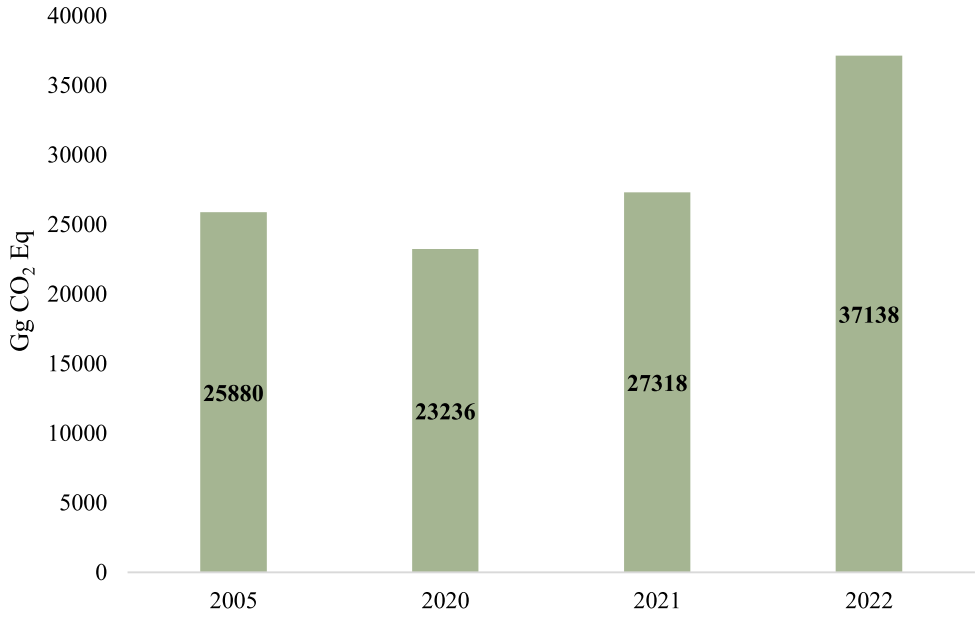


Figure 3.21: GHG emissions from Commercial/institutional (1.A.4.a.) in 2005, 2020-2022

Methodological issues

Emissions for this commercial/institutional sector are typically estimated using either a Tier 1 or Tier 2 approach, as outlined in the 2006 IPCC Guidelines (Volume 2, Chapter 5, "Commercial/Institutional and Residential Sectors"). Tier 1 approach utilizes aggregated national fuel consumption data for the commercial/institutional sector, combined with default IPCC emission factors. Fuel consumption data is usually sourced from national energy balances or statistical surveys that track energy use by sector. Tier 2 involves employing country-specific emission factors for fuels and, where available, more disaggregated activity data (e.g., fuel consumption per unit of commercial floor space, or differentiated by institutional sub-types). Data regarding solid fuels were sourced from coal statistics, while information pertaining to liquid and gaseous fuels was obtained from the PPAC of the Ministry of Petroleum and Natural Gas.

Table 3.22: Activity data for Commercial/institutional in TJ for 2005, 2020-2022

Consumption (TJ)	2005	2020	2021	2022
1.A.4.a. Commercial/institutional	**3,88,682**	**3,32,083**	**3,43,115**	**5,58,166**
Liquid fuels	12,905	42,523	40,670	33,617
Solid fuels	1,02,730	79,753	1,70,900	1,13,933
Gaseous fuels	2,73,046	2,09,806	1,31,545	4,10,616

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 (“Information on Flexibility”) of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

A quantitative uncertainty analysis for this category was conducted using the Tier 1 approach from the 2006 IPCC Guidelines. For each category and gas, a detailed analysis is conducted for the starting and latest reporting years, highlighting the main contributors to overall uncertainty.

Time-series consistency is a cornerstone of the inventory process. For the reported years, consistent methodologies and data sources have been applied to the greatest extent possible to ensure that trends reflect actual changes in emissions.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India’s first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

3.2.7.2. Residential (1.A.4.b.)

Category description and background

This category covers fuel combustion activities within the residential sector. This includes households consuming various fuels for a range of purposes such as cooking, space heating, water heating, lighting, and other household energy needs. Emissions primarily arise from the combustion of solid fuels (e.g., biomass, coal), liquid fuels (e.g., kerosene, LPG), and gaseous fuels (e.g., natural gas). This sector is a significant source of both CO_2 and non-CO_2 greenhouse gas emissions, particularly CH_4 and N_2O from the incomplete combustion of solid and liquid fuels, especially in traditional cookstoves. Emissions rose from 77,465 $GgCO_2$ equivalent in 2005 to 98,323 $GgCO_2$ equivalent in 2022, a 27% change. Similar to commercial/institutional, "Stationary combustion" (1.A.4.b.i.) accounts for all emissions, with "Off-road vehicles and other machinery" (1.A.4.b.ii.) reporting not occurred. For "1A4b Residential, CO_2," Tier 1 and Tier 2 methodologies are employed.

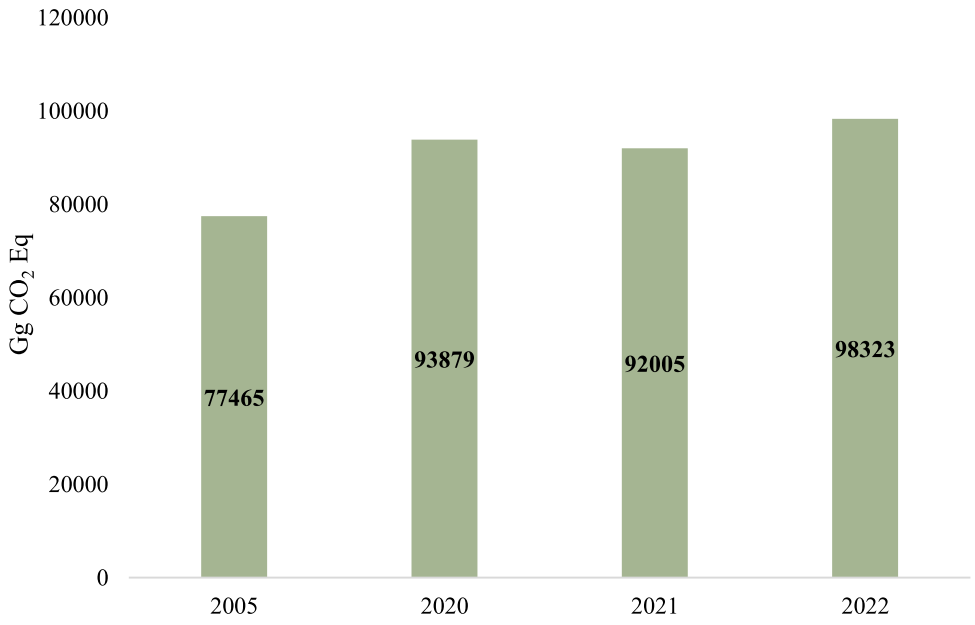


Figure 3.22: GHG emissions from Residential (1.A.4.b.) in 2005, 2020-2022

Methodological issues

Emissions for this category are typically estimated using either a Tier 1 or Tier 2 approach, as outlined in the 2006 IPCC Guidelines (Volume 2, Chapter 5, "Commercial/Institutional and Residential Sectors"). Tier 1 approach utilizes aggregated national fuel consumption data for the residential sector, combined with default IPCC emission factors. Fuel consumption data is usually sourced from national energy balances or statistical surveys that track energy use by sector. Tier 2 involves employing country-specific emission factors for fuels and, where available, more disaggregated activity data (e.g., fuel consumption per unit of commercial floor space, or differentiated by institutional sub-types). Data regarding solid fuels were sourced from coal statistics, while information pertaining to liquid and gaseous fuels was obtained from the PPAC of the Ministry of Petroleum and Natural Gas.

Table 3.23: Activity data for Residential in TJ for 2005, 2020-2022

Consumption (TJ)	2005	2020	2021	2022
1.A.4.b. Residential	**10,79,708**	**14,08,420**	**13,91,263**	**14,66,027**
Liquid fuels	4,12,905	56,608	49,027	26,879
Solid fuels	1,96,445	1,62,909	1,32,770	1,98,927
Gaseous fuels	4,70,358	11,88,903	12,09,466	12,40,222

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

A quantitative uncertainty analysis for this category was conducted using the Tier 1 approach from the 2006 IPCC Guidelines. For each category and gas, a detailed analysis is conducted for the starting and latest reporting years, highlighting the main contributors to overall uncertainty.

Time-series consistency is a cornerstone of the inventory process. For the reported years, consistent methodologies and data sources have been applied to the greatest extent possible to ensure that trends reflect actual changes in emissions.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

3.2.7.3. Agriculture/forestry/fishing (1.A.4.c.)

Category description and background

This category captures greenhouse gas emissions from fuel combustion in agricultural, forestry, and fishing activities, excluding emissions from land-use change and enteric fermentation (reported separately). It includes decentralized energy use in crop cultivation, livestock management, forest operations, and aquatic harvesting, often involving diesel-powered machinery, irrigation pumps, and motorized vessels. These activities are critical to India's rural economy and food security, with energy use patterns shaped by regional practices and mechanization levels. Emissions increased from 6,386 $GgCO_2$ equivalent in 2005 to 11,174 $GgCO_2$ equivalent in 2022, a 75% change. Within this, "Fishing" (1.A.4.c.iii.) saw a significant increase of 127% from 4,139 $GgCO_2$ equivalent in 2005 to 9,413 $GgCO_2$ equivalent in 2022. "Stationary" (1.A.4.c.i.) emissions decreased by 22% from 2,247 $GgCO_2$ equivalent in 2005 to 1,760 $GgCO_2$ equivalent in 2022, while "Off-road vehicles and other machinery" (1.A.4.c.ii.) reported not occurred.

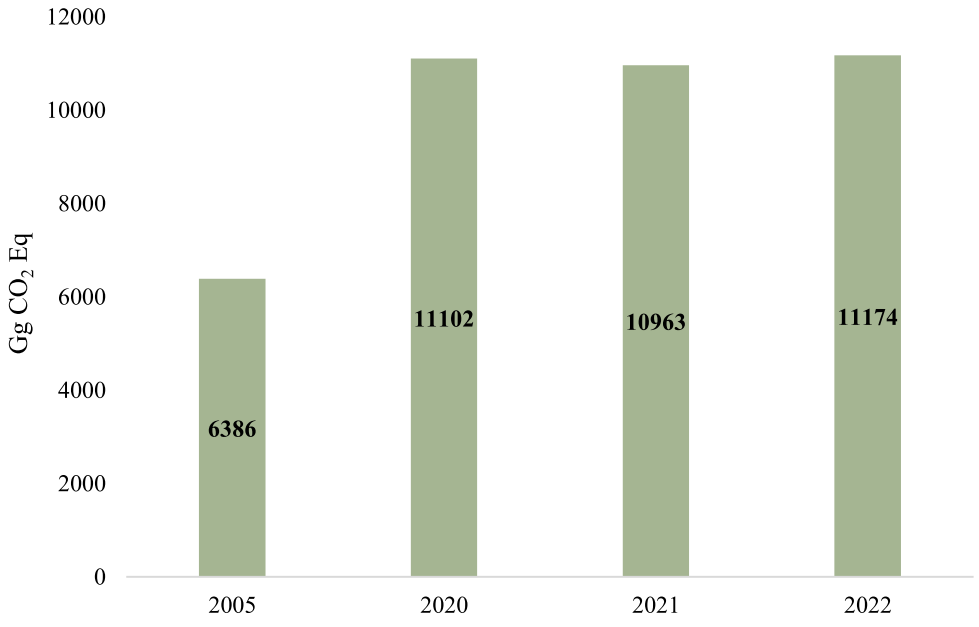


Figure 3.23: GHG emissions from Agriculture/forestry/fishing (1.A.4.c.) in 2005, 2020-2022

Methodological issues

Emissions for the agriculture/forestry/fishing sector are typically estimated using either a Tier 1 or Tier 2 approach, as outlined in the 2006 IPCC Guidelines. This approach relies on aggregated national fuel consumption data specifically allocated to the agriculture, forestry, and fishing sectors, combined with default IPCC emission factors. Fuel consumption data is usually derived from national energy balances or sectoral fuel sales statistics. India has applied the IE notation key due to the unavailability of disaggregated residual fuel oil consumption data for the fishing sector. This consumption is included in domestic navigation as there is no bifurcation available.

Table 3.24 Activity data for Agriculture/forestry/fishing in TJ for 2005, 2020-2022

Consumption (TJ)	2005	2020	2021	2022
1.A.4.c.i. Stationary	**31,484**	**37,043**	**34,276**	**25,073**
Liquid fuels	26,058	30,376	28,394	19,437
Solid fuels	NO	NO	NO	NO
Gaseous fuels	5,426	6,667	5,882	5,636
1.A.4.c.iii. Fishing	**55,313**	**1,13,153**	**1,13,887**	**1,25,800**
Residual fuel oil	IE	IE	IE	IE
Gas/diesel oil	55,313	1,13,153	1,13,887	1,25,800

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

A quantitative uncertainty analysis for this category was conducted using the Tier 1 approach from the 2006 IPCC Guidelines. For each category and gas, a detailed analysis is conducted for the starting and latest reporting years, highlighting the main contributors to overall uncertainty.

Time-series consistency is a cornerstone of the inventory process. For the reported years, consistent methodologies and data sources have been applied to the greatest extent possible to ensure that trends reflect actual changes in emissions.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

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

Category description and background

This broad category captures fuel combustion emissions from sources not allocated to categories 1.A.1 (Energy Industries), 1.A.2 (Manufacturing Industries and Construction), 1.A.3 (Transport), or 1.A.4 (Commercial/ Institutional and Residential). It typically includes small, diverse sources that are individually minor but collectively might be significant. It also serves as a residual category for activities that do not fit into other specific sectors or are otherwise not specified elsewhere. Within this category, detailed information is available for Stationary (Railways) (1.A.5.a.), which accounts for stationary fuel combustion by railway infrastructure that is not directly related to locomotive operation (e.g., heating, power generation at railway stations, workshops, or administrative buildings, and Category 1.A.5.b which is a residual category that captures emissions from fuel combustion in activities not specified elsewhere in the Energy sector).

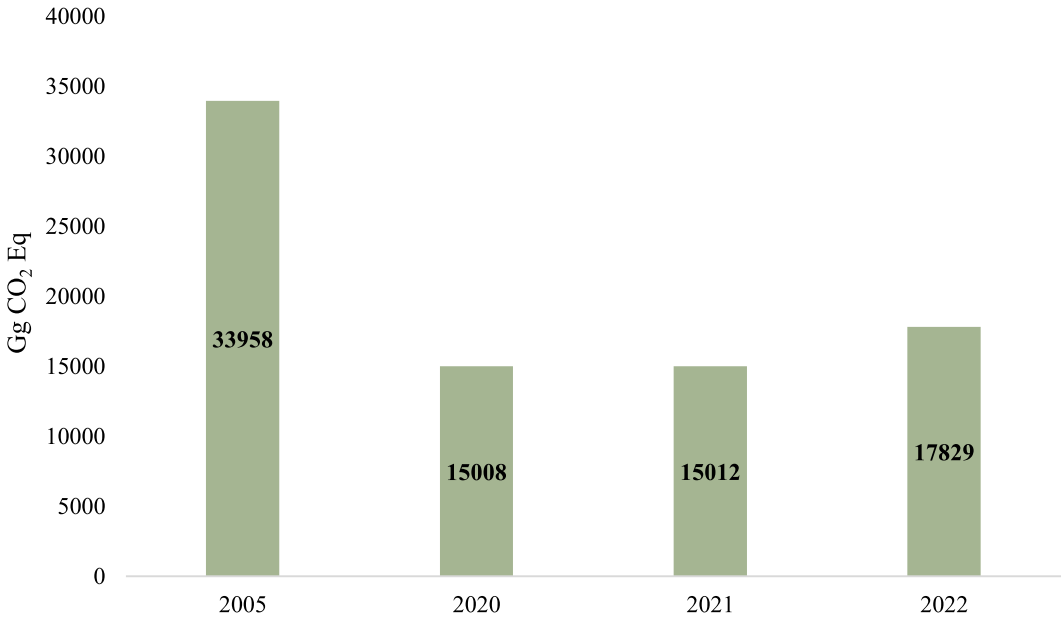


Figure 3.24: GHG emissions from Other (1.A.5.) in 2005, 2020-2022

Methodological issues

Tier 1 approach is practical given the current data availability for these disaggregated sources. The Tier 1 method calculates emissions based on the total amount of fuel consumed and applies default emission factors. The methodological issue pertains to the Residual Fuel Oil (RFO), domestically known as Furnace Oil, that is not explicitly allocated to a specific end-use sector. To uphold the principle of completeness and ensure no emissions are omitted, this unallocated fuel quantity is addressed systematically. After reconciling the total RFO supply with the reported consumption across all defined IPCC categories (like power generation and specific manufacturing industries), the remaining residual volume is assigned to category 1.A.5.b (Other - Stationary Combustion). This allocation is based on the expert judgment that this fuel is consumed by numerous smaller, disaggregated industrial, commercial, or institutional users not individually tracked in national statistics in 2005. The consumption of Light Diesel Oil (LDO), in the Stationary (Railways) category, declined between 2005 and 2020 and was not used in 2021 and 2022 due to a transition to alternative energy sources. Similarly, the consumption of petrol, kerosene, and fuelwood decreased during the period 2005–2022, reflecting the railways sector's gradual shift toward alternative energy sources.

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

A quantitative uncertainty analysis for this category was conducted using the Tier 1 approach from the 2006 IPCC Guidelines. For each category and gas, a detailed analysis is conducted for the starting and latest reporting years, highlighting the main contributors to overall uncertainty.

Time-series consistency is a cornerstone of the inventory process. For the reported years, consistent methodologies and data sources have been applied to the greatest extent possible to ensure that trends reflect actual changes in emissions.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category relative to a previous BTR.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

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

3.3.1. Solid fuels (1.B.1.)

Category description and background

Fugitive emissions (CRT category 1.B.) are defined as the intentional or unintentional release of greenhouse gases that occur during the extraction, processing and delivery of fossil fuels to the point of final use. Unlike combustion emissions, which are predominantly constituted of CO_2, fugitive emissions are mainly includes CH_4. Solid fuels, predominantly coal, are crucial to India's energy landscape, with significant methane (CH_4) emissions generated during coal formation through both biogenic and thermogenic processes, influenced by geological factors and stored within the coal's micropores. India's coal deposits are mainly Permian-age sub-bituminous to bituminous coals found in the Gondwana Basins of eastern and central states, while tertiary coal deposits, often high in sulphur, are prominent in the north-east. Fugitive emissions from solid fuels, primarily methane, have risen with increasing coal production, particularly from surface mines, which consistently exceed emissions from underground mines due to their higher production volumes and a declining share from underground operations, despite a brief decline in overall production in 2020 and 2021 due to COVID-19.

3.3.1.1. Coal mining and handling (1.B.1.a.)

Category description and background

Methane (CH_4) and carbon dioxide (CO_2), collectively known as seam gas, are produced during coal formation

and remain trapped until mining exposes the coal. CH_4 is the primary greenhouse gas released from coal mining and handling, with this source category (1.B.1.a.) encompassing all intentional and unintentional emissions from the extraction, processing, storage, and transport of solid fuel up to its final use, including both underground and surface coal mining activities and associated post-mining operations. Annual coal production and associated CO_2e emissions for various years, along with the summary of methods and emission factors, are specifically covered under this category.

3.3.1.1.1 Underground mines (1.B.1.a.i.)

Category description and background

The general form of the equation for estimating emissions for Tier 2 approaches, based on coal production activity data from underground coal mining and post-mining emissions is given by Equation.

Greenhouse gas emissions = Raw coal production × Emission Factor × Conversion factor

Conversion factor is the density of CH_4 and converts volume of CH_4 to mass of CH_4. The density is taken at 20˚C and 1 atmosphere pressure and has a value of 0.67 × 10-6 Gg m-3.

Table 3.25: Activity data for Underground mines in Mt for 2005, 2020-2022

Source/Sink Categories	Activity Data	2005	2020	2021	2022
1.B.1.a.i. Underground mines	Amount of fuel produced (Mt)	64.41	34.28	32.94	34.43

3.3.1.1.1.1 Mining activities (1. B.1. a.i.1.)

Category description

This source category covers fugitive emissions from the production from underground mines and includes all seam gas emissions vented to atmosphere from coal mine ventilation air. Methane emissions from underground mining activities are estimated at 277.7 Gg, 121.4 Gg, 116.6 Gg and 122.4 Gg for the years 2005, 2020, 2021 and 2022, respectively.

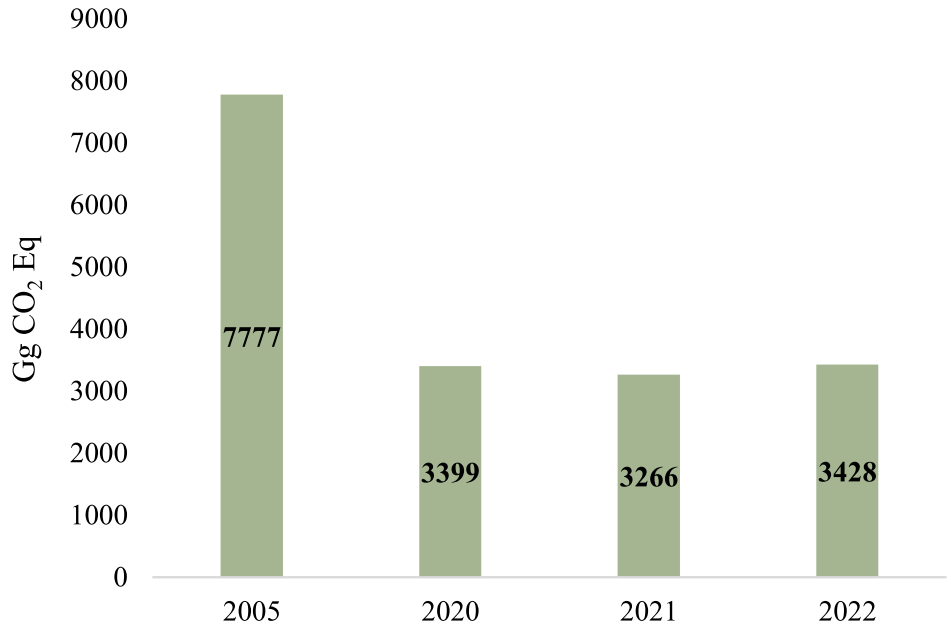


Figure 3.25: GHG emissions from Mining activities (1. B.1. a.i.1.) in 2005, 2020-2022

Methodological issues

Emission factor for fugitive methane emission from underground mining is the amount of methane emitted per tonne of coal production. The gassiness of coal seams generally increases with the depth. Tier 2 approach considers country-specific variables such as depth, gassiness etc. of major coal seams to develop the emission factors. The coal seams in India are classified into following categories based on their gassiness as defined in the Regulation 2(12A) CMr. 1957 of DGMS as shown in Table 3.26. Hence, the degree of gassiness of coal seams is considered for developing the country specific EFs used in this report as these values are more relevant to the national circumstances and to adopt tier 2 approach to estimate the associated emissions.

Table 3.26: Classification of gassiness of coal seams as per DGMS (Deshmukh, 2001).

Gassiness degree	% of inflammable gas in general body of air	Rate of emission of gas m^3/tonne of coal raised
I	Below 0.1 and	Below 1
II	Above 0.1 and /or	1-10
III	–	Above 10

EFs for this category for India have been incorporated in the IPCC Emission Factor Database with designated EF IDs 122973-122975 for underground mining (IPCC, 2020) after due vetting of the Editorial Board. Emission factors for coal basins were derived from ventilation air sample data and a quantitative analysis that takes into account the gas content of the coal seam and the surrounding strata affected by mining activities (Singh and Kumar, 2016). These emission factors, combined with coal production data, were used to calculate the emission factor for underground coal mines. The emission factors used for estimating the emissions from coal mining and handling activities are presented in Table 3.27.

Table 3. 27: Country specific emission factors used for different categories to estimate the fugitive emissions from coal mining and handling activities

Category			Emission Factor (m^3 CH_4/t)
Underground Mines	Mining	Deg. I	2.91
		Deg. II	13.08
		Deg. III	23.64
	Post-Mining	Deg. I	0.98
		Deg. II	2.15
		Deg. III	3.12
Surface Mines	Mining	–	1.18
	Post-Mining	–	0.15

According to the GSI, the country's cumulative geological coal reserves as on April 1, 2024, amounted to 3,89,421 Mt (Coal Controller's Organization, 2023-24). Raw coal production is considered as the activity data for estimating methane emissions from coal mining and handling activities and are collected for underground mines. Coal production data for the year 2005 were collected from Statistics of Mines in India Vol. I (Coal) published by DGMS as it provides production data on a calendar year basis for mines categorised based on the gassiness level that is line with the country specific emission factors used for estimating fugitive emissions. However, this publication was discontinued since 2016. Hence, coal production data for the years 2020, 2021 and 2022 were collected from Annual Coal Directory of India published by Coal Controller's Organization, Ministry of Coal.

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

Fugitive emissions from coal mining and handling activities are estimated for the inventory years 2005, 2020, 2021, and 2022. To ensure time series consistency, activity data i.e. coal production data were collected from Statistics of Mines in India Vol. I (Coal) published by DGMS for the year 2005 and from Annual Coal Directory of India published by Coal Controller's Organization, Ministry of Coal for 2020, 2021 and 2022. Tier 2 approach

was adopted for the base year 2005 following the 2006 IPCC guidelines using the country-specific emission factors and activity data. Since then, coal production in the country has been steadily increasing. From 2005 onward, reporting continued utilizing the Tier 2 approach, as relevant data remains accessible. This consistency in methodology supports the reliability of the emission inventory. While activity data is taken from national statistics and emission factors from UNFCCC emission factor database, the uncertainties are inherited from these sources. However, there are no mention about the uncertainty in the activity data as well as emission factor in the respective sources and based on the expert judgment, the range of uncertainty would be similar to the default range provided in the 2006 IPCC Guidelines viz., ±1-2% for activity data and ±50-75% for emission factor

QA/QC and verification

A routine and consistent check is performed by CSIR-CIMFR for the categories 1.B.1.a.i.1. to ensure data integrity, correctness, and completeness, identify and address errors and omissions, and document and archive inventory material following the 2006 IPCC Guidelines. CSIR-CIMFR reviewed the national circumstances and rationale for selecting specific values and emission factors and provided transparent information on the steps to estimate emissions that includes methods for activity data collection, the data sources and the numbers. QA for the categories 1.B.1.a.i.1. is done by IIM Ahmedabad and NATCOM Cell, MoEFCC. Verifications for category 1.B.1.a.i.1. have been done by TAC, NATCOM Cell, MoEFCC.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

The tier 2 method is expected to continue over future years country-specific activity data available for estimating emissions for underground mines for the inventory purpose. Efforts will also be made to assess the accurate production data for different categories of underground coal mines based on the gassiness in India to improve the emission estimates by BTR-4.

3.3.1.1.1.2 Post-mining activities (1. B.1. a.i.2.)

Category description

Emissions from post-mining activities reflect the fugitive escape of gases from the coal after mining, i.e. during preparation, transportation, storage or crushing.

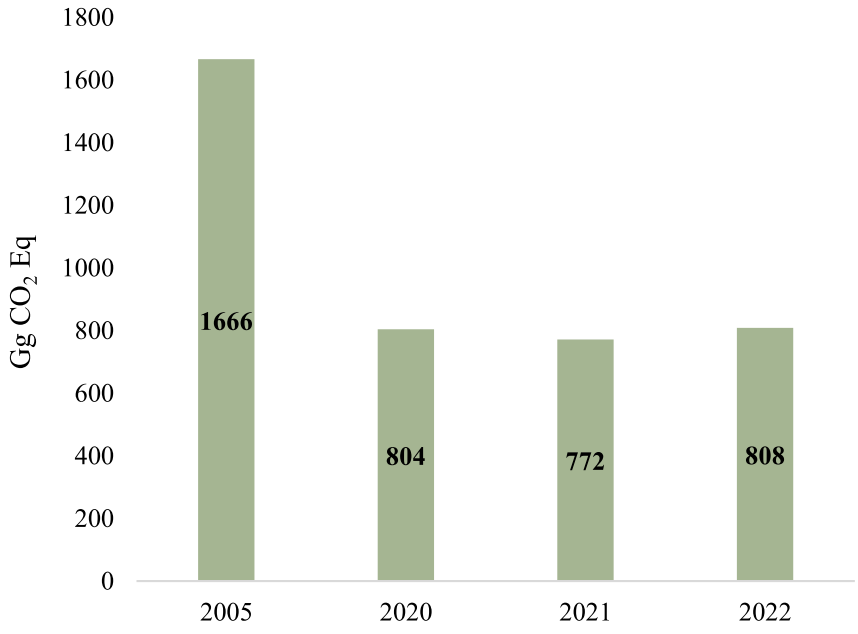


Figure 3.26: GHG emissions from Post-mining activities (1. B.1. a.i.2.) in 2005, 2020-2022

Methodological issues

Tier 2 methods to estimate post-mining emissions take into account the in-situ gas content of the coal. Measurements on coal as it emerges on a conveyor from an underground mine without degasification prior to mining indicate that 25-40 % of the in-situ gas remains in the coal (Williams and Saghafi, 1993). For CH_4 emission calculations, the Tier 2 methodology with country-specific emission factors was used (Singh and Kumar, 2016). These emission factors, combined with coal production data, were used to calculate the emission factor for underground coal mines.

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

Fugitive emissions from this category are estimated for the inventory years 2005, 2020, 2021, and 2022. To ensure time series consistency, activity data i.e. coal production data were collected from Statistics of Mines in India Vol. I (Coal) published by DGMS for the year 2005 and from Annual Coal Directory of India published by Coal Controller's Organization, Ministry of Coal for 2020, 2021 and 2022. This consistency in methodology supports the reliability of the emission inventory. While activity data is taken from national statistics and emission factors from UNFCCC emission factor database, the uncertainties are inherited from these sources. However, there are no mention about the uncertainty in the activity data as well as emission factor in the respective sources and based on the expert judgment, the range of uncertainty would be similar to the default range provided in the 2006 IPCC Guidelines viz., ±1-2% for activity data and ±50% for emission factor (GPG, 2000).

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

The tier 2 method is expected to continue over future years country-specific activity data available for estimating emissions for underground mines for the inventory purpose. Efforts will also be made to assess the accurate production data from different categories of underground coal mines based on the gassiness in India to improve the emission estimates by BTR-4.

3.3.1.1.1.3 Abandoned underground mines (number of mines) (1.B.1.a.i.3.)

Category description

After closure, coal mines that were significant methane emitters during mining operations continue to emit methane unless there is flooding that cuts off the emissions. Even if the mines have been sealed, methane may still be emitted to the atmosphere as a result of gas migrating through natural or manmade conduits such as old portals, vent pipes, or cracks and fissures in the overlying strata. Emissions quickly decline until they reach a near-steady rate that may persist for an extended period of time.

Methodological issues

Historical data on number of abandoned/non-producing mines, their year of closure and flooding conditions are not known which are required to estimate the methane emission from abandoned mines following 2006

IPCC Guidelines. In India, the surface mining accounted for 96.10% of the total coal production, and the rest 3.90% was from underground mining for the year 2022. As reported in BUR-3, opencast coal mines accounts 0.41% of country's total GHG emissions(without LULUCF) for the year 2016 while, underground coal 3 mines accounts only 0.12% of country's total GHG emission for the same year (MoEFCC, 2021). Gassy mines (Degree III) contributed 942 Kt CO_2e emissions for the year 2005. As per expert judgment, the maximum emissions from abandoned/non-producing gassy coal mines that would be possible is 942 Kt CO_2e which is less than 1000 Kt CO_2e and is 0.28% of the total GHG emissions(without LULUCF) of the country. As per MPGs, emission from this sub-category is considered insignificant and hence, not estimated. Due to a very few numbers of abandoned underground coal mines in India, abandonment done many years back, and very low production when the mines were active, the contribution of methane emissions from these is considered insignificant and not estimated. Table 1.1 shows summary of methods and emission factors.

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

Estimates for this category is not prepared as the historical data on number of abandoned/non-producing mines, their year of closure and flooding conditions are not known which are required to estimate the methane emission from abandoned mines following 2006 IPCC Guidelines. As described in the above section, the emission from this category is insignificant and hence not estimated. So, the uncertainty assessment and time-series consistency check are also not required for this category.

QA/QC and verification

The emission from this category is insignificant and hence not estimated. So, the QA/QC and verification are also not required for this category.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Efforts will be made to assess the number of abandoned mines in India to improve the emission estimates by BTR-4.

3.3.1.1.1.4 Flaring of drained methane or conversion of methane to CO_2 (1.B.1.a.i.4.)

Category description

Methane drained from working (or abandoned) underground (or surface) coal mines can be vented directly to the atmosphere, recovered and utilised, or converted to CO_2 through combustion (flaring or catalytic oxidation) without any utilisation. The manner of accounting for drained methane varies, depending on the final use of the methane.

Methodological issues

No coal mine methane drainage projects exist in India. However, coalbed methane (CBM) production from virgin coal seams has been started since 2008, and flaring emissions from this segment was included in 1.B.2.c.ii.3. Combined flaring from oil and natural gas sector.

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

Estimates for this category is not prepared as emissions from CBM production is counted in oil and natural gas sector. As described in the above section, the emission from this category is included elsewhere (IE). So, the uncertainty assessment and time-series consistency check are also not required for this category.

QA/QC and verification

The emission from this category is included elsewhere. So, the QA/QC and verification are also not required for this category.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

There are currently no planned improvements for this category.

3.3.1.1.1.5 Other (please specify) (1.B.1.a.i.5.)

Category description

In current scenario, there are no known sources other than underground mining and post-mining activities.

Methodological issues

No methodology is required as no activity is occurring under this sub-category.

Flexibility applied

No flexibility has been applied.

Uncertainty assessment and time-series consistency

Estimates for this category is not prepared as no known source is occurring. So, the uncertainty assessment and time-series consistency check are also not required for this category.

QA/QC and verification

The emission from this category is not occurring. So, the QA/QC and verification are also not required for this category.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

There are currently no planned improvements for this category.

3.3.1.1.2 Surface mines (1.B.1.a.ii.)

Category description and background

This category includes all seam gas emissions arising from surface coal mining includes bituminous, sub-bituminous and lignites. It was found that the surface mines produced 357 MT, 724 MT, 775 Mt and 875 Mt of coal for the year 2005, 2020, 2021 and 2022 with a corresponding estimate for methane emission of 282.1 Gg, 572.8 Gg, 612.6 Gg and 691.7 Gg, respectively. Corresponding methane emissions due to post-mining activities of coal produced from the surface coal mines for the years 2005, 2020, 2021, 2022 were estimated at 35.8 Gg, 72.8 Gg, 77.9 Gg and 87.9 Gg.

Table 3.28: Activity data for Surface mines in Mt for 2005, 2020-2022

Source/Sink Categories	Activity Data	2005	2020	2021	2022
1.B.1.a.ii. Surface mines (4)	Amount of fuel produced (Mt)	356.76	724.45	774.83	874.91

3.3.1.1.2.1 Mining activities (1.B.1.a.ii.1.)

Category description

This category includes methane emitted during mining from breakage of coal and associated strata and leakage from the pit floor and highwall. For surface mining the emissions of greenhouse gases are generally dispersed over sections of the mine and are best considered area sources. These emissions may be the result of seam gases emitted through the processes of breakage of the coal and overburden, low temperature oxidation of waste coal.

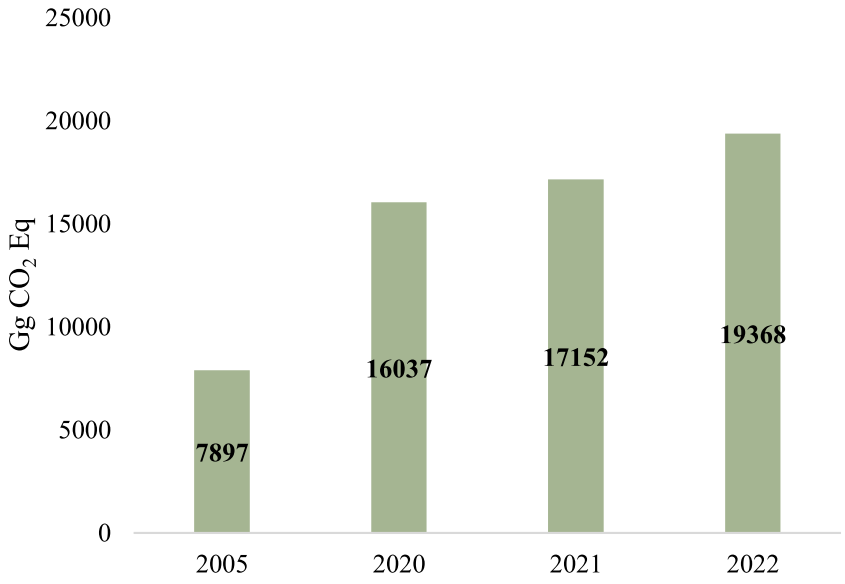


Figure 3.27: GHG emissions from Mining activities (1.B.1.a.ii.1.) in 2005, 2020-2022

Methodological issues

For CH_4 emission calculations, the Tier 2 methodology with country-specific emission factors was used. The emission factors (EFs) for this category for India have been incorporated in the IPCC Emission Factor Database with designated EF IDs 124920 for surface mining (IPCC, 2020) after due vetting of the Editorial Board. Emission factors for coal basins were derived from ventilation air sample data and a quantitative analysis that takes into account the gas content of the coal seam and the surrounding strata affected by mining activities (Singh and Kumar, 2016). These emission factors, combined with coal production data, were used to calculate the emission factor for surface coal mines.

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 (“Information on Flexibility”) of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

Fugitive emissions from this category are estimated for the inventory years 2005, 2020, 2021, and 2022. To ensure time series consistency, activity data i.e. coal production data were collected from Statistics of Mines in India Vol. I (Coal) published by DGMS for the year 2005 and from Annual Coal Directory of India published by Coal Controller’s Organization, Ministry of Coal for 2020, 2021 and 2022. This choice was made because raw coal production data are available for mines. However, there are no mention about the uncertainty in the activity data as well as emission factor in the respective sources and based on the expert judgment, the range

of uncertainty would be similar to the default range provided in the 2006 IPCC Guidelines viz., ±1-2% for activity data and ±50-75% for emission factor (GPG, 2000).

QA/QC and verification

A routine and consistent check is performed by CSIR-CIMFR for this category to ensure data integrity, correctness, and completeness, identify and address errors and omissions, and document and archive inventory material following the 2006 IPCC Guidelines. QA for the categories 1.B.1.a.i.4. is done by IIM Ahmedabad and NATCOM Cell, MoEFCC. Verifications for category 1.B.1.a.i.4. have been done by TAC, NATCOM Cell, MoEFCC.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

There are currently no planned improvements for this category.

3.3.1.1.2.2 post-mining activities (1. B.1.a.ii.2.)

Category description

This category includes methane and CO_2 emitted after coal has been mined, subsequently processed, stored and transported.

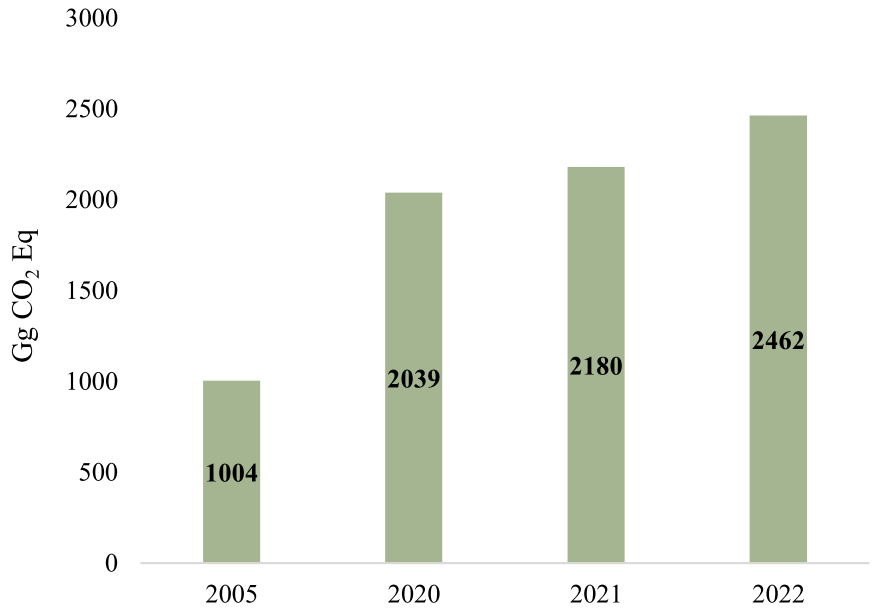


Figure 3.28: GHG emissions from post-mining activities (1. B.1.a.ii.2.) in 2005, 2020-2022

Methodological issues

For CH_4 emission calculations, the Tier 2 methodology with country-specific emission factors was used. The EFs for this category for India have been incorporated in the IPCC Emission Factor Database with designated EF IDs 124921 for post-surface mining (IPCC, 2020) after due vetting of the Editorial Board. Emission factors for coal basins were derived from ventilation air sample data and a quantitative analysis that takes into account the gas content of the coal seam and the surrounding strata affected by mining activities (Singh and Kumar, 2016). These emission factors, combined with coal production data, were used to calculate the emission factor for surface coal mines.

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

Fugitive emissions from this category are estimated for the inventory years 2005, 2020, 2021, and 2022. To ensure time series consistency, activity data i.e. coal production data were collected from Statistics of Mines in India Vol. I (Coal) published by DGMS for the year 2005 and from Annual Coal Directory of India published by Coal Controller's Organization, Ministry of Coal for 2020, 2021 and 2022. This choice was made because raw coal production data are available for mines. However, there are no mention about the uncertainty in the activity data as well as emission factor in the respective sources and based on the expert judgment, the range of uncertainty would be similar to the default range provided in the 2006 IPCC Guidelines viz., ±1-2% for activity data and ±50% for emission factor (GPG, 2000).

QA/QC and verification

A routine and consistent check is performed by CSIR-CIMFR for this category to ensure data integrity, correctness, and completeness, identify and address errors and omissions, and document and archive inventory material following the 2006 IPCC Guidelines. QA for the categories 1.B.1.a.i.4. is done by IIM Ahmedabad and NATCOM Cell, MoEFCC. Verifications for category 1.B.1.a.i.4. have been done by TAC, NATCOM Cell, MoEFCC.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

There are currently no planned improvements for this category.

3.3.1.1.2.3 Other (1.B.1.a.ii.3.)

Category description

After closure, abandoned or decommissioned surface mines may continue to emit methane as the gas leaks from the coal seams that were broken or damaged during mining.

Methodological issues

There are at present no methods for estimating emissions from this source is provided in IPCC 2006 GL.

Flexibility applied

No flexibility has been applied.

Uncertainty assessment and time-series consistency

Estimates for this category is not prepared as no known source is occurring. So, the uncertainty assessment and time-series consistency check are also not required for this category.

QA/QC and verification

The emission from this category is not occurring. So, the QA/QC and verification are also not required for this category.

Recalculations

No recalculations required as the emissions are not occurring for this category.

Planned Improvements

There are currently no planned improvements.

3.3.1.2. Fuel transformation (1.B.1.b.)

Category description and background

This category includes emissions from fuel transformation viz., Charcoal and biochar production, coke production, coal to liquids, coal to gas etc. Table 1.4 shows summary of methods and emission factors for categories 1.B.1.b. Fuel transformations and 1.B.1.c. Other.

Table 3.29: Summary of methods and emission factors: 1.B.1.b. Fuel transformations and 1.B.1.c. Other.

	CH_4		CO_2	
Source Category	Method Applied	Emission Factor	Method Applied	Emission Factor
1.B.1.b. Fuel transformations	NO, IE	NO, IE	NO, IE	NO, IE
1.B.1.b.i. Charcoal and biochar production	NO	NO	NO	NO
1.B.1.b.ii. Coke production	IE	IE	IE	IE
1.B.1.b.iii. Coal to liquids	NO	NO	NO	NO
1.B.1.b.iv. Gas to liquids	NO	NO	NO	NO
1.B.1.b.v. Other	NO	NO	NO	NO
GHG emissions from other gasification	NO	NO	NO	NO
Other fuel transformation	NO	NO	NO	NO
1.B.1.c. Other	NE, NO	NE, NO	NE, NO	NE, NO
Uncontrolled combustion and burning of coal dumps	NE	NE	NE	NE
Other solid fuels	NO	NO	NO	NO

3.3.1.2.1 Charcoal and biochar production (1.B.1.b.i.)

Category description

About half the wood extracted worldwide from forests is used to produce energy, mostly for cooking and heating. Some of the wood is used to make charcoal. Charcoal is produced by the carbonization of wood. Carbonization of fuel is the thermal decomposition in the absence of oxygen at a temperature above 300°C. The carbonization of wood produces charcoal, volatile compounds and a range of gases. The gases produced include direct greenhouse gases (CO_2, CH_4 and N_2O), indirect greenhouse gases (CO) and other gases, including H2. Some biochar is also produced from harvested wood, which is mainly applied in soils (please refer to AFOLU Chapter for details) and also some biochar produced could be used for making biochar briquettes that are used for energy purposes. Charcoal and biochar are produced by the pyrolysis method but under different conditions.

Methodological issues

Emission from this category is not estimated as no methodology has been provided by IPCC 2006 GL and hence, is not mandatory as per MPG.

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

Estimate for this category is not prepared as it is not mandatory as per MPG. So, the uncertainty assessment and time-series consistency check are not required for this category.

QA/QC and verification

The emission from this category is not estimated, the QA/QC and verification are not required for this category.

Recalculations

No recalculations are required as the emissions are not estimated for this category.

Planned Improvements

There are currently no planned improvements for this category.

3.3.1.2.2 Coke production (1.B.1.b.ii.)

Category description

Coke is produced by the pyrolysis of coal. It is a managed thermal treatment of the coal which limits combustion or oxidation of the coal or coke product. Coal pyrolysis at high temperature is called carbonisation. The process produces coke, volatile compounds and a range of other gases. In the process of coke production, the coal is heated indirectly up to 1000 – 1100°C for 14 – 28 hours. Coke is the most important reducing agent used in primary metal production. Other uses of coke include as a heating fuel and feedstock. There are many potential sources of fugitive emissions from the coking process.

Methodological issues

To avoid double counting (carbon mass balance); emissions from physical transformation (crushing and handling) for this category is included under 3.3.1.1.1.2 Post-mining activities (1. B.1. a.i.2.), 3.3.1.1.2.2 Post-mining activities (1. B.1. a.ii.2.) and emissions from chemical transformation part is included under the sub-categories 1.A.2.a. Iron and steel and 2.C.1. Iron and steel production. Thus, emission from this category is included elsewhere (IE).

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 (“Information on Flexibility”) of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

Estimate for this category is not prepared as emissions from this category is counted in post-mining activities (CRT categories 1.B.1.a.i.2. and 1.B.1.a.ii.2.) and sub-categories 1.A.2.a. Iron and steel and 2.C.1. Iron and steel production. As described in the above section, the emission from this category is included elsewhere. So, the uncertainty assessment and time-series consistency check are not required for this category.

QA/QC and verification

The emission from this category is included elsewhere. So, the QA/QC and verification are not required for this category.

Recalculations

No recalculations required as the emissions are included elsewhere for this category.

Planned Improvements

There are currently no planned improvements for this category.

3.3.1.2.3 Coal to liquids (1.B.1.b.iii.)

Category description

Till 2022, no known coal to liquid projects and production facility was occurring in India.

Methodological issues

No method currently exists for estimating emissions from this sub-source category.

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

Estimate for this category is not prepared as no coal to liquid production project is occurring. So, the uncertainty assessment and time-series consistency check are not required for this category.

QA/QC and verification

The emission from this category is not occurring. So, the QA/QC and verification are not required for this category.

Recalculations

No recalculations required as the emissions are not occurring for this category.

Planned Improvements

There are currently no planned improvements for this category.

3.3.1.2.4 Gas to liquids (1.B.1.b.iv.)

Category description

Till 2022, no known coal gasification and gas to liquid projects and production facility was occurring in India.

Methodological issues

No methodology had been applied for emission estimation as no such facility exists.

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

Estimate for this category is not prepared as no gas to liquids production facility or projects occur in the country. So, the uncertainty assessment and time-series consistency check are not required for this category.

QA/QC and verification

The emission from this category is not occurring. So, the QA/QC and verification are also not required for this category.

Recalculations

No recalculations required as the emissions are not occurring for this category.

Planned Improvements

There are currently no planned improvements for this category.

3.3.1.2.5 Other (1.B.1.b.v.)

Category description

There are no known sources are identified under to this segment for the years 2005, 2020, 2021 and 2022.

Methodological issues

No method currently exists for estimating emissions from this sub-source category as per 2006 IPCC GL.

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 (“Information on Flexibility”) of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

Estimates for this category is not prepared as no known source is occurring. So, the uncertainty assessment and time-series consistency check are not required for this category.

QA/QC and verification

The emission from this category is not occurring. So, the QA/QC and verification are not required for this category.

Recalculations

No recalculations required as the emissions are not occurring for this category.

Planned Improvements

There are currently no planned improvements for this category.

3.3.1.3. Other (1.B.1.c.)

Category description

The segment includes CO_2 emissions from uncontrolled combustion and burning coal dumps.

Methodological issues

No method currently exists for estimating emissions from this sub-category as per 2006 IPCC GL.

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 (“Information on Flexibility”) of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

Estimate for this category is not prepared as emissions from uncontrolled combustion and burning coal dumps is not mandatory as per IPCC 2006 Guidelines. So, the uncertainty assessment and time-series consistency check are not required for this category.

QA/QC and verification

The emission from this category is not estimated. So, the QA/QC and verification are not required for this category.

Recalculations

No recalculations required as the emissions are not estimated for this category.

Planned Improvements

There are currently no planned improvements for this category.

3.3.2. Oil and natural gas and other emissions from energy production (1.B.2.)

Category description and background

Oil and natural gas systems (CRT category 1.B.2.) include all infrastructure required to produce, collect, process, refine, and deliver natural gas and petroleum products to market (IPCC, 2019). The system begins at the well head or oil and gas source and ends at the final sales point to the consumer. Fugitive emissions may be unintentional or engineered, and the quantity and composition of emissions is generally subject of significant uncertainty and may be categorised as leakage, venting, and flaring depending on the source type (IPCC, 2019). Oil and natural gas systems include exploring, producing and upgrading, refining or processing, transporting, storage and marketing/distributing crude oil, natural gas and refined products (Fig.3.29). Often, there is sequential extraction of oil and natural gas. Fugitive emissions arise from the release of CH_4 and formation CO_2 present in the oil and gas when leaving the reservoir, and may include N_2O emissions from oil exploration, production and refining, gas production and processing and LPG transport. Venting and flaring constitute distinct fugitive emission sources. Although they occur in practically all segments of the oil and gas industry, they are assigned special categories in the 2006 IPCC Guidelines and in the CRTs. The CRTs include subcategory 1.B.2.c venting and flaring and further subdivided into three subcategories: (i) oil; (ii) gas and (iii) combined. The expansion of onshore and offshore petroleum projects happened till the mid-2010s. In recent years 2020-22, however, fugitive methane emissions from oil and natural gas systems remain significant due to the import associated with the increase in demand for oil, natural gas, and petroleum products in the country. The activities associated with oil and gas extraction, processing, and distribution are thought to be responsible for the growth of these fugitive emissions. In 2022-23, India's crude oil imports rose by 9.57% compared to the previous year, with the majority of emissions stemming from flaring during oil production, transportation, and consumption (IPNG Statistics, 2022-23).

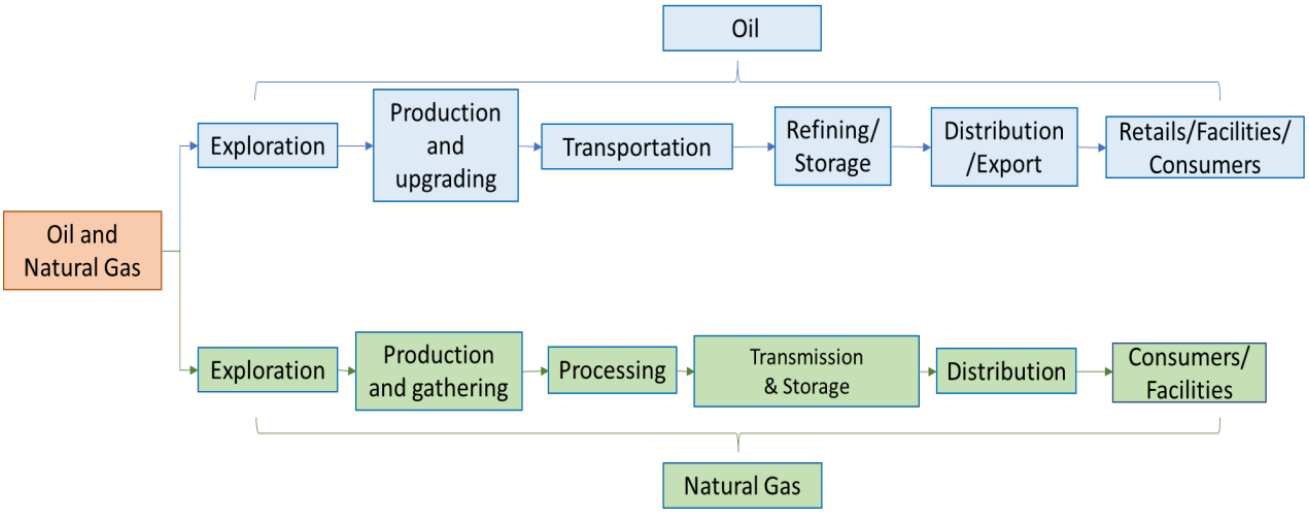


Figure 3.29: Different operational segments of the oil and gas sector

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

Category description and background

Oil systems include exploring, producing and upgrading, refining, transporting, storage and marketing/distributing crude oil. Despite the challenges posed by the COVID-19 pandemic and the Russia-Ukraine war, which created a volatile global energy market, India managed to produce 26% of its energy needs from crude oil and 8% from natural gas (IPNG Statistics, 2022-23). A graphical representation of the different structuring in the 2006 IPCC Guidelines, the 2019 Refinement to the 2006 IPCC Guidelines and the CRT. Activity data values were collected from IPNG Statistics 2005-06, 2008-09, 2009-10 for the year 2005 and IPNG Statistics 2019-20, 2020-21, 2021-22, 2022-23 for the year 2020, 2021 and 2022. India's domestic oil production is currently insufficient to meet its growing energy demand, necessitating substantial imports of crude oil. The emissions from oil accounted 942 $GgCO_2e$ for the years 2005, 1341 $GgCO_2e$ for the years 2020, 1336 $GgCO_2e$ for the years 2021, and 1390 $GgCO_2e$ for the years 2022.

3.3.2.1.1 Exploration (1.B.2.a.i.)

Category description

Fugitive emissions (excluding venting and flaring) from oil well exploration. The emissions from segment had been included in combined venting and combined flaring section.

Methodological issues

The inventory for fugitive emissions from oil sector in India is prepared based on Tier 1 approach using the default emission factors based on 2019 Refinement to the 2006 IPCC Guidelines. According to the 2006 IPCC Guidelines, the Oil sector was broadly divided into three subcategories: venting, flaring, and others. However, as per the 2019 Refinement to the 2006 IPCC Guidelines, this is subcategorized as Oil Exploration, Oil Production and Upgrading, Oil Transport, Refining, Distribution of Oil Products and Abandoned Oil Wells, which further divided into venting, flaring and leakage. This refined classification allows for more precise calculation of venting, flaring and leakage percentages across each subcategory, improving the accuracy and ease of the emissions reporting (IPCC, 2019). The structuring in the 2019 Refinement to the 2006 IPCC Guidelines is based on the major types of activities in the oil and gas industry without explicitly mentioning venting and flaring (IPCC, 2019). To develop separate estimates for venting, flaring and leak emissions from the aggregated emissions estimated using the default tier 1 EFs in section 4.2.2.3, annex 4A.2 to the 2019 Refinement to the 2006 IPCC Guidelines (p.4.128) provides default fractions of emissions in each subcategory.

Disaggregated emission factor for all the components viz. leaks, vents and flare are obtained by multiplying this default emission factor with disaggregation percentage (IPCC, 2019). This disaggregated EF is multiplied with activity data to estimate the proportions of emissions resulting from venting, flaring, and leakage.

Tier 1 default EF has been used for each category. However, the choice of emission factor for some sub-segments is based on technologies practiced in the country. Since the technology practiced is either limited or not very clearly known for the following sub-segments in India, the choice of default EFs is made in accordance with the 2019 Refinement to the 2006 Guidelines. Onshore conventional oil production was used as activity data. The emission from this category is included elsewhere as in sub-categories 1.B.2.c.i.3. and 1.B.2.c.ii.3.

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 (“Information on Flexibility”) of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

Fugitive emission estimates for oil and natural gas systems (1.B.2.) have been prepared in accordance to the Tier 1 approach as laid down in 2006 IPCC Guidelines for National Greenhouse Gas Inventories for the base year 2005. The activity data were accessed from IPNG Statistics, Ministry of Petroleum and Natural Gas that provide data for Oil and Natural gas sectors in India. The methodologies and default EFs were used from 2019 Refinement to 2006 IPCC Guidelines. As the corresponding activity data for all the years are available in IPNG statistics, same method is followed using the same EFs to maintain the time series consistency. The uncertainty in activity data is not provided in the national statistics. The default uncertainty in activity data and EFs are as specified in 2019 Refinement to 2006 IPCC Guidelines.

QA/QC and verification

The emission from this category is included elsewhere in sub-categories 1.B.2.c.i.3. combined venting and 1.B.2.c.ii.3. combined flaring. So, the QA/QC and verification are also not required for this category.

Recalculations

No recalculations required as the emissions are included elsewhere for this category.

Planned Improvements

There are currently no planned improvements for this category.

3.3.2.1.2 Production and upgrading (1.B.2.a.ii.)

Category description

Fugitive emissions from oil production (excluding venting and flaring) occur at the oil wellhead or at the oil sands or shale oil mine through to the start of the oil transmission system. This includes fugitive emissions related to oil production, transport of untreated production to treating or extraction facilities, activities at extraction and upgrading facilities, associated gas re-injection systems and produced water disposal systems.

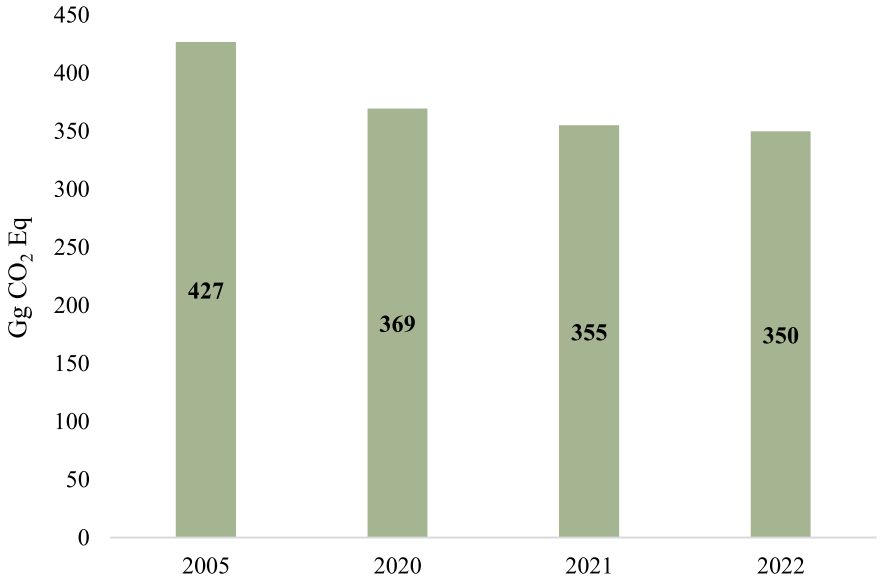


Figure 3.30: GHG emissions from Production and upgrading (1.B.2.a.ii.) in 2005, 2020-2022

Methodological issues

The inventory for fugitive emissions from oil sector in India is prepared based on Tier 1 approach using the default emission factors based on 2019 Refinement to the 2006 IPCC Guidelines. The emission factor opted for onshore oil production is based on "Most activities are occurring with higher-emitting technologies and practices" as the use of lower-emitting technologies is rare or unknown in Indian context. Total onshore and offshore crude oil productions were used as activity data and are taken from IPNG statistics. The CO_2 emission from this category is included elsewhere as in sub-categories 1.B.2.c.i.3. Combined (Venting) and 1.B.2.c.ii.3. Combined (Flaring).

Table 3.30: Activity data for Production and upgrading in 10^3 m^3 for 2005, 2020-2022

Source/ Sink Category	Activity Data	2005	2020	2021	2022
1.B.2.a.ii. Production and upgrading	Oil produced (10^3m^3)	37813.57	35855.21	34823.02	34237.02

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

Fugitive emission estimates for this category had been prepared in accordance to the Tier 1 approach as laid down in 2006 IPCC Guidelines for National Greenhouse Gas Inventories for the base year 2005 and same method was applied for subsequent years. The uncertainty in activity data is not provided in the national statistics. The default uncertainty in activity data and EFs are as specified in 2019 Refinement to 2006 IPCC Guidelines.

QA/QC and verification

A routine and consistent check is performed by CSIR-CIMFR for this category. QA is done by IIM Ahmedabad and NATCOM Cell, MoEFCC. Verifications have been done by TAC, NATCOM Cell, MoEFCC.

Recalculations

No recalculations required for this category.

Planned Improvements

There are currently no planned improvements for this category.

3.3.2.1.3 Transport (1.B.2.a.iii.)

Category description

Fugitive emissions (excluding venting and flaring) related to the transport of marketable crude oil to upgraders and refineries. The transportation systems may comprise pipelines, tank trucks and rail cars, tanks, and tanker ships. Evaporation losses from storage, filling and unloading activities and fugitive equipment leaks are the primary sources of these emissions.

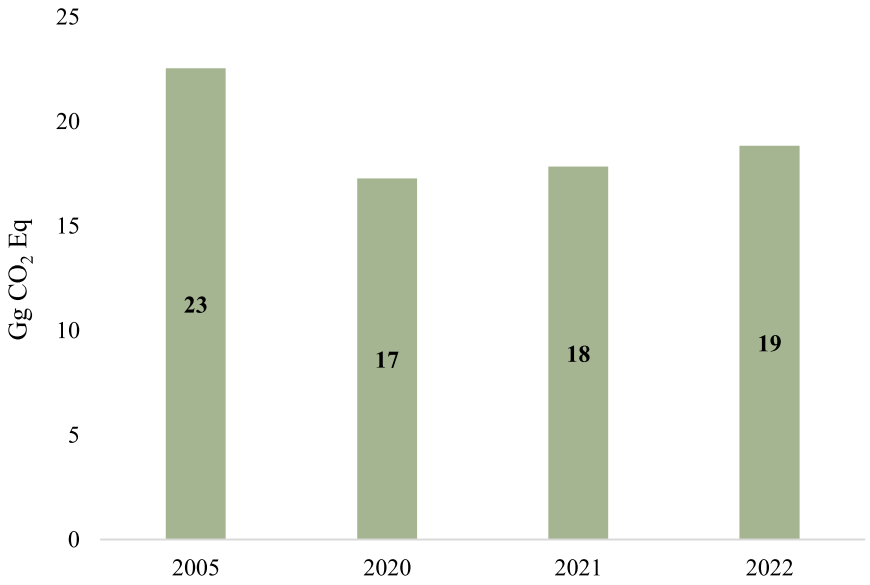


Figure 3.31: GHG emissions from Transport (1.B.2.a.iii.) in 2005, 2020-2022

Methodological issues

The inventory for fugitive emissions from oil sector in India is prepared based on Tier 1 approach using the default emission factors based on 2019 Refinement to the 2006 IPCC Guidelines. Total refinery crude throughput (pipelines) was used as activity data and was taken from IPNG statistics.

Table 3.31: Activity data for Transport in 10^3 m^3 for 2005, 2020-2022

Source/ Sink Category	Activity Data	2005	2020	2021	2022
1.B.2.a.iii. Transport	Oil transported by pipelines (10^3m^3)	148596	113917	117618.4	124218.13

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 (“Information on Flexibility”) of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

Fugitive emission estimates for this category had been prepared in accordance with the Tier 1 approach as laid down in 2006 IPCC Guidelines for National Greenhouse Gas Inventories for the base year 2005 and same method was applied for subsequent years. The uncertainty in activity data is not provided in the national statistics.

The default uncertainty in activity data and EFs are as specified in 2019 Refinement to 2006 IPCC Guidelines.

QA/QC and verification

A routine and consistent check is performed by CSIR-CIMFR for this category. QA is done by IIM Ahmedabad and NATCOM Cell, MoEFCC. Verifications have been done by TAC, NATCOM Cell, MoEFCC.

Recalculations

No recalculations required for this category.

Planned Improvements

There are currently no planned improvements for this category.

3.3.2.1.4 Refining/storage (1.B.2.a.iv.)

Category description

This segment includes fugitive emissions (including leaks, venting, and flaring) at petroleum refineries. Refineries process crude oils, natural gas liquids and synthetic crude oils to produce final refined products (e.g., primarily fuels and lubricants). Methane emission sources include storage tanks, blowdowns, asphalt blowing, equipment leaks, vents, loading operations, wastewater treating, cooling towers, catalytic cracking/reforming/fluid cracking, flares.

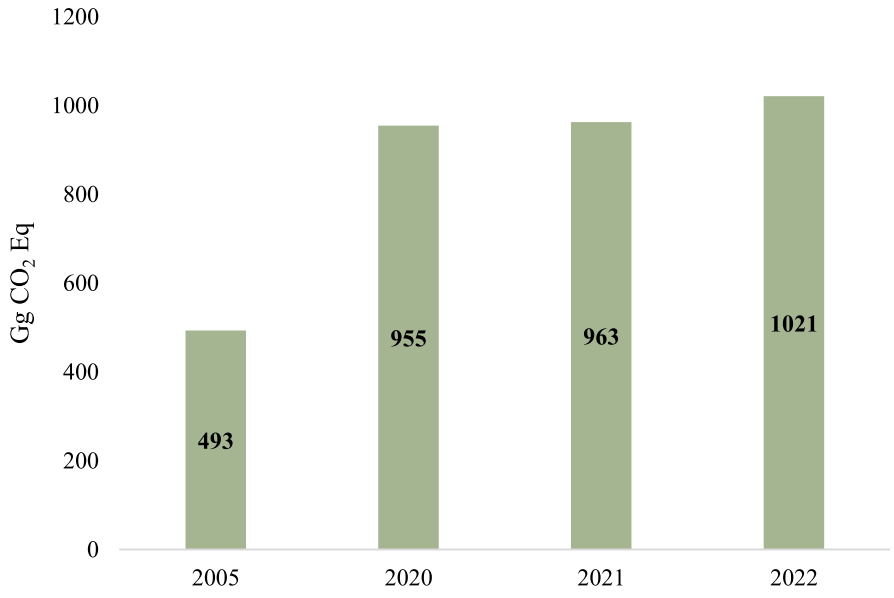


Figure 3.32: GHG emissions from Refining/storage (1.B.2.a.iv.) in 2005, 2020-2022

Methodological issues

The inventory for fugitive emissions from oil sector in India is prepared based on Tier 1 approach using the default emission factors based on 2019 Refinement to the 2006 IPCC Guidelines. Crude oil processed from IPNG statistics was used as activity data.

Table 3.32 Activity data for Refining/storage in 10^3 m^3 for 2005, 2020-2022

Source/ Sink Category	Activity Data	2005	2020	2021	2022
1.B.2.a.iv. Refining/storage	Crude processed (10^3m^3)	142382	275580.75	277999.29	294816.07

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

Fugitive emission estimates for this category had been prepared in accordance with the Tier 1 approach as laid down in 2006 IPCC Guidelines for National Greenhouse Gas Inventories for the base year 2005 and same method was applied for subsequent years. The methodologies and default EFs were used from 2019 Refinement to 2006 IPCC Guidelines. The uncertainty in activity data is not provided in the national statistics. The default uncertainty in activity data and EFs are as specified in 2019 Refinement to 2006 IPCC Guidelines.

QA/QC and verification

A routine and consistent check is performed by CSIR-CIMFR for this category. QA is done by IIM Ahmedabad and NATCOM Cell, MoEFCC. Verifications have been done by TAC, NATCOM Cell, MoEFCC.

Recalculations

This category required no recalculations.

Planned Improvements

There are currently no planned improvements.

3.3.2.1.5 Distribution of oil products (1.B.2.a.v.)

Category description

This segment includes fugitive emissions (including leaks and venting) from the transport and distribution of refined products, including those at bulk terminals and retail facilities. Evaporation losses from storage, filling and unloading activities and equipment leaks are the primary sources of these emissions.

Methodological issues

No emission factor had been provided for this segment in 2006 IPCC GL. Therefore, it is not mandatory as per MPG and hence, not estimated (NE).

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

Estimates for this category is not prepared as emissions from this segment is not mandatory following MPG. So, the uncertainty assessment and time-series consistency check are not required for this category.

QA/QC and verification

The emission from this category is not estimated. So, the QA/QC and verification are not required for this category.

Recalculations

No recalculations required as the emissions are not estimated for this category.

Planned Improvements

There are currently no planned improvements.

3.3.2.1.6 Other (1.B.2.a.vi.)

Category description and background

This category deals with the emissions from abandoned wells and other sources that are not included in any category.

3.3.2.1.6.1 Abandoned wells (1.B.2.a.vi.1.)

Category description

Abandoned wells are defined as wells that are no longer producing petroleum or exploration activities have ceased. There are several reasons of well abandonment exist viz., if wells have fulfilled their purpose; after the surrender of a production license; due to geological reasons; due to technical reasons; due to technological, ecological and other reasons.

Methodological issues

No method currently exists for estimating emissions from this sub-source category in 2006 IPCC GL and hence it is not a mandatory requirement as per MPG. So, these emissions are not estimated.

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

Estimates for this category is not prepared as emissions from this segment is not mandatory and hence, not estimated. So, the uncertainty assessment and time-series consistency check are not required for this category.

QA/QC and verification

The emission from this category is not estimated. So, the QA/QC and verification are not required for this category.

Recalculations

No recalculations required as the emissions are not estimated for this category.

Planned Improvements

There are currently no planned improvements for this category.

3.3.2.1.6.2 Other (1.B.2.a.vi.2.)

Category description

There exist no known sources in India to allocated under this segment.

Methodological issues

No methodology had been used.

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

Estimates for this category is not prepared as emissions from this segment is not occurring. So, the uncertainty assessment and time-series consistency check are not required for this category.

QA/QC and verification

The emission from this category is not occurring neither a methodology provided in IPCC GL. So, the QA/QC and verification are not required for this category.

Recalculations

No recalculations required as the emissions are not occurring for this category.

Planned Improvements

There are currently no planned improvements for this category.

3.3.2.2. Natural gas (1.B.2.b.)

Category description and background

Natural gas systems (CRT category 1.B.2.b.) include all infrastructure required to produce, collect, process, refine, and deliver natural gas to market (IPCC, 2019). The system begins at the well head or gas source and ends at the final sales point to the consumer. Fugitive emissions may be unintentional or engineered, and the quantity and composition of emissions is generally subject of significant uncertainty (IPCC, 2019). Natural gas systems include exploring, producing and gathering, processing, transmission, storage and marketing/distributing natural gas. The emissions from natural gas accounted 7873 $GgCO_2$ equivalent for the years 2005, 8254 $GgCO_2$ equivalent for the years 2020, 8844 $GgCO_2$ equivalent for the years 2021, and 8823 $GgCO_2$ equivalent for the years 2022.

3.3.2.2.1 Exploration (1.B.2.b.i.)

Category description

This segment includes fugitive emissions (includes equipment leaks) from gas field activities prior to production (e.g., prospecting and exploratory well drilling, well/drill stem testing, and well completions). No emissions had been provided by 2019 Refinement to the 2006 IPCC Guidelines for leakage.

Methodological issues

The inventory for fugitive emissions from natural gas sector in India is prepared based on Tier 1 approach using the default emission factors based on 2019 Refinement to the 2006 IPCC Guidelines. Onshore natural gas production and Onshore CBM was used as activity data; and it was taken from IPNG statistics. The EFs for leakage is zero as provided by 2019 Refinement to the 2006 IPCC Guidelines. The emissions from this category are included in sub-categories 1.B.2.c.i.3. Combined (Venting) and 1.B.2.c.ii.3. Combined (Flaring). Hence notation key IE is used.

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 (“Information on Flexibility”) of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

Estimates for this category is not prepared as emissions from this segment is included elsewhere, IE. So, the uncertainty assessment and time-series consistency check are not required for this category.

QA/QC and verification

The emission from this category is included elsewhere. So, the QA/QC and verification are not required for this category.

Recalculations

No recalculations required as the emissions are included elsewhere for this category.

Planned Improvements

There are currently no planned improvements for this category.

3.3.2.2.2 Production and gathering (1.B.2.b.ii.)

Category description

This segment includes fugitive emissions (includes leaks) from the gas wellhead through to the inlet of gas processing plants, or, where processing is not required, to the tie-in points on gas transmission systems. In the production stage, wells are used to withdraw raw gas from underground formations. Gathering and boosting emission sources are included within the production sector. The gathering and boosting stations receive natural gas from production sites and transfer it, via gathering pipelines, to processing facilities or transmission pipelines.

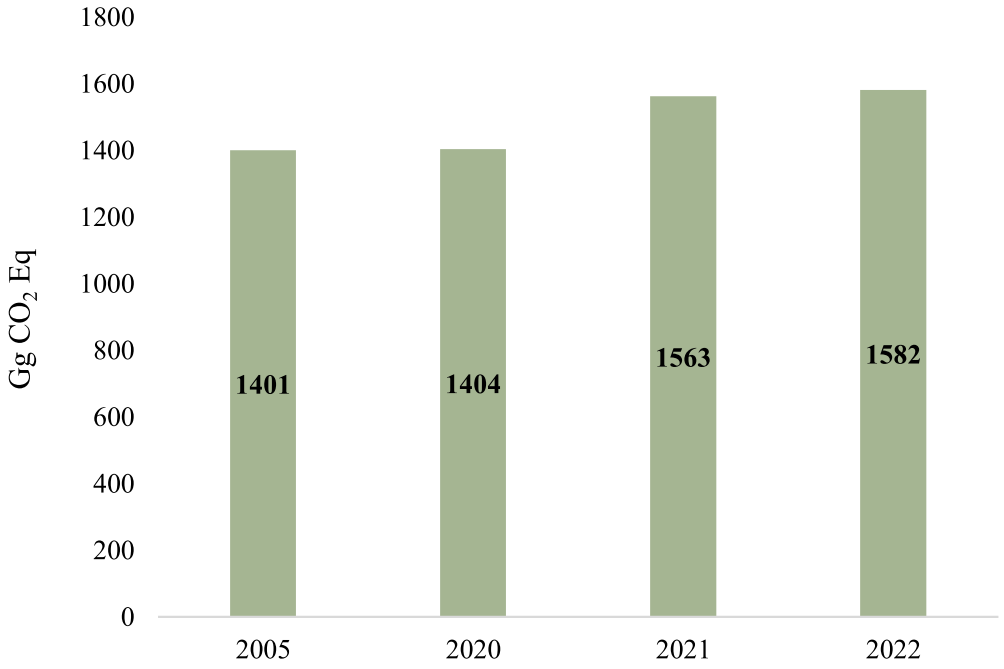


Figure 3.33: GHG emissions from Production and gathering (1.B.2.b.ii.) in 2005, 2020-2022

Methodological issues

The inventory for fugitive emissions from natural gas sector in India is prepared based on Tier 1 approach using the default emission factors based on 2019 Refinement to the 2006 IPCC Guidelines. Onshore natural gas, CBM and offshore gas production, in volume, are used as activity data taken from IPNG statistics. As the use of lower-emitting technologies and practices in India is infrequent or unknown, the emission factor for onshore natural gas is opted for the category 'most activities occurring with higher-emitting technologies and practices" as specified in 2019 Refinement to 2006 IPCC GL.

Table 3.33: Activity data for Production and gathering in 10^6 m^3 for 2005, 2020-2022

Source/Sink Category	Activity Data	2005	2020	2021	2022
1.B.2.b.ii. Production and gathering	Natural gas produced (10^6m^3)	31999	28493	33218	34218

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

Fugitive emission estimates for this category had been prepared in accordance with the Tier 1 approach as laid down in 2006 IPCC Guidelines for National Greenhouse Gas Inventories for the base year 2005 and same method was applied for subsequent years. The methodologies and default EFs were used from 2019 Refinement to 2006 IPCC Guidelines. The uncertainty in activity data is not provided in the national statistics. Hence, the uncertainty in activity data and EFs are set to the default values specified in 2019 Refinement to 2006 IPCC Guidelines.

QA/QC and verification

A routine and consistent check is performed by CSIR-CIMFR for this category. QA is done by IIM Ahmedabad and NATCOM Cell, MoEFCC. Verifications have been done by TAC, NATCOM Cell, MoEFCC.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Tier 1 default EF has been used for each category. However, the choice of emission factor for some sub-segments is based on technologies practiced in the country. Since the technology practiced is either limited or not very clearly known for the following sub-segments in India, the choice of default EFs are made in accordance with the 2019 Refinement to the 2006 Guidelines. Efforts will be made to assess the extent of different technologies practiced in different sub-segments across the oil and gas industry in India to select better EFs and to improve the emission estimates.

3.3.2.2.3 Processing (1.B.2.b.iii.)

Category description

This segment includes fugitive emissions (only leaks) from gas processing facilities. In this stage, natural gas liquids (NGLs) and various other constituents (e.g. sulphur) from the raw gas are removed, resulting in "pipeline quality" gas, which is injected into the transmission system. Emission sources include compressors, equipment leaks, pneumatic controllers, uncombusted gas from engines.

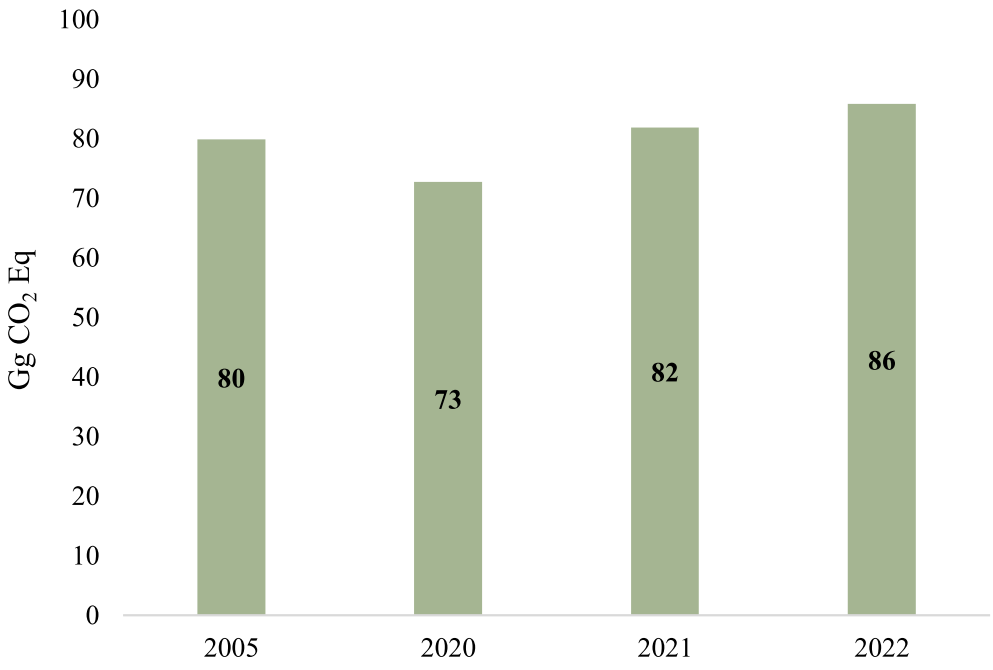


Figure 3.34: GHG emissions from Processing (1.B.2.b.iii.) in 2005, 2020-2022

Methodological issues

The inventory for fugitive emissions from natural gas sector in India is prepared based on Tier 1 approach using the default emission factors based on 2019 Refinement to the 2006 IPCC Guidelines. Total net availability of natural gas from IPNG statistics was used as activity data. The CO_2 emission from this category is included elsewhere (IE) in sub-categories 1.B.2.c.i.3. Combined (Venting) and 1.B.2.c.ii.3. Combined (Flaring). The emission factor corresponding to "Without LDAR, or with limited LDAR, or less than 50% of centrifugal compressors have dry seals" was used as the use LDAR technologies and practices is infrequent or unknown in India and the basis for disaggregation was chosen that of gas processed.

Table 3.34: Activity data for Processing in 10^6 m^3 for 2005, 2020-2022

Source/Sink Category	Activity Data	2005	2020	2021	2022
1.B.2.b.iii. Processing	Net availability (10^6m^3)	31187.50	28402.25	31783	33515

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

Fugitive emission estimates for this category had been prepared in accordance with the Tier 1 approach as laid down in 2006 IPCC Guidelines for National Greenhouse Gas Inventories for the base year 2005 and same method was applied for subsequent years. The methodologies and default EFs were used from 2019 Refinement to 2006 IPCC Guidelines. The uncertainty in activity data is not provided in the national statistics. Hence, the uncertainty in activity data and EFs are set to the default values specified in 2019 Refinement to 2006 IPCC Guidelines.

QA/QC and verification

A routine and consistent check is performed by CSIR-CIMFR for this category. QA is done by IIM Ahmedabad and NATCOM Cell, MoEFCC. Verifications have been done by TAC, NATCOM Cell, MoEFCC.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Tier 1 default EF has been used for each category. However, the choice of emission factor for some sub-segments is based on technologies practiced in the country. Since the technology practiced is either limited or not very clearly known for the following sub-segments in India, the choice of default EFs is made in accordance with the 2019 Refinement to the 2006 Guidelines. Efforts will be made to assess the extent of different technologies practiced in different sub-segments across the oil and gas industry in India to improve the emission estimates by BTR-4.

3.3.2.2.4 Transmission and storage (1.B.2.b.iv.)

Category description

This segment includes fugitive emissions (only leaks) from systems used to transport processed natural gas to market (i.e., to industrial consumers and natural gas distribution systems), including natural gas storage systems. Natural gas transmission involves high pressure, large diameter pipelines that transport gas long distances from field production and processing areas to distribution systems or large volume customers such as power plants or chemical plants. Compressor station facilities are used to move the gas throughout the transmission system. Emissions from natural gas liquids extraction plants on gas transmission systems should be reported as part of natural gas processing.

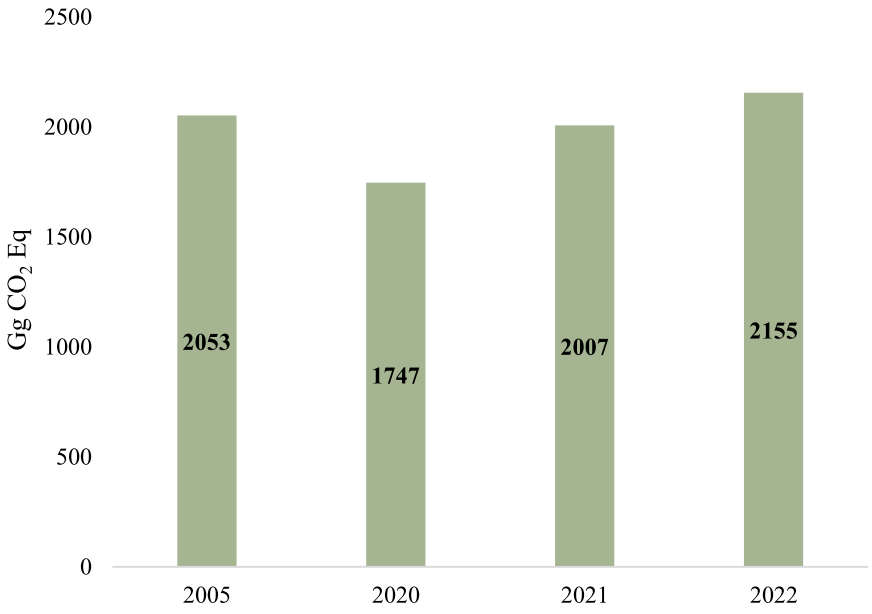


Figure 3.35: GHG emissions from Transmission and storage (1.B.2.b.iv.) in 2005, 2020-2022

Methodological issues

The inventory for fugitive emissions from natural gas sector in India is prepared based on Tier 1 approach using the default emission factors based on 2019 Refinement to the 2006 IPCC Guidelines. Natural gas sales (in volume) and LNG terminals (in number) from IPNG statistics are used as activity data. The emission factor applied for gas transmission is for the option "Limited LDAR or less than 50% of centrifugal compressors have dry seals"; and for gas storage is for the option "Limited LDAR or most activities occurring with higher-emitting technologies and practices" as the extent of technologies and practices occurring in India is either infrequent or unknown. The activity data used for both transmission and storage is volumetric gas consumption data in million cubic meters.

Table 3.35: Activity data for Transmission and storage in 10^6 m^3 for 2005, 2020-2022

Source/Sink Category	Activity Data	2005	2020	2021	2022
1.B.2.b.iv. Transmission and storage	Sales and consumed (10^6m^3), Terminal	52965	61389.25	63365	61017.5

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

Fugitive emission estimates for this category had been prepared in accordance with the Tier 1 approach as laid down in 2006 IPCC Guidelines for National Greenhouse Gas Inventories for the base year 2005 and same method was applied for subsequent years. The methodologies and default EFs were used from 2019 Refinement to 2006 IPCC Guidelines. The uncertainty in activity data is not provided in the national statistics. Hence, the uncertainty in activity data and EFs are set to the default values specified in 2019 Refinement to 2006 IPCC Guidelines.

QA/QC and verification

A routine and consistent check is performed by CSIR-CIMFR for this category. QA is done by IIM Ahmedabad and NATCOM Cell, MoEFCC. Verifications have been done by TAC, NATCOM Cell, MoEFCC.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Tier 1 default EF has been used for each category. However, the choice of emission factor for some sub-segments is based on technologies practiced in the country. Since the technology practiced is either limited or not very clearly known for the following sub-segments in India, the choice of default EFs is made in accordance with the 2019 Refinement to the 2006 Guidelines. Efforts will be made to assess the extent of different technologies practiced in different sub-segments across the oil and gas industry in India to improve the emission estimates by BTR-4.

3.3.2.2.5 Distribution (1.B.2.b.v.)

Category description

This segment includes fugitive emissions (including all sources) from the distribution of natural gas. Distribution pipelines take the high-pressure gas from the transmission system at "city gate" stations, reduce the pressure and distribute the gas through primarily underground mains and service lines to individual end users. Emission sources include leaks from pipelines, metering and regulating stations, meters and short-term surface storage. Short term surface storage means a man-made above-ground storage facilities, viz., spherical and pipe storage tanks, and other types of low-pressure containers, are used for storage of medium-sized quantities of natural gas, help meet and balance rapid fluctuations in demand.

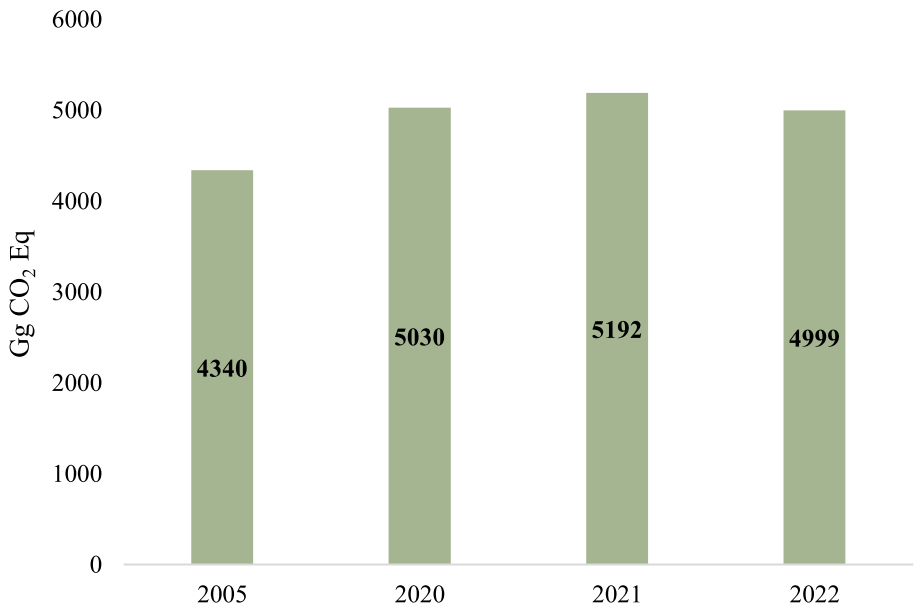


Figure 3.36: GHG emissions from Distribution (1.B.2.b.v.) in 2005, 2020-2022

Methodological issues

The inventory for fugitive emissions from natural gas sector in India is prepared based on Tier 1 approach using the default emission factors based on 2019 Refinement to the 2006 IPCC Guidelines. The first set of emission factors for gas distribution had been used ("Less than 50% plastic pipelines or limited or no leak detection and repair programs"). Total natural gas consumption was used as activity data; and it was taken from IPNG statistics.

The emission factor for gas distribution opted is based on "Less than 50% plastic pipelines or limited or no leak detection and repair programs" as the extent of LDAR practised is unknown in Indian context. The activity data selected is volumetric natural gas consumption in million cubic metres.

Table 3.36: Activity data for Distribution in 10^6 m^3 for 2005, 2020-2022

Source/Sink Category	Activity Data	2005	2020	2021	2022
1.B.2.b.v. Distribution	Natural gas consumed (10^6m^3)	52965.00	61389.25	63365.00	61017.50

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

Fugitive emission estimates for this category had been prepared in accordance with the Tier 1 approach as laid down in 2006 IPCC Guidelines for National Greenhouse Gas Inventories for the base year 2005 and same method was applied for subsequent years. The methodologies and default EFs were used from 2019 Refinement to 2006 IPCC Guidelines. The uncertainty in activity data is not provided in the national statistics. Hence, the uncertainty in activity data and EFs are set to the default values specified in 2019 Refinement to 2006 IPCC Guidelines.

QA/QC and verification

A routine and consistent check is performed by CSIR-CIMFR for this category. QA is done by IIM Ahmedabad and NATCOM Cell, MoEFCC. Verifications have been done by TAC, NATCOM Cell, MoEFCC.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Tier 1 default EF has been used for each category. However, the choice of emission factor for some sub-segments is based on technologies practiced in the country. Since the technology practiced is either limited or not very clearly known for the following sub-segments in India, the choice of default EFs are made in accordance with the 2019 Refinement to the 2006 Guidelines. Efforts will be made to assess the extent of different technologies practiced in different sub-segments across the oil and gas industry in India to improve the emission estimates by BTR-4.

3.3.2.2.6 Other (1.B.2.b.vi.)

Category description and background

This segment includes fugitive emissions beyond gas meters and from natural gas-fuelled vehicles.

3.3.2.2.6.1 Gas post-meter (1.B.2.b.vi.1.)

Category description

This segment includes fugitive emissions beyond gas meters and from natural gas-fueled vehicles. The emission factors for appliances and power plants include leakage emissions beyond gas meters, such as internal piping and the end of pipe appliances (e.g. home heating, water heating, stoves, barbecues).

Methodological issues

It is not a mandatory requirement as per MPG as no method exists in 2006 IPCC Guidelines for estimating these emissions. Hence, it is not estimated (NE).

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

Estimates for this category is not prepared as emissions from this segment is not mandatory and hence, not estimated. So, the uncertainty assessment and time-series consistency check are not required for this category.

QA/QC and verification

The emission from this category is not estimated. So, the QA/QC and verification are not required for this category.

Recalculations

No recalculations required as the emissions are not estimated for this category.

Planned Improvements

No improvement plans for this category.

3.3.2.2.6.2 Abandoned wells (1.B.2.b.vi.2.)

Category description

Wells that are no longer producing petroleum or where exploration has stopped are considered abandoned. There are a number of reasons why wells are abandoned, including when they have served their function, after a production license has been revoked, for geological reasons, for technical reasons, for ecological reasons, or for other reasons.

Methodological issues

No method exists as per 2006 IPCC Guidelines for estimating emissions from this sub-source category and hence, it is not a mandatory requirement as per MPG.

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

Estimate for this category is not prepared as no methodology provided in IPCC 2006 Guidelines. So, the uncertainty assessment and time-series consistency check are not required for this category.

QA/QC and verification

The emission from this category is not estimated. So, the QA/QC and verification are not required for this category.

Recalculations

No recalculations required as the emissions are not estimated for this category.

Planned Improvements

No improvement plans for this category.

3.3.2.2.6.3 Other (1.B.2.b.vi.3.)

Category description

Fugitive emissions (includes leaks) from natural gas systems not otherwise accounted for in the above categories. This may include emissions from well blowouts and pipeline ruptures or dig-ins, accidents, and emergency pressure releases.

Methodological issues

No method exists as per 2006 IPCC Guidelines for estimating emissions from this sub- category.

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

Estimates for this category is not prepared as the methodology is not provided in IPCC 2006 Guidelines. So, the uncertainty assessment and time-series consistency check are not required for this category.

QA/QC and verification

The emission from this category is not occurring. So, the QA/QC and verification are not required for this category.

Recalculations

No recalculations required as the emissions are not occurring for this category

Planned Improvements

No improvement plans for this category.

3.3.2.3. Venting and flaring (1.B.2.c.)

Category description and background

Venting (1.B.2.c.i.) refers to emissions that are the result of process or equipment design or operational practices. Venting at oil and gas processing facilities is mainly associated with the release of CO_2, which is extracted from the raw gas stream during gas processing (IPCC, 2019). 'Venting' denotes reported venting of waste associated and solution gas at oil production facilities and waste gas volumes from blowdown, purging and emergency relief events at gas facilities (IPCC, 2006). 'Flaring' denotes emissions from all continuous and emergency flare systems. Flare systems are designed to convey and dispose of the specified gas stream from various units safely and efficiently by flaring (IPCC, 2019). Table 8 shows summary of methods and emission factors for 1.B.2.c Venting and Flaring and 1.B.2.d. Other. The emissions from venting and flaring estimated 3714 $GgCO_2$ equivalent for the years 2005, 3186 $GgCO_2$ equivalent for the years 2020, 3536 $GgCO_2$ equivalent for the years 2021, and 3619 $GgCO_2$ equivalent for the years 2022.

3.3.2.3.1 Venting (1.B.2.c.i.)

Category description and background

Venting (1.B.2.c.i.) refers to emissions that are the result of process or equipment design or operational practices. 'Venting' denotes reported venting of waste associated and solution gas at oil production facilities and waste gas volumes from blowdown, purging and emergency relief events at gas facilities (IPCC, 2006). As separation of the other components of the gas stream from the CO_2 is incomplete, the vented CO_2 contains small quantities of CH_4.

In India, venting is prohibited as per 1986 CPCB guidelines, reaffirmed in 2005. Hence, flaring systems are in place in most facilities across the oil and gas industry in the country. Flare systems are designed to convey and dispose of the specified gas stream from various units safely and efficiently by flaring. Typically, gas sent to flare is mostly CH_4 with smaller concentrations of other volatile hydrocarbons and is usually different in composition to pipeline gas. Condensates and other petroleum liquids may also be flared in small quantities for disposal. Key components include a pipeline network for gas conveyance, a flare tip for combustion, and a continuous pilot system for ignition. To prevent flammable gas backflow and potential explosions, it is crucial to exclude oxygen/air from the flare stack, achieved by maintaining a constant purge gas bleed. Additionally, liquid seals, such as a water seal drum, function as non-return valves to prevent air leakage, while knockout drums are

utilized to separate liquid particles from the flare gas. However, some amount of emission may occur through venting because of technical reasons. Hence, volume natural gas losses as reported in IPNG statistics is used to estimate the emissions through venting that accounted 1595 $GgCO_2$ equivalent for the years 2005, 1238 $GgCO_2$ equivalent for the years 2020, 1626 $GgCO_2$ equivalent for the years 2021, and 1922 $GgCO_2$ equivalent for the years 2022.

3.3.2.3.1.1 Oil (1.B.2.c.i.1.)

Category description

'Venting' denotes reported venting of waste associated and solution gas at oil production facilities and waste gas volumes from blowdown, purging and emergency relief events at gas facilities (IPCC, 2006).

Methodological issues

The emission from this segment was reported under 1.B.2.c.i.3. Combined. Hence, the notation key IE is used.

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

Estimates for this category is not prepared as emissions from this segment is included elsewhere following IPCC 2006 Guidelines. So, the uncertainty assessment and time-series consistency check are not required for this category.

QA/QC and verification

The emission from this category is included elsewhere. So, the QA/QC and verification are not required for this category.

Recalculations

No recalculations required as the emissions are included elsewhere for this category.

Planned Improvements

There are currently no planned improvements for this category.

3.3.2.3.1.2 Gas (1.B.2.c.i.2.)

Category description

'Venting' denotes reported venting of waste associated and solution gas at oil production facilities and waste gas volumes from blowdown, purging and emergency relief events at gas facilities (IPCC, 2006).

Methodological issues

The emission from this segment was reported under Combined (1.B.2.c.i.3.). Hence, the notation key IE is used.

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

Estimates for this category is not prepared as emissions from this segment is included elsewhere following IPCC 2006 Guidelines. So, the uncertainty assessment and time-series consistency check are not required for this category.

QA/QC and verification

The emission from this category is included elsewhere. So, the QA/QC and verification are not required for this category.

Recalculations

No recalculations required as the emissions are included elsewhere for this category.

Planned Improvements

There are currently no planned improvements for this category.

3.3.2.3.1.3 Combined (1.B.2.c.i.3.)

Category description

'Venting' denotes reported venting of waste associated and solution gas at oil production facilities and waste gas volumes from blowdown, purging and emergency relief events at gas facilities.

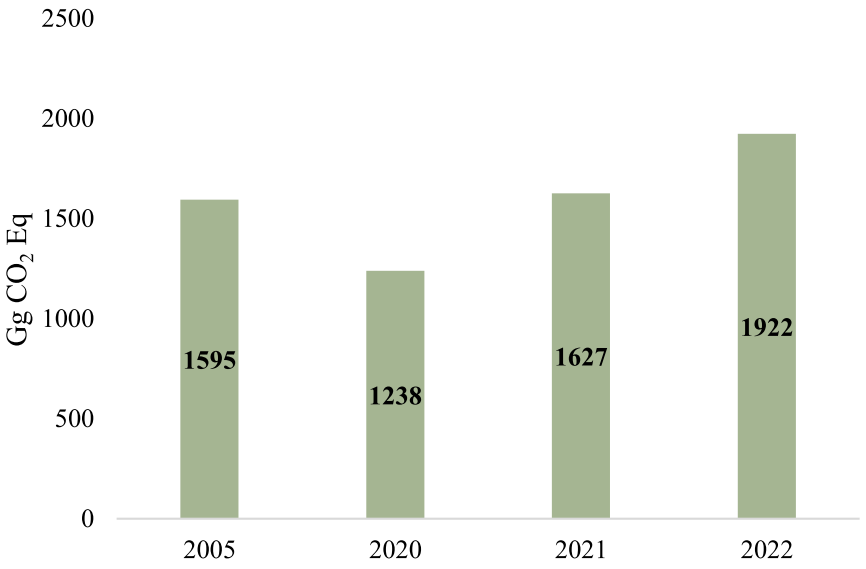


Figure 3.37: GHG emissions from Combined (1.B.2.c.i.3.) in 2005, 2020-2022

Methodological issues

As per 2006 IPCC Guidelines (Note 'g', Table no.4.2.5), where waste gas volumes are known, these should be used to determine venting emissions rather than applying the emission factors to production rates. The emission factors for direct estimation of CH_4 and CO_2 emissions from reported vented volumes are 0.66 and 0.0049 Gg, respectively, per 106 m3 of gas vented; it had been used. The actual vented volumes (losses) were known; and it was taken from IPNG Statistics.

Table 3.37: Activity data for Combined in 10^6 m^3 for 2005, 2020-2022

Source/ Sink Category	Activity Data	2005	2020	2021	2022
1.B.2.c.i.3. Combined	Gas losses (10^6m^3)	86	67	88	104

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

Fugitive emission estimates for this category had been prepared in accordance with the Tier 1 approach as laid down in 2006 IPCC Guidelines for National Greenhouse Gas Inventories for the base year 2005 and same method was applied for subsequent years. The methodologies and default EFs were used from 2006 IPCC Guidelines. The uncertainty in activity data is not provided in the national statistics. Hence, the uncertainty in AD and EFs are set to default values specified in 2019 Refinement to 2006 IPCC Guidelines.

QA/QC and verification

A routine and consistent check is performed by CSIR-CIMFR for this category. QA is done by IIM Ahmedabad and NATCOM Cell, MoEFCC. Verifications have been done by TAC, NATCOM Cell, MoEFCC.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

There are currently no planned improvements for this category.

3.3.2.3.2 Flaring (1.B.2.c.ii.)

Category description and background

'Flaring' denotes emissions from all continuous and emergency flare systems. Flare systems are designed to convey and dispose of the specified gas stream from various units safely and efficiently by flaring (IPCC, 2019). Typically, gas sent to flare is mostly CH_4 with smaller concentrations of other volatile hydrocarbons and is usually different in composition to pipeline gas. The emissions from flaring accounted 2119 $GgCO_2$ equivalent for the years 2005, 1947 $GgCO_2$ equivalent for the years 2020, 1909 $GgCO_2$ equivalent for the years 2021, and 1696 $GgCO_2$ equivalent for the years 2022.

3.3.2.3.2.1 Oil (1.B.2.c.ii.1.)

Category description

'Flaring' denotes emissions from all continuous and emergency flare systems. Flare systems are designed to convey and dispose of the specified gas stream from various units safely and efficiently by flaring (IPCC, 2019). Typically, gas sent to flare is mostly CH_4 with smaller concentrations of other volatile hydrocarbons and is usually different in composition to pipeline gas.

Methodological issues

The emission from this segment was reported under the sub-category 1.B.2.c.ii.3. Combined (Flaring). Hence, notation key IE is used.

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

Estimates for this category is not prepared as emissions from this segment is included elsewhere following IPCC 2006 Guidelines. So, the uncertainty assessment and time-series consistency check are not required for this category.

QA/QC and verification

The emission from this category is included elsewhere. So, the QA/QC and verification are not required for this category.

Recalculations

No recalculations required as the emissions are included elsewhere for this category

Planned Improvements

There are currently no planned improvements for this category.

3.3.2.3.2.2 Gas (1.B.2.c.ii.2.)

Category description

'Flaring' denotes emissions from all continuous and emergency flare systems. Flare systems are designed to convey and dispose of the specified gas stream from various units safely and efficiently by flaring (IPCC, 2019). Typically, gas sent to flare is mostly CH_4 with smaller concentrations of other volatile hydrocarbons and is usually different in composition to pipeline gas.

Methodological issues

The emission from this segment was reported under the sub-category 1.B.2.c.ii.3. Combined (Flaring). Hence, notation key IE is used.

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

Estimates for this category is not prepared as emissions from this segment is included elsewhere following IPCC 2006 Guidelines. So, the uncertainty assessment and time-series consistency check are not required for this category.

QA/QC and verification

The emission from this category is included elsewhere. So, the QA/QC and verification are not required for this category.

Recalculations

No recalculations required as the emissions are included elsewhere for this category.

Planned Improvements

There are currently no planned improvements for this category.

3.3.2.3.2.3 Combined (1.B.2.c.ii.3.)

Category description

'Flaring' denotes emissions from all continuous and emergency flare systems. Flare systems are designed to convey and dispose of the specified gas stream from various units safely and efficiently by flaring (IPCC, 2019). Typically, gas sent to flare is mostly CH_4 with smaller concentrations of other volatile hydrocarbons and is usually different in composition to pipeline gas.

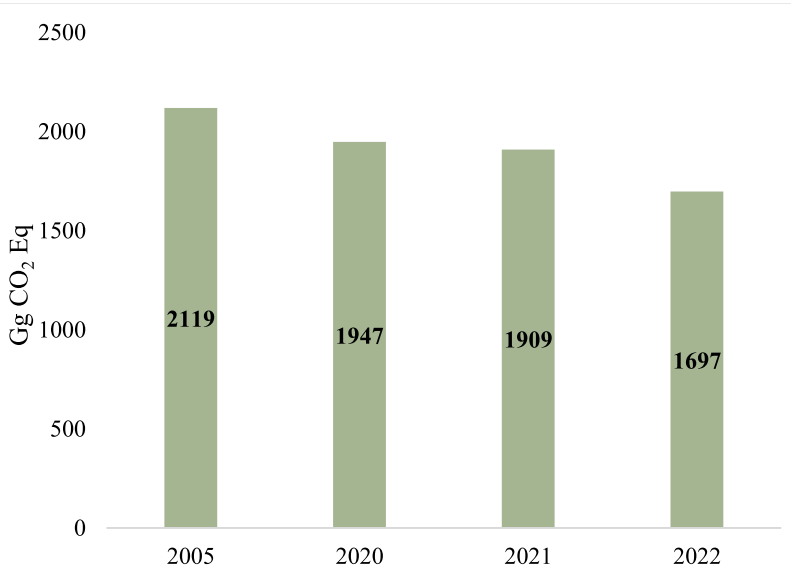


Figure 3.38: GHG emissions from Combined (1.B.2.c.ii.3.) in 2005, 2020-2022

Methodological issues

As per 2006 IPCC Guidelines (Note 'e', Table no.4.2.5), where actual flared volumes are known, these should be used to determine flaring emissions rather than applying the emission factors to production rates. The emission factors for direct estimation of CH_4, CO_2 and N_2O emissions from reported flared volumes are 0.012, 2.0 and 0.000023 Gg, respectively, per 106 m3 of gas flared. Hence, the flaring emission in this report is calculated based on the actual volume of gas flared as available in IPNG statistics.

Table 3.38 Activity data for Combined in 10^6 m^3 for 2005, 2020-2022

Source/Sink Category	Activity Data	2005	2020	2021	2022
1.B.2.c.ii.3. Combined	Gas flared (10^6m^3)	904.75	831.50	815.25	724.50

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

Fugitive emission estimates for this category had been prepared in accordance with the Tier 1 approach as laid down in 2006 IPCC Guidelines for National Greenhouse Gas Inventories for the base year 2005 and same method was applied for subsequent years. The methodologies and default EFs were used from 2006 IPCC Guidelines. The uncertainty in activity data is not provided in the national statistics. Hence, the uncertainty in AD and EFs are set to default values specified in 2006 IPCC Guidelines.

QA/QC and verification

CSIR-CIMFR conducts a regular and reliable check for this category. IIM Ahmedabad and the MoEFCC's NATCOM Cell handle quality assurance. TAC, NATCOM Cell, and MoEFCC have all conducted verifications.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

There are currently no planned improvements for this category.

3.3.2.4. Other (1.B.2.d.)

Category description

N_2O emissions from oil and natural gas systems as well as from other energy production sources fall under this category. However, there are any other known sources of energy production in India for this category.

Methodological issues

The inventory for fugitive emissions from natural gas sector in India is prepared based on Tier 1 approach using the default emission factors based on 2019 Refinement to the 2006 IPCC Guidelines. N_2O emission from sub-category '1.B.2.b.ii. Production and gathering' is appearing under '1.B.2.d. Other - N_2O emissions from Oil and Natural Gas Systems' UNFCCC CRT. Onshore production of natural gas from IPNG Statistics is used as the activity data for preparing the emission estimates.

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

Estimates for this category is not prepared as emissions from this segment is not occurring following IPCC 2006 Guidelines. So, the uncertainty assessment and time-series consistency check are also not required for this category.

QA/QC and verification

The emission from this category is not occurring. So, the QA/QC and verification are also not required for this category.

Recalculations

No recalculations required as the emissions are not occurring for this category.

Planned Improvements

There are currently no planned improvements for this category.

3.4. Carbon dioxide transport and storage (1.C.)

Category description and background

This category addresses GHG emissionsand removals associated with the transportation, injection, and geological storage of captured carbon dioxide (CO_2). It is relevant to Carbon Capture, Utilization, and Storage (CCUS) systems deployed in industrial and energy sectors. While India's CCUS infrastructure is still emerging, this category supports future inventory readiness and aligns with mitigation pathways under the Long-Term Low Emission Development Strategy (LT-LEDS). India has used 'NA' notation key for this category for current inventory reporting.

3.5. Memo items (1.D.)

CO_2 emissions from biomass are reported under Memo Items (CRT category 1.D.3) in accordance with the IPCC Guidelines and are not included in the total national emissions.

3.5.1. International bunkers (1.D.1.)

Category description

International bunkers refer to transportation between countries via both aviation and maritime routes. According to the IPCC 2006 guidelines, this includes emissions from fuel used by vessels of any flag engaged in international water-borne navigation, whether on the open sea, inland lakes, waterways, or coastal waters. It covers emissions from trips that begin in one country and end in another. And in case of aviation, it applies to emissions from flights departing from one country and landing in another. This section provides estimation methodology used for the CO_2, CH_4 and N_2O emission inventory of international bunkers.

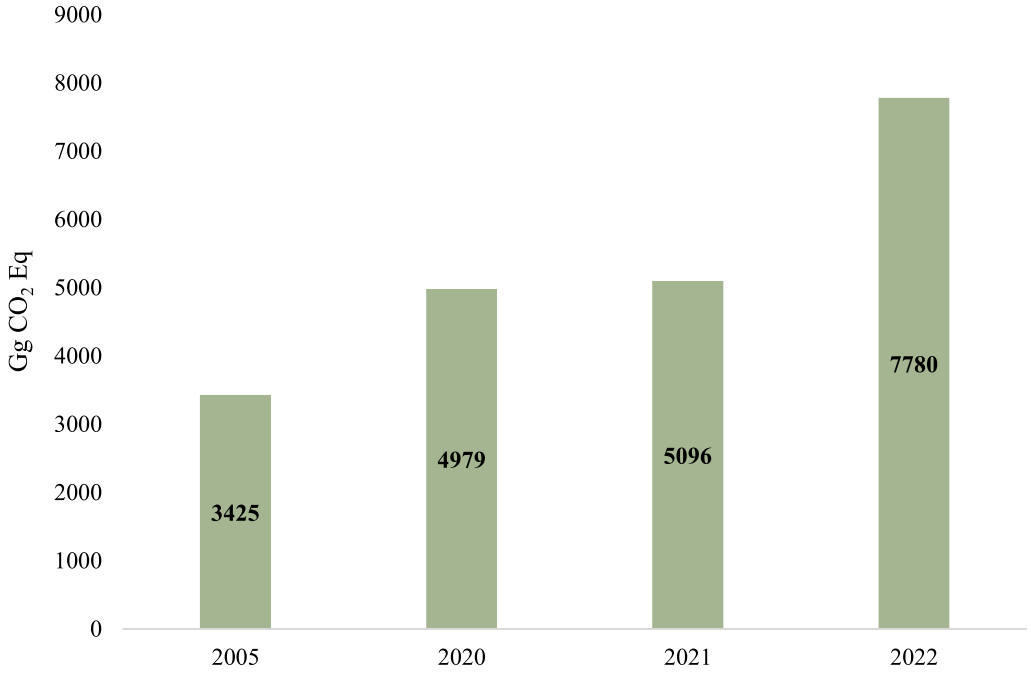


Figure 3.39: GHG emissions from International bunkers (1.D.1.) in 2005, 2020-2022

Methodological issues

The Ministry of Petroleum and Natural Gas (MoPNG) provides annual fuel consumption statistics for each financial year. For international aviation, it reports ATF consumption separately under foreign airlines, and this data is used. Similarly, the consumption data for Fuel Oil (FO), High-Speed Diesel Oil (HSDO), and Light Diesel Oil (LDO) for international navigation is also published annually by the MoPNG in its Indian Petroleum and Natural Gas Statistics (IPNGS) publications. CO_2, CH_4, and N_2O, emission factors and net calorific values of the above-mentioned fuels applied are the default values from the IPCC 2006 guidelines, similar to those used for domestic aviation (1.A.3.a) and domestic water-borne navigation (1.A.3.d).

Table 3.39: Activity data for international bunkers in TJ for 2005, 2020-2022

Fuel Category (TJ)	2005	2020	2021	2022
ATF	46327.05	44687.63	40971.11	68707.8
Fuel Oil	755.48	20038.4	25573.2	34138
High Speed Diesel	192.425	2591.906	1958.739	2179.528
Light Diesel Oil	184.9	NO	NO	NO

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

A quantitative uncertainty analysis for this category was conducted using the Tier 1 approach from the 2006 IPCC Guidelines. For each category and gas, a detailed analysis is conducted for the starting and latest reporting years, highlighting the main contributors to overall uncertainty.

Time-series consistency is a cornerstone of the inventory process. For the reported years, consistent methodologies and data sources have been applied to the greatest extent possible to ensure that trends reflect actual changes in emissions

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

There are currently no planned improvements for this category.

CHAPTER-4

INDUSTRIAL PROCESSES AND PRODUCT USE

INDUSTRIAL PROCESSES AND PRODUCT USE

4.1. Overview of the sector (e.g. quantitative overview and description, including trends and methodological tiers by category) and background information

Greenhouse gas (GHG) emissions from the Industrial Processes and Product Use (IPPU) sector are reported across multiple subsectors under category 2 of the IPCC classification. The sector covers emissions arising from chemical and physical transformations in industrial activities that are not related to fuel combustion or energy use. These emissions are reported across six main categories:

(i) Mineral Industry (2A)
(ii) Chemical Industry (2B)
(iii) Metal Industry (2C)
(iv) Non Energy Products from fuel and solvent use (2D)
(v) Electronics industry (2E)
(vi) Product uses as substitute for ODS (2F)
(vii) Other product manufacture and use (2G)

The gases reported under the IPPU sector include CO_2, CH_4, N_2O, HFCs, PFCs, unspecified mixtures of HFCs and PFCs, and SF_6. These emissions arise as by-products of industrial reactions or from the intentional use of specific chemicals or substances in manufacturing processes.

Chemical and physical transformation in industrial processes releases GHGs into the atmosphere. Emissions from this sector arise mainly in two ways:

- As byproducts of industrial processes not related to energy use.
- From the application of specific substances during manufacturing.

The Industrial Processes and Product Use (IPPU) sector represents a significant source of national greenhouse gas emissions, registering a 21.83% increase from 247092 Gg CO_2eq in 2005 to 301,023 Gg CO_2eq in 2022. This growth is primarily attributed to the rapid expansion of manufacturing and infrastructure, notably within the cement industry. In 2022, the IPPU sector contributed approximately 9% of total emissions.

All methodologies, emission factors, and activity data used for estimating emissions from IPPU categories undergo rigorous technical review, including expert validation and evaluation by the Technical Advisory Committee, prior to approval by the Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India.

Methodological tiers

The GHG inventory for the IPPU sector is prepared in accordance with the methodological approaches prescribed in the 2006 IPCC Guidelines. A combination of Tier 1 and Tier 2 methods is applied, based on data availability and the relative significance of each source category, to achieve the highest level of accuracy. For cement production (2.A.1), identified as a key category, a Tier 2 approach is employed, utilising detailed activity data and country-specific emission factors. A Tier 2 approach is also adopted for selected sub-sectors within the chemical industry (2.B). For the estimation of F-gas emissions across relevant sectors, a Tier 1 approach has been used for BTR-1. Details of methodological tiers is presented in table 1.1.

Emission profile

The table provides India's GHG emissions from the IPPU Sector, measured in $GgCO_2$ eq, for 2005, 2020, 2021, and 2022. The total emissions from the IPPU sector have significantly increased from 247092 $GgCO_2$ Equivalent in 2005 to 301023 $GgCO_2$ eq in 2022.

Mineral industry (2A), represent the largest source of emissions within the IPPU sector. These emissions rose from 123176 $GgCO_2$ eq in 2005 to 175231 $GgCO_2$ eq in 2022. The largest sub-category here is Cement production (2.A.1), which alone accounted for 152265 $GgCO_2$ eq in 2022, up from 96201 $GgCO_2$ eq in 2005.

Chemical industry (2.B) is another substantial contributor, with emissions increasing from 84041 $GgCO_2$ eq in 2005 to 68235 $GgCO_2$ eq in 2022. In the metal industry (2.C), emissions have increased from 36842 $GgCO_2$ eq in 2005 to 27580 $GgCO_2$ eq. Here, Iron and steel production (2.C.1) is reported as IE as the emissions are accounted in the energy sector.

Table 4.1: Summary of India's GHG emissions from the IPPU Sector in $GgCO_2e$

Source/Sink Categories	Total Gg CO_2 Equivalent			
	2005	2020	2021	2022
2. Industrial Processes and Product Use (IPPU)	247092	255512	279869	301023
2.A. Mineral industry	**123176**	**152270**	**164200**	**175231**
2.A.1. Cement production	96201	136874	133529	152265
2.A.2. Lime production	26768	15008	30282	22609
2.A.3. Glass production	199	364	364	331
2.A.4. Other process uses of carbonates	7	25	26	27
2.A.4.a. Ceramics	7	25	26	27
2.A.4.b. Other uses of soda ash	0	0	0	0
2.A.4.c. Non-metallurgical magnesium production	0	0	0	0
2.A.4.d. Other (please specify)	0	0	0	0
2.B. Chemical industry	**84041**	**61925**	**67424**	**68235**
2.B.1. Ammonia production	15260	11049	11679	12428
2.B.2. Nitric acid production	1086	1954	2103	2224
2.B.3. Adipic acid production	0	0	0	0
2.B.4. Caprolactam, glyoxal and glyoxylic acid production	282	194	241	296
2.B.4.a. Caprolactam	282	194	241	296
2.B.4.b. Glyoxal	0	0	0	0
2.B.4.c. Glyoxylic acid	0	0	0	0
2.B.5. Carbide production	68	94	105	96
2.B.5.a. Silicon carbide	0	0	0	0
2.B.5.b. Calcium carbide	68	94	105	96
2.B.6. Titanium dioxide production	80	68	74	66
2.B.7. Soda ash production	741	887	959	1029
2.B.8. Petrochemical and carbon black production	19844	29362	30386	28208
2.B.8.a. Methanol	285	161	135	69
2.B.8.b. Ethylene	5790	26771	27685	25519
2.B.8.c. Ethylene dichloride and vinyl chloride monomer	141	305	308	324

Source/Sink Categories	Total Gg CO_2 Equivalent			
	2005	2020	2021	2022
2.B.8.d. Ethylene oxide	78	260	282	271
2.B.8.e. Acrylonitrile	28	0	0	0
2.B.8.f. Carbon black	1765	1864	1977	2025
2.B.8.g. Other	11758	0	0	0
2.B.8.g.i. Styrene	0	0	0	0
2.B.8.g.ii. Other (please specify)	11758	0	0	0
2.B.9. Fluorochemical production	46681	18318	21876	23888
2.B.9.a. By-product emissions	46443	17463	20380	21752
2.B.9.a.i. Production of HCFC-22	46443	17463	20380	21752
2.B.9.a.ii. Other (please specify)	0	0	0	0
2.B.9.b. Fugitive emissions	238	855	1495	2136
2.B.9.b.i. Production of HFC-134a	43	439	602	766
2.B.9.b.ii.Production of SF6	0	0	0	0
2.B.9.b.iii.Production of NF3	0	0	0	0
2.B.9.b.iv. Other (Production of HFC-125)	0	156	633	1110
2.B.9.b.v. Other (Production of HFC-32)	194	260	260	260
2.B.10. Other	0	0	0	0
2.B.10.a. Hydrogen production	0	0	0	0
2.B.10.b. Other (please specify)	0	0	0	0
2.C. Metal industry	**36843**	**25060**	**27002**	**27580**
2.C.1. Iron and steel production	0	0	0	0
2.C.2. Ferroalloys production	2367	9694	10050	10016
2.C.3. Aluminium production	33361	14897	16436	17017
2.C.3.a. By-product emissions	33361	14897	16436	17017
2.C.3.b. F-gases used in foundries	0	0	0	0
2.C.4. Magnesium production	1093	330	392	407
2.C.5. Lead production	7	105	88	102
2.C.6. Zinc production	13	34	36	38
2.C.7. Other	0	0	0	0
2.C.7.a. Rare earths production	0	0	0	0
2.C.7.b.Other (please specify)	0	0	0	0
2.D. Non-energy products from fuels and solvent use	**1249**	**2546**	**2756**	**2456**
2.D.1. Lubricant use	1119	2377	2611	2323
2.D.2. Paraffin wax use	130	169	144	133
2.D.3. Other	0	0	0	0
2.D.3.a. Solvent use	0	0	0	0
2.D.3.b. Road paving with asphalt	0	0	0	0
2.D.3.c. Asphalt roofing	0	0	0	0
2.D.3.d. Other (please specify)	0	0	0	0
2.E. Electronics industry	**1**	**0**	**0**	**0**
2.E.1. Integrated circuit or semiconductor	0	0	0	0
2.E.2. TFT flat panel display	0	0	0	0
2.E.3. Photovoltaics	1	0	0	0
2.E.4. Heat transfer fluid	0	0	0	0
2.E.5. Other	0	0	0	0
2.E.5.a. Microelectromechanical systems (MEMS)	0	0	0	0
2.E.5.b. Other (please specify)	0	0	0	0

Source/Sink Categories	Total Gg CO_2 Equivalent			
	2005	2020	2021	2022
2.F. Product uses as substitutes for ODS	**1033**	**11746**	**16649**	**25397**
2.F.1. Refrigeration and air conditioning	550	10562	13395	15172
2.F.1.a. Commercial refrigeration	11	2856	4743	5536
2.F.1.b. Domestic refrigeration	1	51	1981	47
2.F.1.c. Industrial refrigeration	137	1768	132	2200
2.F.1.d. Transport refrigeration	2	99	132	176
2.F.1.e. Mobile air-conditioning	8	2965	3473	4028
2.F.1.f. Stationary air-conditioning	391	2825	3016	3185
2.F.2. Foam blowing agents	149	600	638	1076
2.F.2.a. Closed cells	0	600	135	162
2.F.2.b. Open cells	149	0	504	914
2.F.3. Fire protection	0	0	563	1634
2.F.4. Aerosols	334	583	1368	4131
2.F.4.a. Metered dose inhalers	334	583	593	602
2.F.4.b. Other (please specify)	0	0	775	3529
2.F.5. Solvents	0	0	2	2
2.F.6. Other applications	0	0	683	3382
2.F.6.a. Emissive	0	0	683	3382
2.F.6.b. Contained	0	0	0	0
2.G. Other product manufacture and use	**749**	**1965**	**1839**	**2124**
2.G.1. Electrical equipment	749	1965	1839	2124
2.G.2. SF6 and PFCs from other product use	0	0	0	0
2.G.2.a. Military applications	0	0	0	0
2.G.2.b. Accelerators	0	0	0	0
2.G.2.c. Soundproof windows	0	0	0	0
2.G.2.d. Adiabatic properties: shoes and tyres	0	0	0	0
2.G.2.e. Other	0	0	0	0
2.G.2.e.i. Waterproofing electronic circuits	0	0	0	0
2.G.2.e.ii. Other (please specify)	0	0	0	0
2.G.3. N_2O from product uses	0	0	0	0
2.G.3.a. Medical applications	0	0	0	0
2.G.3.b. Other	0	0	0	0
2.G.3.b.i. Propellant for pressure and aerosol products	0	0	0	0
2.G.3.b.ii. Other (please specify)	0	0	0	0
2.G.4. Other	0	0	0	0
2.H. Other	**0**	**0**	**0**	**0**
2.H.1. Pulp and paper	0	0	0	0
2.H.2. Food and beverages industry	0	0	0	0
2.H.3. Other (please specify)	0	0	0	0

4.2. Mineral Industry (CRT 2.A)

Category description and background

In 2022, GHG emissions from mineral activities accounted for 58% of total emissions from the Industrial Processes and Product Use sector, amounting to 175,231 GgCO_2 equivalent. Compared to 2005 levels, emissions from this category increased by 42.26%. The key categories within this sector for India include CO_2 emissions from cement, lime, and glass production and other process uses of carbonates (ceramics).

4.2.1. Cement Production (2.A.1)

Category description

CO_2 emissions from cement production primarily arise from the calcination of limestone, which contains calcium carbonate ($CaCO_3$). The decarbonation of limestone releases CO_2, forming clinker, an intermediate product in the cement production process. While limestone remains the main raw material, the presence of magnesium carbonate ($MgCO_3$) in Indian limestone also adds to the emission profile. In the baseline year of 2005, emissions from cement production were recorded at 96,201.47 Gg CO_2 Equivalent. Over the subsequent years, this category witnessed a substantial increase in its emissions profile. By 2020, emissions had increased to 136,874 Gg CO_2 Equivalent. Overall, between 2005 and 2022, the emissions from cement production increased by 58.28%. In 2022, cement production was the single most dominant source of emissions within the broader Industrial Processes and Product Use (IPPU) sector. It was responsible for 51% of the entire IPPU sector's emissions (152,265 Gg out of a total 301,023 GgCO_2 equivalent). Furthermore, within its direct parent sub-sector, the Mineral industry, cement production is the largest contributor. In 2022, it accounted for approximately 87% of the total emissions from the Mineral industry (152,265 Gg out of 175,231 GgCO_2 equivalent).

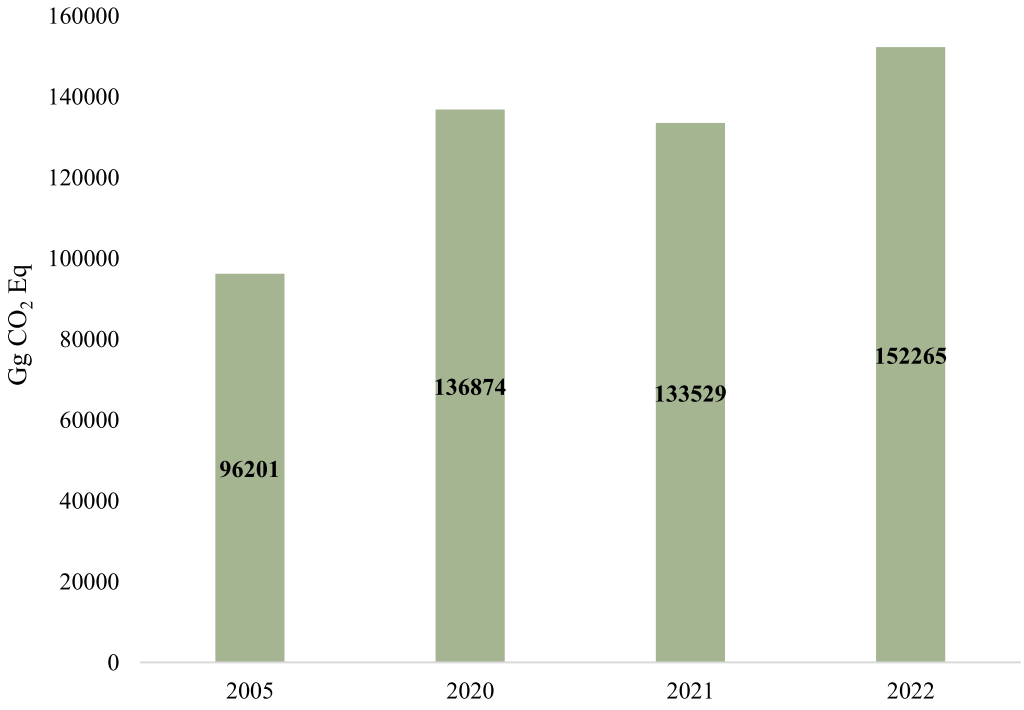


Figure 4.1 GHG emissions from Cement Production (2.A.1) in 2005, 2020-2022

Methodological issues

The Tier 2 methodology from the 2006 IPCC Guidelines is applied for calculating emissions. In India, CO_2 emissions from clinker production are estimated by multiplying the clinker output with country-specific emission factors, derived from national studies and cement associations, such as the Cement Manufacturers' Association of India (CMA). In India, the cement sector incorporates waste-derived materials such as:

- Fly ash from coal-fired power plants
- Blast furnace slag from steel industries
- Incineration residues and municipal solid waste ash

The emission factors are updated periodically to account for changes in material use patterns, fuel composition, and technology upgrades. Emission factors for CO_2 from cement production in India have been sourced from the Cement Manufacturers Association (CMA) and the National Council for Cement and Building Materials (NCCBM). Fuel-related CO_2 emissions are calculated based on the types of fuels used and their corresponding carbon content factors (CCF) and carbon oxidation factors (COF), as provided by the IPCC guidelines.

Table 4.1 Activity data for Cement Production in kt for 2005, 2020-2022

Source/Sink Categories	Unit	2005	2020	2021	2022
Cement Production	kt	181786.60	258642.86	252321.43	287725.84

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

As per the IPCC guidelines, for uncertainty of emission factors, +/- 3% uncertainty has been taken and for uncertainty of Activity data, +/- 2% uncertainty has been taken. The combined uncertainty is +/- 3.6 %. CO_2 emission data from clinker production in India are consistently reported from FY2000 onwards, based on the 2006 IPCC Guidelines.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

4.2.2. Lime Production (2.A.2)

Category description

Lime production, similar to cement, involves the calcination of limestone, releasing CO_2. Lime is widely used in industries like steel manufacturing, paper production, and water treatment. In India, lime production is primarily coal-based.

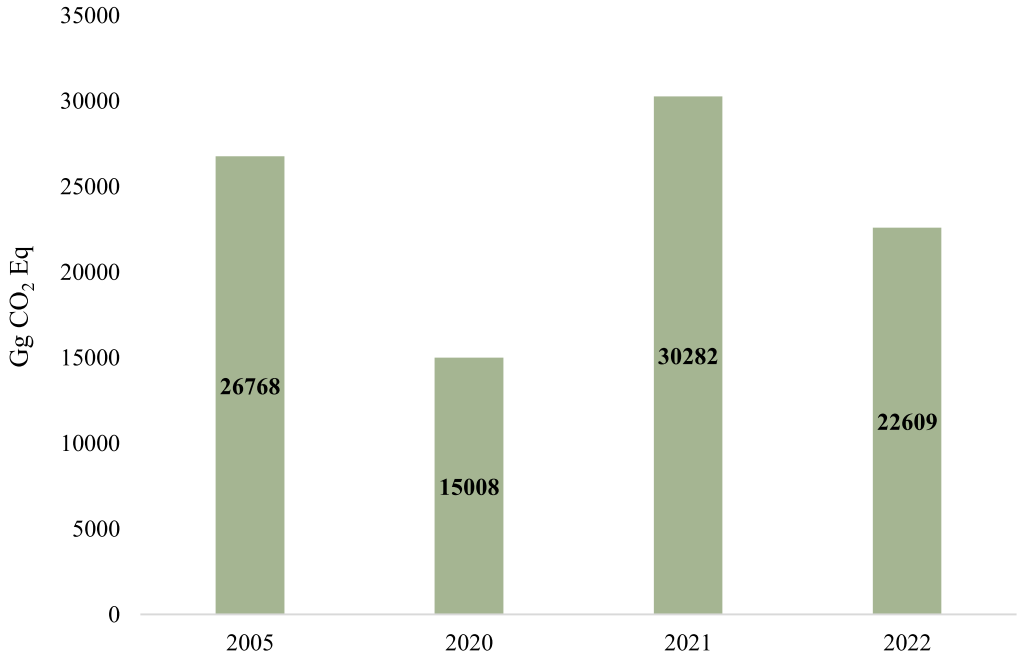


Figure 4.2 GHG emissions from Lime Production (2.A.2) in 2005, 2020-2022

Methodological issues

The activity data for Lime sector is the production quantities of limestone and dolomite as supplied by Ministry of Mines (Government of India). The same has been considered for all the 4 reporting years. The emissions pertaining to the Lime sector in this subcategory are calculated by subtracting the lime related emissions from cement sub sector from emissions pertaining to overall national lime production. The almost doubling of emissions in this sub sector in 2021 as compared to 2020 is due to increase in overall lime production on a national level. The Emission factor per unit raw material is taken from the IPCC 2006 default values provided in volume 3, Table 2.4.

Table 4.2: Activity data for Lime Production in kt for 2005, 2020-2022

Source/Sink Category	Unit	2005	2020	2021	2022
Lime Production	kt	164539	203286	219454	233945

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 (“Information on Flexibility”) of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

As per the IPCC guidelines, for uncertainty of emission factors, +/- 2% uncertainty has been taken and for uncertainty of Activity data, +/- 2% uncertainty has been taken. The combined uncertainty is +/- 2.8 %. Limestone consumption data is provided by the Indian Bureau of Mines, Government of India. The same source of data is being used for all the four reporting years. The emission factors are constant for all years from, therefore, CO_2 emission from lime production has been estimated in a consistent manner throughout the time-series.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists,

review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

4.2.3. Glass Production (2.A.3)

Category description

Glass production contributes to GHG emissions through the melting of raw materials such as silica (SiO_2), sodium carbonate (Na_2CO_3), and limestone ($CaCO_3$), releasing CO_2 during the process. This sector also involves indirect CO_2 emissions from fuel combustion.

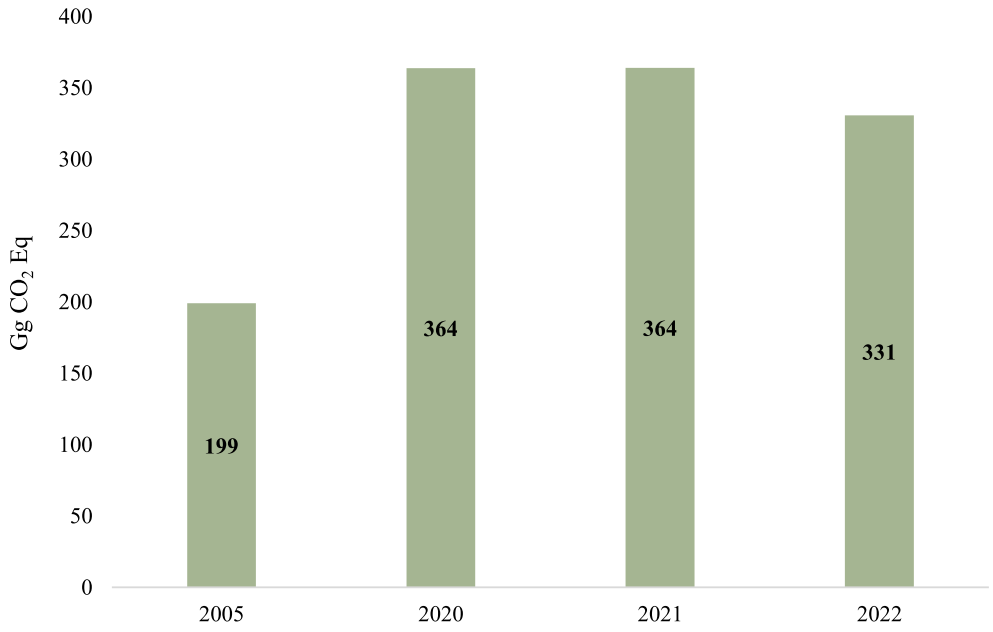


Figure 4.3 GHG emissions from Glass Production (2.A.3) in 2005, 2020-2022

Methodological issues

CO_2 emissions are calculated using the Tier 2 method, with data sourced from glass manufacturing associations and the Ministry of Commerce and Industry. Post 2018, the data pertaining to the production is not available and hence extrapolation method has been used for arriving at the production data. Average cullet ration has been taken as per the range provided by IPCC guidelines (Table 2.6, Volume 3), and has been verified against the industry data. For Float and sheet glass the cullet ratio has been considered as 0.175 and for Bottle/glassware it is considered as 0.45. The emission factors considered are the default emission factors as per the IPCC 2006 guidelines (Table 2.6, Volume 3).

Table 4.3 Activity data for Glass Production in kt for 2005, 2020-2022

Source/ Sink Categories	Unit	2005	2020	2021	2022
Glass Production	kt	1434.81	2392.03	2393.76	2204.05

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

As per the IPCC guidelines, for uncertainty of emission factors, +/- 60% uncertainty has been taken and for uncertainty of Activity data, +/- 5% uncertainty has been taken. The combined uncertainty is +/- 60 %. The glass production data is being provided by the Glass Manufacturing Association. Although coordinated data collection is not happening in recent years and statistical methods are used to arrive at the data, efforts are being made to ensure proper data reporting on part of glass manufacturing association. The emission factors are constant for all years from, therefore, CO_2 emission from lime production has been estimated in a consistent manner throughout the time-series.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

4.2.4. Other Process Uses of Carbonates (2.A.4)

Category description and background

4.2.4.1. Ceramics (2.A.4.a)

Category description

Limestone contains $CaCO_3$ and minute amounts of $MgCO_3$, and dolomite contains $CaCO_3$ and $MgCO_3$. The heating of limestone and dolomite releases CO_2 derived from $CaCO_3$ and $MgCO_3$.

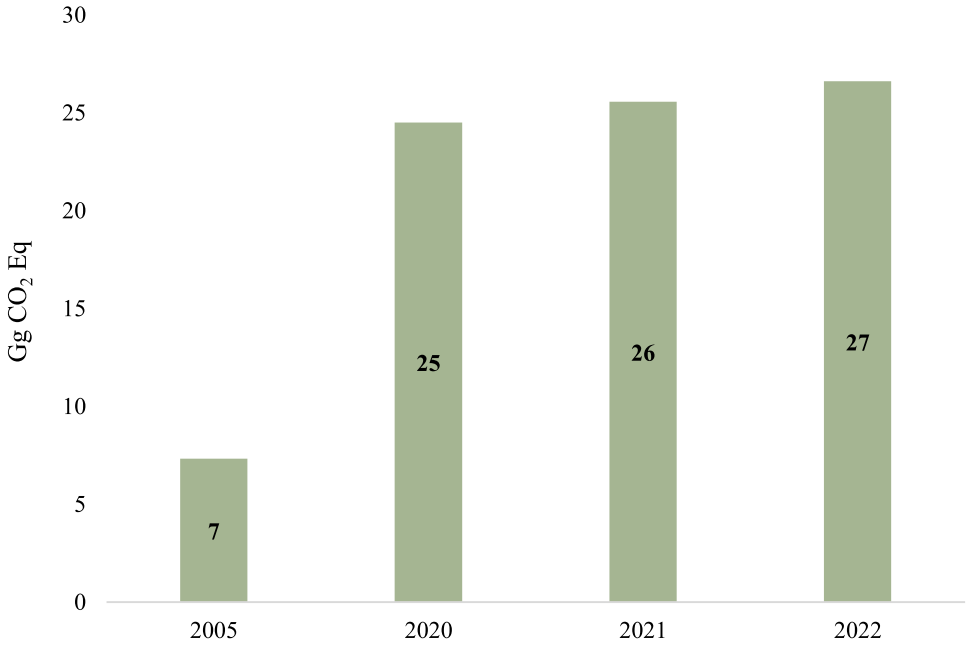


Figure 4.4 GHG emissions from Ceramics (2.A.4.a) in 2005, 2020-2022

Methodological issues

The activity data for the sub sector is the consumption of dolomite and calcite by the Indian Industry records as provided by records from Indian bureau of Mines. The CO_2 emission factor has been calculated using IPCC 2006 methodology, Manual 1, Reference 1, pg. 2.10. The Fraction of purity of Calcium Carbonate used is 95% for Ceramics (Ref: Table 6, Calcite, Indian Mineral Yearbook,2011). The dolomite use in ceramics is not reflected in Table 6 of IMYB therefore fraction of dolomite use is taken as 1. The $CaCO_3$ use has been taken from Calcite chapter in IMYB 2010, 2011 and 2012. The data is only available for 2007-08 to 2010-11.

Table 4.4 Activity data for Ceramics in kt for 2005, 2020-2022

Source/Sink Categories	Unit	2005	2020	2021	2022
Ceramics	kt	16.28	54.66	57.00	59.34

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

As per the IPCC guidelines, for uncertainty of emission factors, +/- 5% uncertainty has been taken and for uncertainty of Activity data, +/- 3% uncertainty has been taken. The combined uncertainty is +/- 5.8 %. Calcium carbonate and Dolomite data is provided by the Indian Bureau of Mines, Government of India. The same source of data is being used for all the four reporting years. The emission factors are constant for all years from, therefore, CO_2 emission from lime production has been estimated in a consistent manner throughout the time-series.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

4.2.4.2. Other uses of soda ash (2.A.4.b)

Not Estimated (NE) notation key was used. The soda ash is generally used in Glass , soaps and detergent and other speciality chemicals. Since the exact quantity estimate is not available from authentic sources, we are considering the same as NE.

4.2.4.3. Non-metallurgical magnesium production (2.A.4.c)

Not Estimated (NE) notation key was used. There is no consolidated public figure or official national series that states India's production of processed non-metallurgical magnesium compounds (e.g., dead-burned magnesia (DBM), caustic-calcined magnesia (CCM), fused magnesia, magnesium hydroxide) in recent years. Hence this is not estimated in the current BTR. This will be further explored in the subsequent BTRs.

4.3. Chemical Industry (CRT 2.B)

Category description and background

In line with 2006 IPCC Guidelines and the 2019 amendment, this section deals with the following subsectors:

- 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.)
- Fluorochemical production (2.B.9)
- Other (2.B.10.)

In 2022, GHG emissions from these chemical activities accounted for 24.50 % of total emissions from the Industrial Processes and Product Use (IPPU) sector, amounting to 68234.65 Gg CO_2 equivalent. Compared to 2005 levels, emissions from this category increased by 94.23%. Key categories for India in the chemicals sector are CO_2 from ammonia production, CO_2 from ethylene production and N_2O from Nitric Acid production.

4.3.1. Ammonia Production (2.B.1)

Category description

Ammonia gas is used directly as a fertiliser, in heat treating, paper pulping, nitro compound manufacture, explosives of various types, and as a refrigerant. Amines, amides, and miscellaneous other organic compounds, such as urea, are made from ammonia.

The production of ammonia is highly complex and energy intensive. In India, two primary technologies are employed for ammonia production: turbo compressors and centrifugal compressors. Centrifugal compressors

are more commonly used due to their higher energy efficiency, as they allow for the recovery of waste heat in the form of steam, which can be used as a driving force. Ammonia production in India relies on three major fuel sources: gas-based, oil-based, and naphtha-based. Production using oil-based fuel has been stopped since 2014.

The emission trend exhibited a steady rise from 2020 to 2022. Emissions in 2005 were higher than in any of these three years. This can be explained by two main factors: the shift away from oil-based production methods that were in use in 2005, and the reduced capacity of urea production to act as a sink during that period.

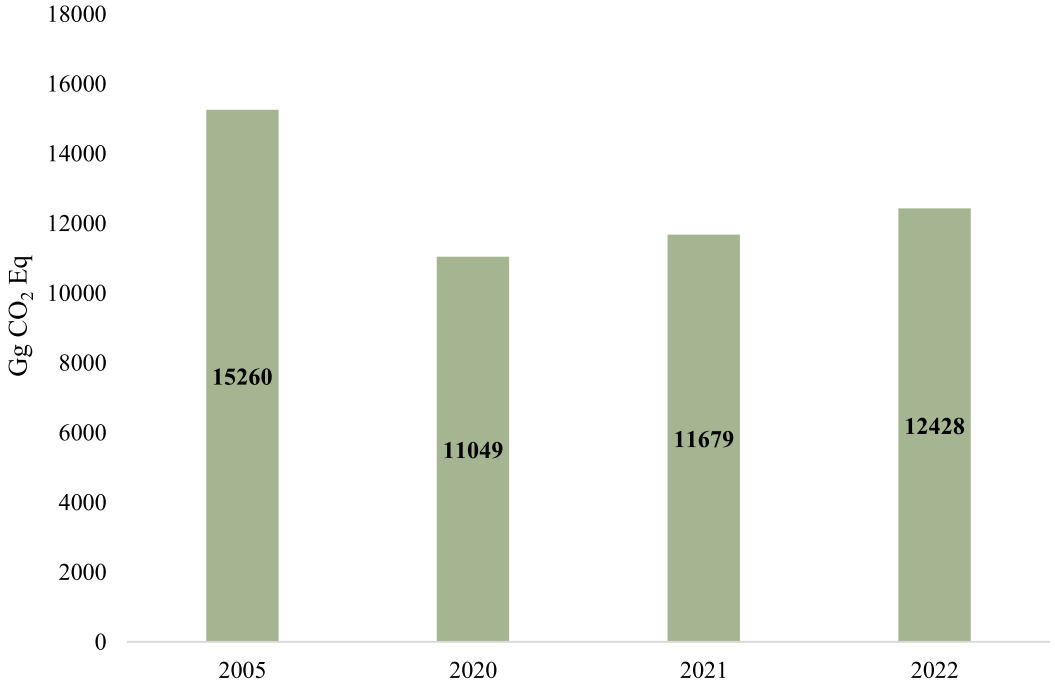


Figure 4.5 GHG emissions from Ammonia Production (2.B.1) in 2005, 2020-2022

Methodological issues

Tier 2 methodology as per the 2006 IPCC Guidelines was used to estimate the CO_2 emissions. Fuel requirement for ammonia production is annually weighted average of energy consumption in ammonia production. The data is provided by the Department of Fertiliser, Ministry of Chemicals & Fertilizers and the Fertilizer Association of India. The annual fuel requirement per unit of GJ/MT ammonia produced using all the three fuels used in India. The quantity of CO_2 recovered for downstream use in urea production was subtracted from the total quantity of CO_2 generated from ammonia production to derive the net CO_2 emitted. The fuel wise production of ammonia has been provided by the Department of Fertiliser, Ministry of Chemicals & Fertilizers. The production amount of urea has also been provided by the Department of Fertiliser, Ministry of Chemicals & Fertilizers which were used for the calculations. The Carbon content of the fuel (CCF) and Carbon oxidation factor (COF) were taken as the default values from Table 3.1, Chapter 3, Volume 3, and Table 1.3, Chapter 1, Volume 2, of 2006 IPCC guidelines.

Table 4.5 Activity data for Ammonia Production in kt for 2005, 2020-2022

Source/ Sink Categories	Unit	2005	2020	2021	2022
Ammonia Production	kt	111150	258642.86	252321.43	287725.84

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

For this category, +/-5% uncertainty of emission factors and activity data has been taken. The combined uncertainty is +/-7%. For activity data the same sources are used throughout the time series, from Department of Fertiliser, Ministry of Chemicals & Fertilizers. The emission factor is also based on the data provided by Department of Fertiliser, Ministry of Chemicals & Fertilizers. Therefore, CO_2 emission from ammonia production has been estimated in a consistent manner throughout the time-series.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

4.3.2. Nitric Acid Production (2.B.2)

Category description

Nitric acid is used as a raw material mainly in the manufacture of nitrogenous-based fertiliser. Nitric acid may also be used in the production of adipic acid and explosives (e.g., dynamite), for metal etching and in the processing of ferrous metals. In India, nitric acid is produced through the Ostwald process, a chemical method that involves three key steps: the oxidation of ammonia, the dissociation of nitric oxide, and the oxidation of nitrogen dioxide. This process efficiently converts ammonia into nitric acid. Nitrous oxide (N_2O) is emitted during the process and is estimated and reported.

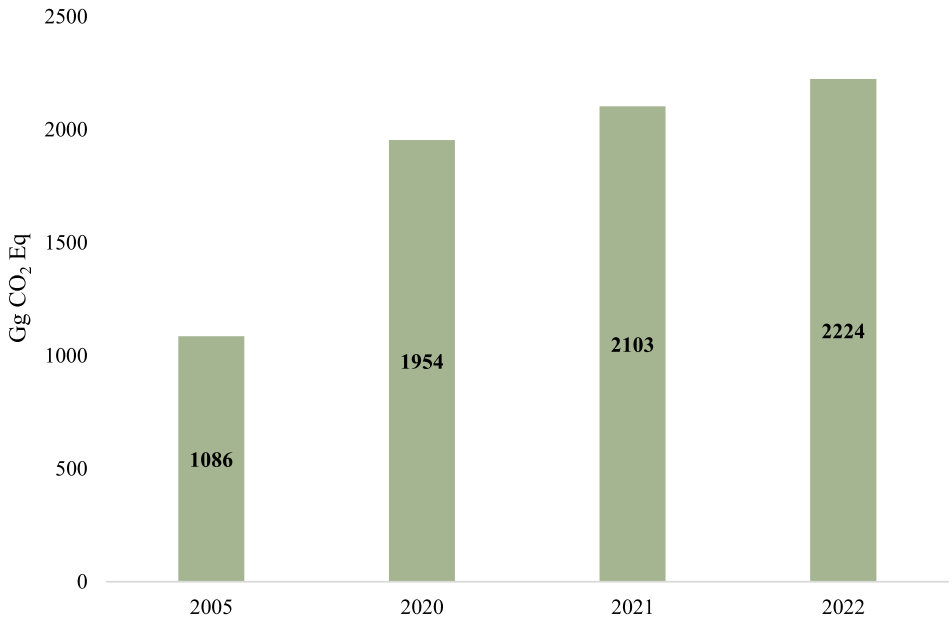


Figure 4.6 GHG emissions from Nitric Acid Production (2.B.2) in 2005, 2020-2022

Methodological issues

For calculating emissions associated with Nitric Acid production, company specific activity data (Tier 2) was used along with company specific emission factors (Tier 2). Emissions were then calculated using Tier 1 equation mentioned in the 2006 IPCC Guidelines since technology type production of nitric acid could not be obtained which shall be used for Tier 2 equation. Emissions are calculated by multiplying the amount of nitric acid produced company wise by company specific emission factors. The production data which was earlier (till India's Third National Communication) taken from prowess or calculated using statistical methods based on assumption has now been directly provided by the companies. There are seven players in Indian market who produces nitric acid. Two of them who are the major players and contributes to nearly 70% of the production in the sector has provided the production numbers directly and the rest 30% of the production has been extrapolated using statistical methods.

Table 4.6 Activity data for Nitric Acid Production in kt for 2005, 2020-2022

Source/Sink Categories	Unit	2005	2020	2021	2022
Nitric Acid Production	kt	815.68	1500.13	1612.85	1707.26

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

For uncertainty of emission factors, +/-20% uncertainty has been taken and for uncertainty of Activity data, +/-2% uncertainty has been taken. The combined uncertainty is +/-20%. For activity data the same sources are used throughout the time series. The emission factor taken are also consistent throughout the timeseries. Therefore, N_2O emission from nitric acid production has been estimated in a consistent manner throughout the time-series.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

4.3.3. Adipic Acid Production (2.B.3)

NE notation key is used in the sub sector as activity data is unavailable. According to officially referenced sources and industry analysis, there is no significant domestic production of adipic acid in India in the recent past. Official government documents and market studies confirm that India meets its adipic acid demand primarily through imports, and the domestic industry has not established commercial-scale manufacturing of this chemical.

4.3.4. Caprolactam, glyoxal, and glyoxylic acid production (2.B.4)

There are no publicly verifiable recent data giving India's total glyoxal production. India meets glyoxylic acid requirement through Imports. There are no publicly verifiable recent data giving India's total glyoxylic acid production. Efforts are being made to include this in the subsequent BTRs.

Category description and background

4.3.4.1. Caprolactam (2.B.4.a)

Category description

Caprolactam is a key monomer used in the production of nylon-6, which is widely utilized in the manufacture of fibres for carpets and other applications, as well as in resin materials. Nearly all caprolactam produced annually is consumed in the production of nylon-6 fibres and plastics. Commercially, caprolactam is manufactured through processes based on either toluene or benzene. N_2O is emitted during the manufacturing process and is estimated and reported.

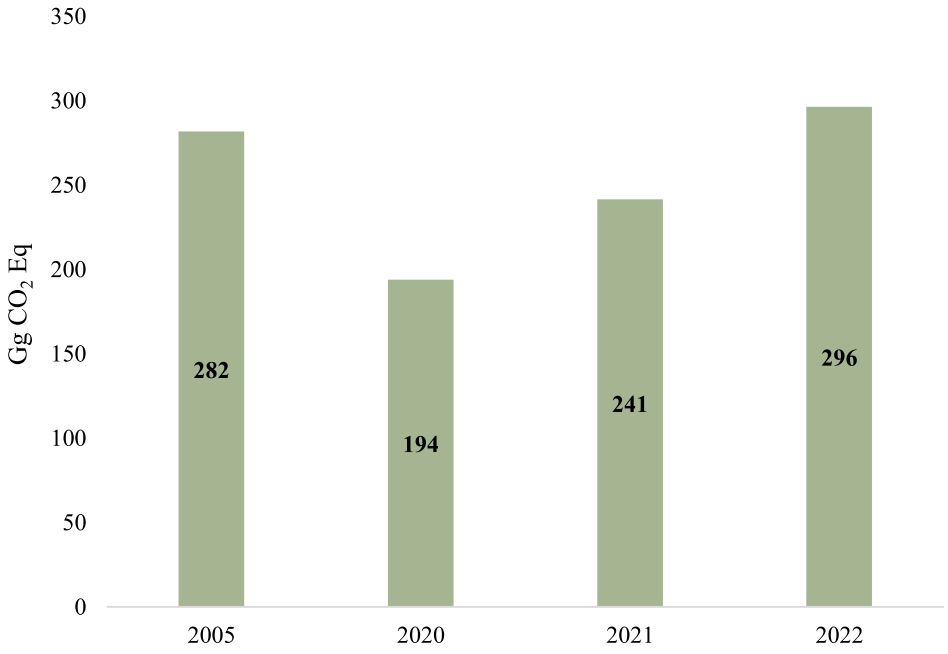


Figure 4.7 GHG emissions from Caprolactam (2.B.4.a) in 2005, 2020-2022

Methodological issues

Tier 1 methodology as per the 2006 IPCC Guidelines was used to estimate the N_2O emissions. Emissions are calculated by multiplying the amount of caprolactam produced by emission factor. Default emission factor mentioned in the 2006 IPCC guidelines were used to calculate the N_2O emissions from caprolactam production.

Table 4.7 Activity data for Caprolactam in kt for 2005, 2020-2022

Source/Sink Categories	Unit	2005	2020	2021	2022
Caprolactam	kt	118.11	81.32	101.23	124.27

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

For uncertainty of emission factors, 5% uncertainty has been taken and for uncertainty of Activity data, 10% uncertainty has been taken. The combined uncertainty is +/-40%. For activity data the same sources are used throughout the time series, from Department of Chemicals and Petrochemicals, Ministry of Chemicals & Fertilizers. The emission factor is taken from 2006 IPCC guidelines. Therefore, N_2O emission from caprolactam production has been estimated in a consistent manner throughout the time-series.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

4.3.4.2. Glyoxal (2.B.4.b)

NE notation key is used in the sub sector as activity data is unavailable due to technical and financial capacity contraints.

4.3.4.3. Glyoxylic acid (2.B.4.c)

NE notation key is used in the sub sector as activity data is unavailable due to technical and financial capacity contraints.

4.3.5. Carbide production (2.B.5)

4.3.5.1. Silicon carbide (2.B.5.a)

NO notation key is used as there is no production of silicon carbon in India.

There are no authoritative published data for total domestic production (tonnage) of silicon carbide. Most of the domestic requirements are met through Imports. This will be further Investigated in the subsequent BTRs to find authentic data sources for the activity data.

4.3.5.2. Calcium carbide (2.B.5.b)

Category description

GHG emissions are associated with production of carbide. In India, only calcium carbide is produced currently. CO_2 is generated in the process of making the quicklime and is also emitted by the combustion of CO occurring from calcium carbide production. The most important application of calcium carbide is producing acetylene (C_2H_2) by reacting CaC2 with water. A substantial use of acetylene is welding applications.

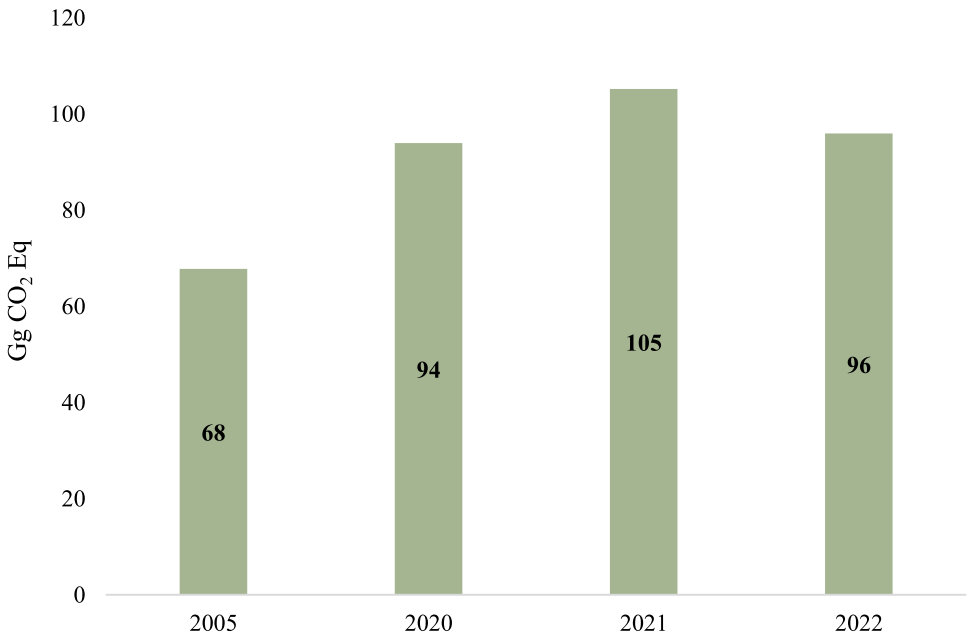


Figure 4.8 GHG emissions from Calcium carbide (2.B.5.b) in 2005, 2020-2022

Methodological issues

Tier 1 methodology as per the 2006 IPCC Guidelines was used to estimate the CO_2 emissions. Emissions are calculated by multiplying the amount of calcium carbide produced by emission factor. Default emission factor mentioned in the 2006 IPCC guidelines were used to calculate the CO_2 emissions from carbide production.

Table 4.8 Activity data for Calcium carbide in kt for 2005, 2020-2022

Source/Sink Categories	Unit	2005	2020	2021	2022
Calcium carbide	kt	61.66	85.42	95.66	87.23

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 (“Information on Flexibility”) of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

For uncertainty of emission factors, +/-40% uncertainty has been taken and for uncertainty of Activity data, +/-2 % uncertainty has been taken. The combined uncertainty is +/-11%. For activity data the same sources are used throughout the time series, from Department of Chemicals and Petrochemicals, Ministry of Chemicals & Fertilizers. The emission factor is taken from 2006 IPCC guidelines. Therefore, CO_2 emission from carbide production has been estimated in a consistent manner throughout the time-series.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

4.3.6. Titanium dioxide production (2.B.6)

Category description

Titanium dioxide (TiO_2) is one of the most commonly used white pigments. The main use is in paint manufacture followed by paper, plastics, rubber, ceramics, fabrics, floor covering, printing ink, and other miscellaneous uses. CO_2 is emitted from the oxidization of carbon electrodes in the production of titanium slag in electric furnaces, from the oxidization of black coal during the production of synthetic rutile, and from the oxidization of oil coke in the chloride route.

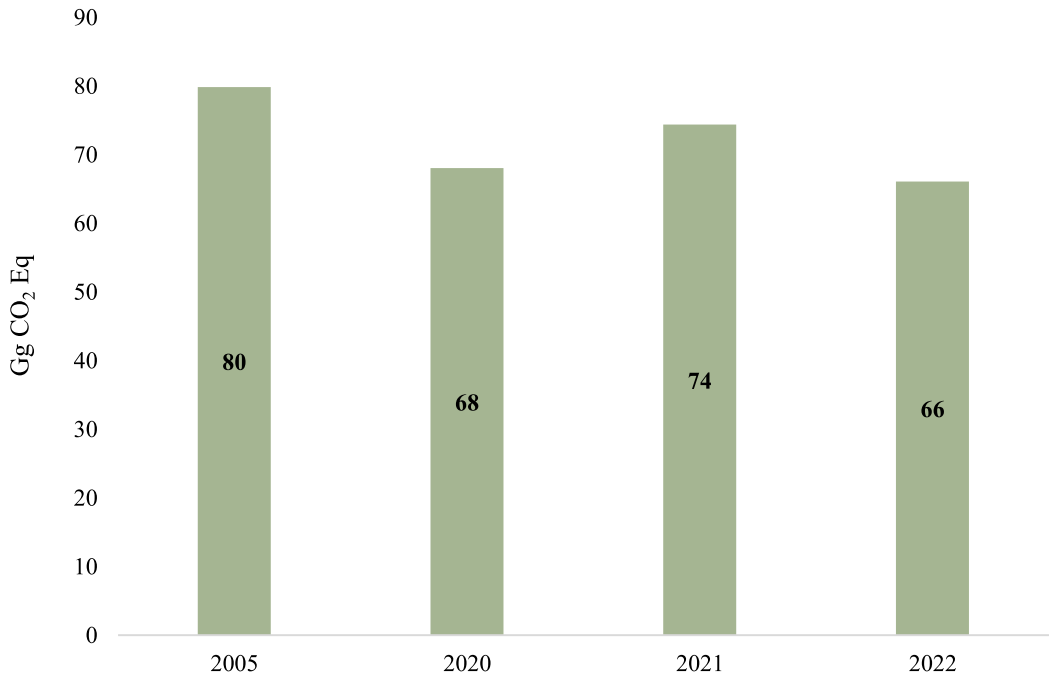


Figure 4.9 GHG emissions from Titanium dioxide production (2.B.6) in 2005, 2020-2022

Methodological issues

Tier 1 methodology as per the 2006 IPCC Guidelines was used to estimate the CO_2 emissions. Emissions are calculated by multiplying the amount of rutile TiO_2 produced by emission factor. Default emission factors mentioned for rutile titanium dioxide in the 2006 IPCC guidelines were used to calculate the CO_2 emissions from titanium dioxide production. The annual production of rutile titanium dioxide which was earlier extracted from Chemical and Petrochemical Statistics till India's Third National Communication has now been provided directly by the Department of Chemicals and Petrochemicals, Ministry of Chemicals & Fertilizers for BTR.

Table 4.9 Activity data for Titanium dioxide production in kt for 2005, 2020-2022

Source/Sink Categories	Unit	2005	2020	2021	2022
Titanium dioxide	kt	59.61	50.79	55.52	49.35

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

For uncertainty of emission factors, +/-15% uncertainty has been taken and for uncertainty of Activity data, +/-5% uncertainty has been taken. The combined uncertainty is +/-16%. For activity data the same sources are used throughout the time series, from Department of Chemicals and Petrochemicals, Ministry of Chemicals & Fertilizers. The emission factor is taken from 2006 IPCC guidelines. Therefore, CO_2 emission from titanium dioxide production has been estimated in a consistent manner throughout the time-series.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

4.3.7. Soda ash production (2.B.7)

Category description

In India, soda ash is manufactured primarily through the Solvay process, an industrial method that utilizes limestone ($CaCO_3$) as a key raw material. In this process, limestone is heated to produce carbon dioxide (CO_2), which then reacts with ammonia (NH_3) dissolved in brine (a concentrated solution of sodium chloride, NaCl). This reaction ultimately results in the production of sodium carbonate, commonly known as soda ash, which is a vital component in various industries. CO_2 is emitted in the production of Soda ash which is estimated and reported.

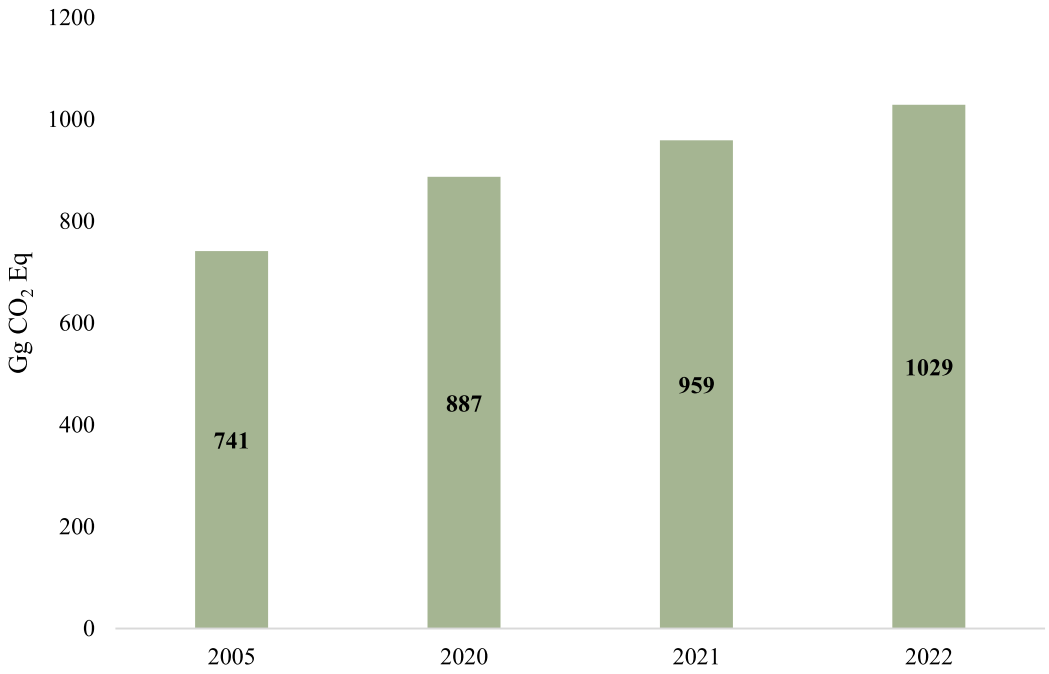


Figure 4.10 GHG emissions from Soda ash production (2.B.7) in 2005, 2020-2022

Methodological issues

Country specific emission factor has been taken from Technical EIA Guidance for Soda Ash Industry prepared for Ministry of Environment, Forest and Climate Change by IL&FS Environment in 2010. The emission factor taken for estimating the emission is 0.323 tonnes CO_2/tonnes of soda ash produced. The annual production of soda ash which was earlier provided by Alkali Manufacturers Association of India till India's Third National Communication has now been provided directly by the Department of Chemicals and Petrochemicals, Ministry of Chemicals & Fertilizers for BTR.

Table 4.10 Activity data for Soda ash production in kt for 2005, 2020-2022

Source/Sink Categories	Unit	2005	2020	2021	2022
Soda ash	kt	2295.49	2745.95	2968.71	3184.21

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

For uncertainty of emission factors, +/-10% uncertainty has been taken and for uncertainty of Activity data, +/- 5% uncertainty has been taken. The combined uncertainty is +/-11%. For activity data the same sources are used throughout the time series, from Department of Chemicals and Petrochemicals, Ministry of Chemicals & Fertilizers. The emission factor used is country specific and used throughout the time series. Therefore, CO_2 emission from soda ash production has been estimated in a consistent manner throughout the time-series.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists,

review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

4.3.8. Petrochemical and carbon black production (2.B.8)

Category description and background

4.3.8.1. Methanol (2.B.8.a)

Category description

In India feed stock used for the production of methanol is natural gas. The natural gas to methanol production produces methanol and emits CO_2 and CH_4 which are estimated and reported. The PETSTAT report from the Ministry of Chemicals and Fertilizers highlights a continuous rise in methanol consumption in India. However, domestic production has been inconsistent, leading to irregular emission trends. As consumption grows and production fails to keep up, the gap has been filled by increased imports, which have steadily risen over time. India's limited natural gas reserves, which are crucial for methanol production, further complicate the situation. With most of the natural gas being imported, production costs remain high, making locally produced methanol less competitive compared to imports. Despite government efforts like the Methanol Economy program, there are still existing challenges and areas where additional support is needed to stimulate domestic production. Tier 1 methodology as per the 2006 IPCC Guidelines was used to estimate the CO_2 and CH_4 emissions. Emissions are calculated by multiplying the amount of methanol produced by emission factor.



Figure 4.11 GHG emissions from Methanol (2.B.8.a) in 2005, 2020-2022

Methodological issue

Default emission factors mentioned for methanol in the 2006 IPCC guidelines were used to calculate the CO_2 and CH_4 emissions from methanol production. The value taken is 0.67 tonnes CO_2/ tonne product and 2.3 tonnes CH_4/ tonne product respectively. The annual production of methanol which was earlier extracted from Chemical and Petrochemical Statistics till India's Third National Communication has now been provided directly by the Department of Chemicals and Petrochemicals, Ministry of Chemicals & Fertilizers.

Table 4.11 Activity data for Methanol in kt for 2005, 2020-2022

Source/Sink Categories	Unit	2005	2020	2021	2022
Methanol	kt	388.12	219.53	184.29	93.88

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

For uncertainty of emission factors, +/-30% (CO_2) and CH_4: -80 to +30 uncertainty has been taken and for uncertainty of Activity data, +/-30% uncertainty has been taken. The combined uncertainty for CO_2 and CH_4 is +/-42%. For activity data the same sources are used throughout the time series, from Department of Chemicals and Petrochemicals, Ministry of Chemicals & Fertilizers. The emission factor is taken from 2006 IPCC guidelines. Therefore, CO_2 and CH_4 emissions from methanol production has been estimated in a consistent manner throughout the time-series.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

4.3.8.2. Ethylene (2.B.8.b)

Category description

CO_2 is emitted in the ethylene production process. CH_4 is emitted by naphtha cracking through steam cracking in the ethylene production process. Both the gases are estimated and reported. Carbon losses in the ethylene production process are accounted for under petrochemicals in the Energy transformation & own use sector of the General Energy Statistics (Energy Balance Table). Ethylene production in India has been steadily increasing since 2005. This growth can be attributed to several factors, including rising domestic demand, advancements in production technology, and increased availability of feedstocks such as naphtha and imported ethane. The expansion of petrochemical complexes by major players has also played a crucial role in boosting production capacity. Additionally, government initiatives promoting the petrochemical sector and the development of integrated refinery-petrochemical hubs have further supported this upward trend.

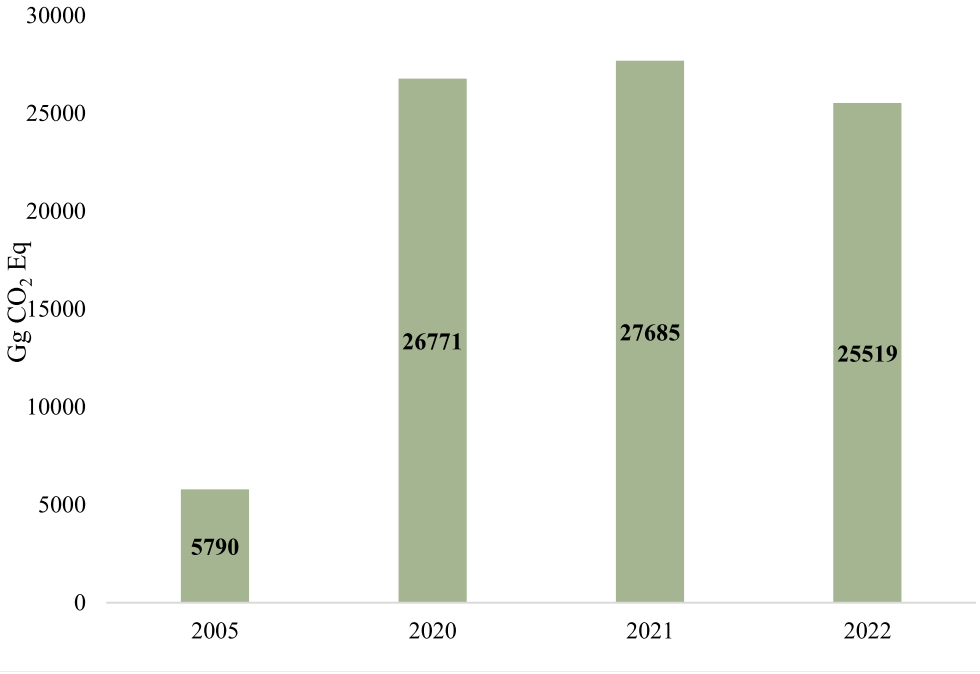


Figure 4.12 GHG emissions from Ethylene (2.B.8.b) in 2005, 2020-2022

Methodological issues

Tier 1 methodology as per the 2006 IPCC Guidelines was used to estimate the CO_2 and CH_4 emissions. Emissions are calculated by multiplying the amount of feed stock wise ethylene produced by default emission factor. Default emission factors mentioned for ethylene in the 2006 IPCC guidelines were used to calculate the CO_2 and CH_4 emissions from ethylene production. The value taken for emission factor for CO_2 emissions for Naphtha is 1.73 tonnes CO_2/ tonne product, for Gas oil is 2.17 tonnes CO_2/ tonne product and for Alcohol 1.73 tonnes CO_2/ tonne product respectively. The production values were further classified into feedstock wise production data based on the data published by the Programme Objectives Based Environmental Studies (PROBES) report of the Central Pollution Control Board and that of MoPNG.

Table 4.12 Activity data for Ethylene in kt for 2005, 2020-2022

Source/Sink Categories	Unit	2005	2020	2021	2022
Ethylene	kt	2233.63	10887.99	11278.59	10391.38

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 (“Information on Flexibility”) of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

For uncertainty of emission factors, CO_2: +/-30% and CH_4: +/-10% and for uncertainty of Activity data, +/- 30% uncertainty has been taken. The combined uncertainty for CO_2 and CH_4 is +/-42% and +/-32% respectively. For activity data the same sources are used throughout the time series, from Department of Chemicals and Petrochemicals, Ministry of Chemicals & Fertilizers. The emission factor is taken from 2006 IPCC guidelines. Therefore, CO_2 and CH_4 emissions from ethylene production has been estimated in a consistent manner throughout the time-series.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities,

including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

4.3.8.3. Ethylene dichloride and vinyl chloride monomer (2.B.8.c)

Category description

In India, Ethylene Dichloride (EDC) and Vinyl Chloride Monomer (VCM) are produced using a balanced process that combines direct chlorination and oxychlorination methods. The direct chlorination process is used to produce EDC, while the cracking of EDC results in the production of VCM. This process generates an excess of hydrogen chloride, which is efficiently utilized in the oxychlorination process, ensuring minimal waste and better resource management. By integrating both the direct chlorination and oxychlorination processes, the facilities maintain a balance in production. Additionally, the balanced process produces vent gas containing by-product CO_2, a result of the direct oxidation of ethylene feedstock. EDC & VCM production result in the emission of CO_2 which is estimated and reported. Production also results in negligible emission of CH_4 which is currently not estimated.

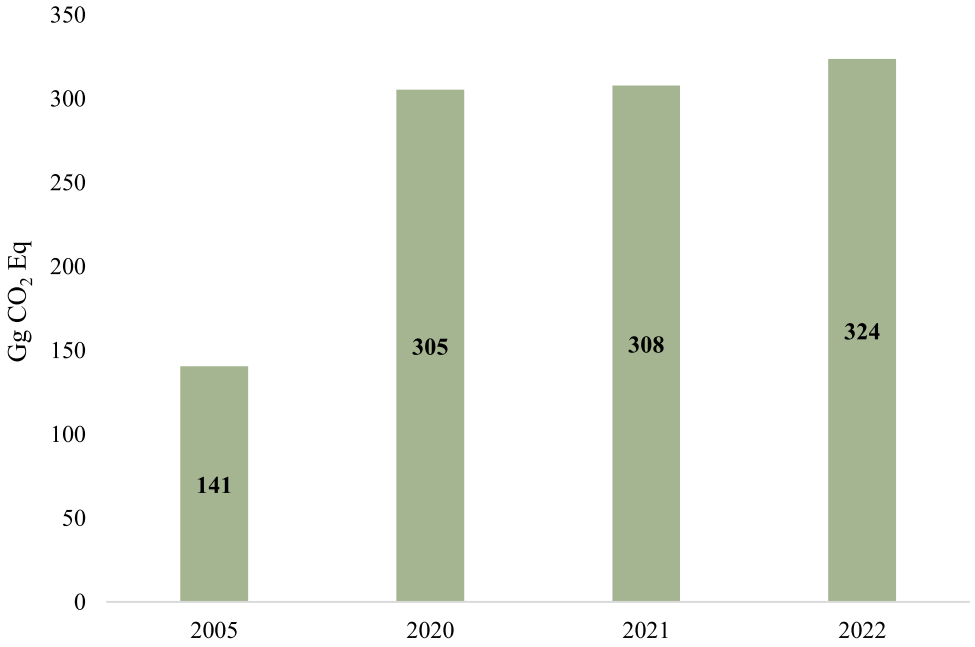


Figure 4.13 GHG emissions from Ethylene dichloride and vinyl chloride monomer (2.B.8.c) in 2005, 2020-2022

Methodological issues

Tier 1 methodology as per the 2006 IPCC Guidelines was used to estimate the CO_2 emissions. Emissions are calculated by multiplying the amount of EDC & VCM produced by emission factor. Default emission factors mentioned for EDC & VCM in the 2006 IPCC guidelines were used to calculate the CO_2 emissions from EDC & VCM production. The value taken is 0.196 tonne CO_2/ tonne EDC produced and 0.294 tonne CO_2/tonne

VCM produced respectively. The annual production of EDC & VCM which was earlier extracted from Chemical and Petrochemical Statistics till India's Third National Communication has now been provided directly by the Department of Chemicals and Petrochemicals, Ministry of Chemicals & Fertilizers. No CH_4 emissions are estimated and NE notation key is used as the emissions are negligible and therefore not estimated in accordance to the MPGs.

Table 4.13 Activity data for Ethylene dichloride and vinyl chloride monomer in kt for 2005, 2020-2022

Source/Sink Categories	Unit	2005	2020	2021	2022
Ethylene dichloride and vinyl chloride monomer	kt	564.93	1149.04	1166.39	1230.96

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

For uncertainty of emission factors, CO_2: -50% to +20% and for uncertainty of Activity data, +/- 2% uncertainty has been taken. The combined uncertainty is +/-20%. For activity data the same sources are used throughout the time series, from Department of Chemicals and Petrochemicals, Ministry of Chemicals & Fertilizers. The emission factor is taken from 2006 IPCC guidelines. Therefore, CO_2 emissions from EDC & VCM production have been estimated in a consistent manner throughout the time-series.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

4.3.8.4. Ethylene oxide (2.B.8.d)

Category description

Ethylene oxide is manufactured by reacting ethylene with oxygen over a catalyst. The oxygen may be supplied to the process through either air or through pure oxygen separated from air.

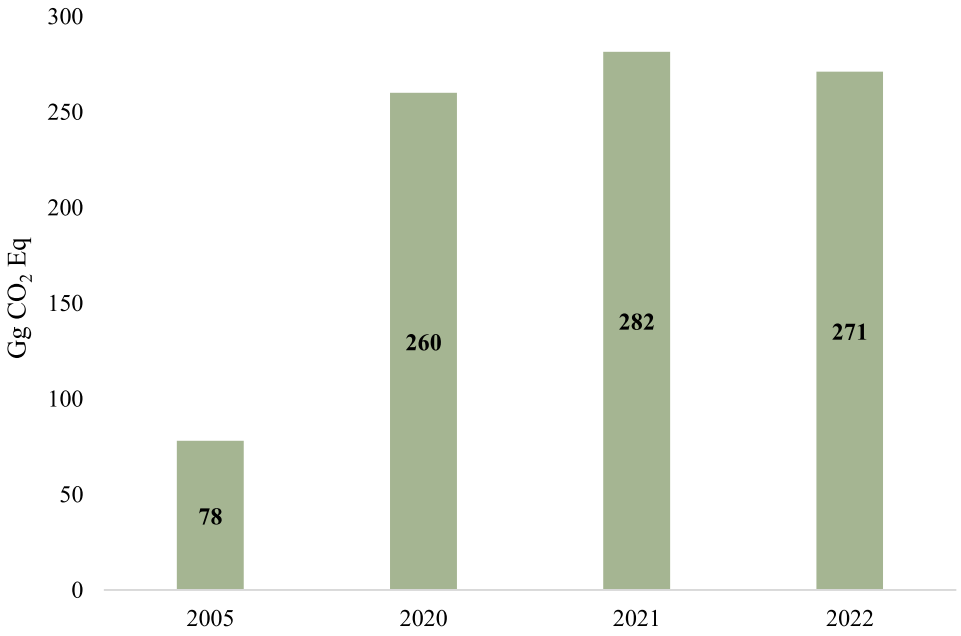


Figure 4.14 GHG emissions from Ethylene oxide (2.B.8.d) in 2005, 2020-2022

Methodological issues

Tier 1 methodology as per the 2006 IPCC Guidelines was used to estimate the CO_2 and CH_4 emissions. Emissions are calculated by multiplying the amount of ethylene oxide produced by emission factor. Default emission factors mentioned for ethylene oxide in the 2006 IPCC guidelines were used to calculate the CO_2 and CH_4 emissions from ethylene oxide production. The value taken is 0.863 tonnes CO_2/ tonne product and 1.79 tonnes CH_4/ tonne product respectively. The annual production of ethylene oxide which was earlier extracted from Chemical and Petrochemical Statistics till India's Third National Communication has now been provided directly by the Department of Chemicals and Petrochemicals, Ministry of Chemicals & Fertilizers.

Table 4.14 Activity data for Ethylene oxide in kt for 2005, 2020-2022

Source/Sink Categories	Unit	2005	2020	2021	2022
Ethylene oxide	kt	85.45	284.82	308.41	296.92

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

For uncertainty of emission factors, CO_2: +/-10% and CH_4: +/-60% uncertainty has been taken and for uncertainty of Activity data, +/-10% uncertainty has been taken. The combined uncertainty for CO_2 and CH_4 is +/-14% and +/-61%. For activity data the same sources are used throughout the time series, from Department of Chemicals and Petrochemicals, Ministry of Chemicals & Fertilizers. The emission factor is taken from 2006 IPCC guidelines. Therefore, CO_2 and CH_4 emissions from ethylene oxide production has been estimated in a consistent manner throughout the time-series.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process

but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

4.3.8.5. Acrylonitrile (2.B.8.e)

Category description

Acrylonitrile is commonly used as raw material for acrylic fibre or synthetic resin. It is produced by way of direct ammoxidation of propylene with ammonia and oxygen over a catalyst called as SOHIO process.

Methodological issues

Tier 1 methodology as per the 2006 IPCC Guidelines was used to estimate the CO_2 and CH_4 emissions. Emissions are calculated by multiplying the amount of acrylonitrile produced by emission factor. Default emission factors mentioned for acrylonitrile in the 2006 IPCC guidelines were used to calculate the CO_2 and CH_4 emissions from acrylonitrile production. The value taken is 0.79 tonnes CO_2/ tonne product and 0.18 tonnes CH_4/ tonne product respectively. The annual production of acrylonitrile which was earlier extracted from Chemical and Petrochemical Statistics till India's Third National Communication has now been provided directly by the Department of Chemicals and Petrochemicals, Ministry of Chemicals & Fertilizers.

NO notation key is used as there is no production of Acrylonitrile between 2020-2022.There is no reliable evidence of Acrylonitrile production. The only possible producer likely shut down between 2015 and 2020, so production is listed as NO for 2020–2022.

Table 4.15 Activity data for Acrylonitrile in kt for 2005, 2020-2022

Source/Sink Categories	Unit	2005	2020	2021	2022
Acrylonitrile	kt	34.62	NO	NO	NO

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

For uncertainty of emission factors, CO_2: +/-60% and CH_4: +/-10% uncertainty has been taken and for uncertainty of Activity data, +/- 10% uncertainty has been taken. The combined uncertainty for CO_2 and CH_4 is +/-61% and +/-14%. For activity data the same sources are used throughout the time series, from Department of Chemicals and Petrochemicals, Ministry of Chemicals & Fertilizers. The emission factor is taken from 2006 IPCC guidelines. Therefore, CO_2 and CH_4 emissions from acrylonitrile production has been estimated in a consistent manner throughout the time-series.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists,

review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

4.3.8.6. Carbon black (2.B.8.f)

Category description

In India, carbon black is produced by channel black process. It involves partial oxidation of vaporised carbon black feedstock that is burned in a furnace with a carrier gas (which may be coke oven gas, hydrogen, or methane). Carbon black production result in the emission of CO_2 and CH_4 which is estimated and reported.

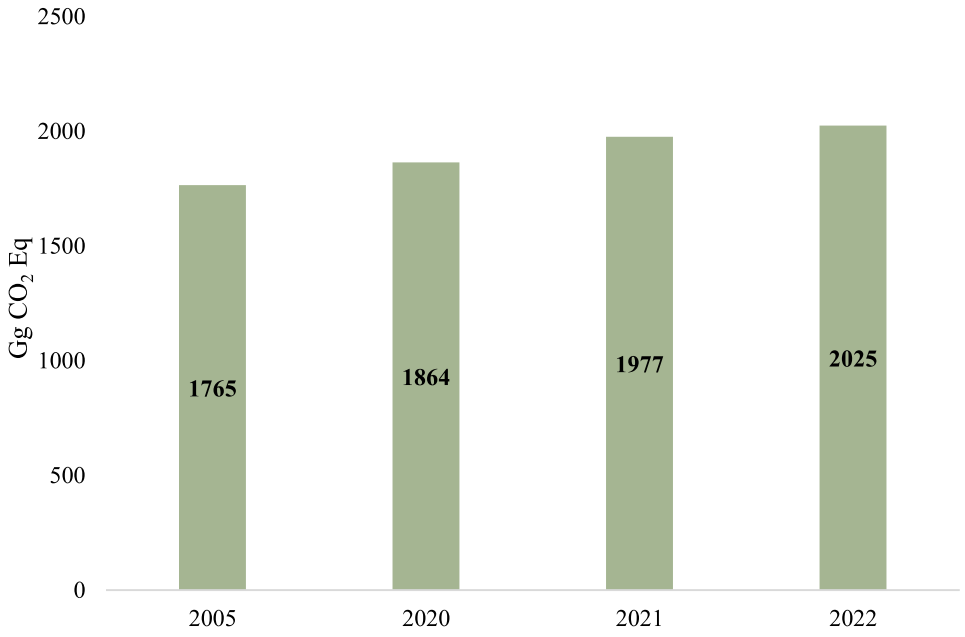


Figure 4.15 GHG emissions from Carbon black (2.B.8.f) in 2005, 2020-2022

Methodological issues

Tier 2 methodology as per the 2006 IPCC Guidelines was used to estimate the CO_2 emissions and Tier 1 methodology as per the 2006 IPCC Guidelines was used to estimate the CH_4 emissions from carbon black production. CO_2 emissions are calculated using the carbon balance approach, subtracting the Carbon content of Carbon Black from Carbon Content of Feed Stock (CBFS). Since only carbon black production data is available in India, the feedstock consumption is estimated by applying a factor of 2.2, which represents the standard relationship between carbon black production and CBFS consumption. Default carbon content factors mentioned for carbon black and carbon black feedstock in the 2006 IPCC guidelines were used to calculate the CO_2 emissions from carbon black production. Further, for calculating the CH_4 emissions, default emission factor as per 2006 IPCC guidelines has been used. The values taken is 28.7 kg CH_4/tonne carbon black produced. The annual production of carbon black which was earlier extracted from Chemical and Petrochemical Statistics till India's Third National Communication has now been provided directly by the Department of Chemicals and Petrochemicals, Ministry of Chemicals & Fertilizers.

Table 4.16 Activity data for Carbon black in kt for 2005, 2020-2022

Source/Sink Categories	Unit	2005	2020	2021	2022
Carbon black	kt	391.64	413.62	438.56	449.37

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

For uncertainty of emission factors, CO_2: +/-15% and CH_4: +/-85% uncertainty has been taken and for uncertainty of Activity data, +/-10% uncertainty has been taken. The combined uncertainty for CO_2 and CH_4 is +/-18% and +/-86%. For activity data the same sources are used throughout the time series, from Department of Chemicals and Petrochemicals, Ministry of Chemicals & Fertilizers. The emission factor and carbon content factors are taken from 2006 IPCC guidelines. Therefore, CO_2 and CH_4 emissions from carbon black production has been estimated in a consistent manner throughout the time-series.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

4.3.8.7. Other (2.B.8.g)

Category description and background

CO_2 is emitted from various petrochemical production concluded as 'Others'.

4.3.8.7.1. Styrene (2.B.8.g.i)

Category description

NO notation key has been used. As of recent reports, India currently does not have any domestic styrene monomer (SM) production capacity. All demand is met through imports.

4.3.8.7.2. Other (please specify) (2.B.8.g.ii)

Category description

Tier 1 methodology as per th

Methodological issues

In India, as per the Petrochemical Statistics published by the Department of Chemicals and Petrochemicals, Ministry of Chemicals & Fertilizers, the datasets for the Naphtha usage in petrochemical sector is being released for every year. Naphtha is a prime feedstock in many of the petrochemical categories like ethylene. As per the 2005 report, there is a lack of clarity in the usage of the naphtha across various petrochemicals. To match the energy balance, after tracking naphtha used in ammonia, ethylene etc. the remaining is being put in the category 'Others'. For the year 2020, 2021 and 2022 there was a usage clarity and therefore zero/NA is reported in 'Others' category for these subsequent years. Default emission factors mentioned for ethylene in the 2006 IPCC guidelines were used to calculate the CO_2 emissions. The value taken is 1.73 tonne CO_2/ tonne ethylene produced. In this category Ethylene related parameters are considered for other petrochemical categories also.

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

For uncertainty of emission factors, CO_2: -10% to +10% and for uncertainty of Activity data, +/- 30% uncertainty has been taken. The combined uncertainty is +/-32%.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

4.3.9. Fluorochemical Production (2.B.9)

4.3.9.1. By-product Emissions (2.B.9.a)

4.3.9.1.1. Production of HCFC-22 (2.B.9.a.i)

Category description

While manufacturing HCFC-22, which is used as a refrigerant and as feedstock for the production of PTFE (Polytetrafluoroethylene - Teflon), HFC-23 is produced as a by-product. Most of HFC-23 is likely vented into atmosphere by the manufacturers. Since 2009-10, HCFC-22 has been classified as a controlled substances under Annex-C Group-I of the Montreal Protocol (2024), because of which all HCFCs need to be reduced and eventually phased out. The India HCFC phase-out programme is under implementation, and the schedule of phaseout is reproduced.

The largest producers of HCFC-22 in India reports that earlier HFC-23 was produced as a byproduct and was thermally destroyed. The thermal destruction used to result in consumption of utilities and emissions generation.

Now HFC-23 is being utilised for producing BTFM, a raw material for various insecticides. Any leftover HFC-23 is destroyed in the Thermal Oxidiser using RLNG. During thermal destruction, HF gas is produced which is quenched in water to produce 20% DHF (Dilute Hydrofluoric Acid) and this DHF is a raw material for Ethyl di-fluoroacetate (EDFA). This is in line with the notification issued by the Indian government in 2016, requiring all manufacturers of HCFC-22 to maintain a proven abatement system and ensure capacity for the storage of HFC-23 for abatement system down-time.

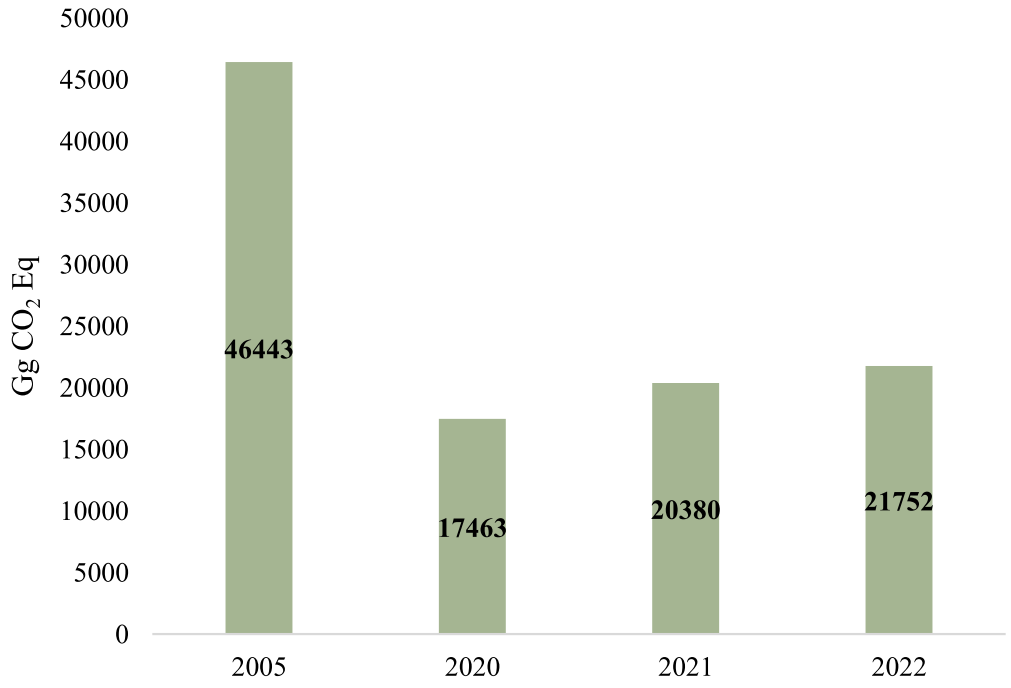


Figure 4.16 GHG emissions from Production of HCFC-22 (2.B.9.a.i) in 2005, 2020-2022

Methodological issues

The IPCC 2006 Tier 1 methodology has been applied to estimate the HFC-23 production from HCFC-22 production. Note that re-utilisation of HFC-23 for producing other products has not been taken into account, as this would require additional data collection on the amount recycled. This data is proposed to be gathered in future communications for all plants operational in India that are producing HCFC-22. The HCFC-22 production data is sourced from the Ozone Cell, Ministry of Environment, Forest, and Climate Change, Government of India. It collates the HCFC-22 production data from each of the manufacturing units in India. The 5 Indian companies producing HCFC-22 undertook a CDM project to reduce HFC-23 emissions from HCFC22 production during the period 2009 to 2013. While CDM was operational, the HFC-23/HCFC22 ratio reported ranged from 0-0.009. Prior to that the companies reported an average HFC23/HCFC 22 ratio of 0.031. Post the CDM project duration, measurements by Say et al., 2019 indicate an average emission factor of 0.022. These variations in HFC-23/HCFC-22 have been captured across the time series to obtain HFC23 emission from HCFC22 production. The emissions of HFC-23 in 2005 is estimated as 46443 Gg of CO_2eq. In 2020, HFC-23 emissions were 17463 Gg CO_2eq. In 2021 the HFC-23 emissions increased to 20380 Gg CO_2eq, and it increased further to 21752 Gg CO_2eq in 2022.

Table 4.17 Activity data for Production of HCFC-22 in kt for 2005, 2020-2022

Source/Sink Categories	Unit	2005	2020	2021	2022
Production of HCFC-22	Ton (t)	88289.24	64012.59	74708.33	79736.03

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 (“Information on Flexibility”) of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

The associated uncertainty is adjudged as 50% as per the guidance provided in IPCC 2006 guidelines Tier-1 methodology. The Ozone Cell of the Ministry of Environment, Forest, and Climate Change collates data on HCFC-22 production data from each of the manufacturing units in India. Data is available for the period 1998 to present.

QA/QC and verification

The data collected by the Ozone Cell, Ministry of Environment, Forests and Climate Change from the manufacturing units, is checked by the cell as it is used for reporting as per the reporting requirements under Article 7 of the Montreal Protocol. The data on production, import, export and feedstock of CFCs, Halons, CTC, HCFC and Methyl Bromide for each year is submitted to the Ozone Secretariat. It must be noted that installation-based emission (HFC23) measurements were specifically done during the CDM project undertaken in India during the period. In 2016 whole air flask samples collected over India during June and July 2016 and analysed to derive the emission ratio of HFC23 from HCFC22 production.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

4.3.9.1. Fugitive Emissions (2.B.9.b)

Category description and background

Unintentional releases, of HFCs, PFCs, SF_6, and NF_3 or 'fugitive emissions' may occur during their production and distribution processes. In the case of gas containers/cylinders are concerned, fugitive emissions occur when residual gas is decomposed and the containment shell is cleansed, or when there is release into the atmosphere. In this section we have reported fugitive emissions during manufacturing of HFC-134a, HFC-32 and HFC-125.

4.3.9.2.1. Production of HFC-134a (2.B.9.b.i)

Category description

HFC-134a is emitted as fugitive emission during its manufacturing process and distribution. In the present estimation, production data is being used to calculate the related fugitive emissions. There is only one bulk manufacturer of HFC-134a in India.

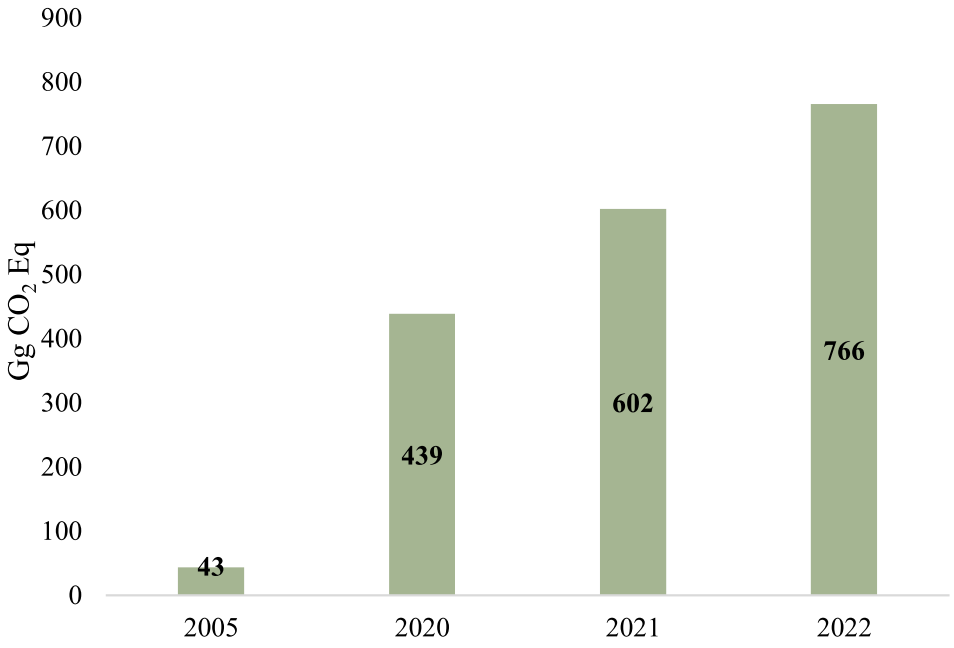


Figure 4.17 GHG emissions from Production of HFC-134a (2.B.9.b.i) in 2005, 2020-2022

Methodological issues

The IPCC 2006 Tier 1 methodology has been used to estimate the HFC-134a production. HFC-134a production data is sourced from Ozone Cell of the MoEFCC as a part of their HFC phaseout plan. It is available for 2021 and 2022. The 2020 data has been extrapolated from 2021 and 2022. In the absence of availability of actual HFC-134a production in 2005, production capacity in that year has been considered. The default emission factor of 0.04 kg HFC134a emitted/ kg of HFC-134a produced is used as per IPCC 2019 update of the IPCC 2006 guidelines (see Table 3.28 A, Volume 3, Chapter 3, Page 3.28, IPCC 2019).

Table 4.18 Activity data for Production of HFC-134a in t for 2005, 2020-2022

Source/Sink Categories	Unit	2005	2020	2021	2022
Production of HFC-134a	Ton (t)	833.0	8433.36	11580.59	14727.82

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 (“Information on Flexibility”) of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

The default uncertainty associated with activity data is 1% for the HFC-134a production and default emission factor uncertainty of 50% is used from (Volume 3, Chapter 3, Page 3.106).

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India’s first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

4.3.9.2.2. Production of SF_6 (2.B.9.b.ii)

NO notation key is used here as there is no production of SF_6 is reported from India. Neither is there any data available on quantity of SF_6 imported.

Planned Improvement

It is proposed to develop the database on SF_6 production and distribution by BTR 3. Data flows will be mapped across industries using SF_6 to quantify SF_6 utilisation from imports or indigenous production in India.

4.3.9.2.3. Production of NF_3 (2.B.9.b.iii)

NO notation key is used here as there is no reported production data of NF_3 available. Further, Government trade data so far provides only imports of overall traded commodities under broad categories but no specific figure for NF_3 imports into India is so far available.

Planned Improvement

It is proposed to develop the database on NF_3 production and distribution by BTR 3. Data flows will be mapped across industries using NF_3 to quantify NF_3 utilisation from imports or indigenous production in India..

4.3.9.2.4. Other (Production of HFC-125) (2.B.9.b.iv)

Category description

HFC 125 is used for extinguishing Class A, Class B and Class C fires and also where electrical risks are present. HFC-125 production in India started in late 2000. Production data could be collated only for the period 2021 and 2022. The production of HFC-125 for the year 2020 is estimated using annual growth rate.

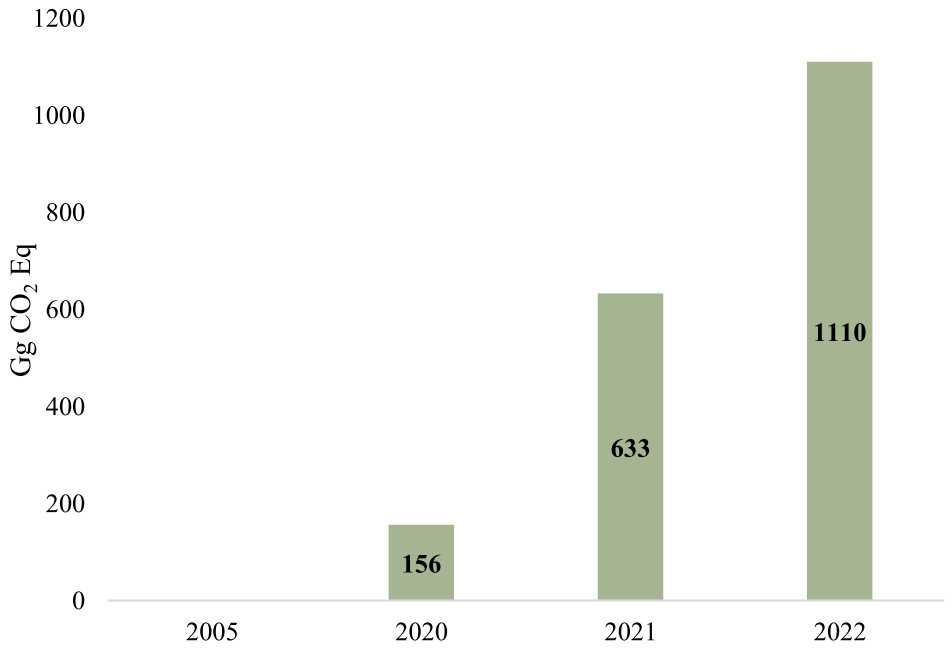


Figure 4.18 GHG emissions from Production of HFC-125 (2.B.9.b.iv) in 2005, 2020-2022

Methodological issues

The IPCC 2006 Tier 1 methodology has been used to estimate the HFC-125 production. The HFC-125 production data is available for the period 2021 and 2022 (Table 35). This data is sourced from the Ozone Cell, Ministry of Environment, Forest, and Climate Change, Government of India. The 2020 data have been extrapolated. The default emission factor uncertainty of 0.04 is used from Table 3.28 A (Volume 3, Chapter 3, Page 3.28, IPCC 2019). The emission estimates show an increase in HFC-125 emissions from 49.292 tons in 2005 to 199.7412 t in 2020 to 350.190 t in 2022.

Table 4.19 Activity data for Production of HFC-125 in t for 2005, 2020-2022

Source/Sink Categories	Unit	2005	2020	2021	2022
Production of HFC-125	Ton (t)	NE	1232.31	4993.53	8754.75

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

The default uncertainty associated with activity data is 1% for the HFC production and default emission factor uncertainty of 50% is used from (Volume 3, Chapter 3, Page 3.106). uncertainty for the activity data has been taken to be 1% as per IPCC 2006 guidelines.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

4.3.9.2.5. Other (Production of HFC-32) (2.B.9.b.v)

Category description

HFC-32 are emitted as fugitive emissions during manufacturing.

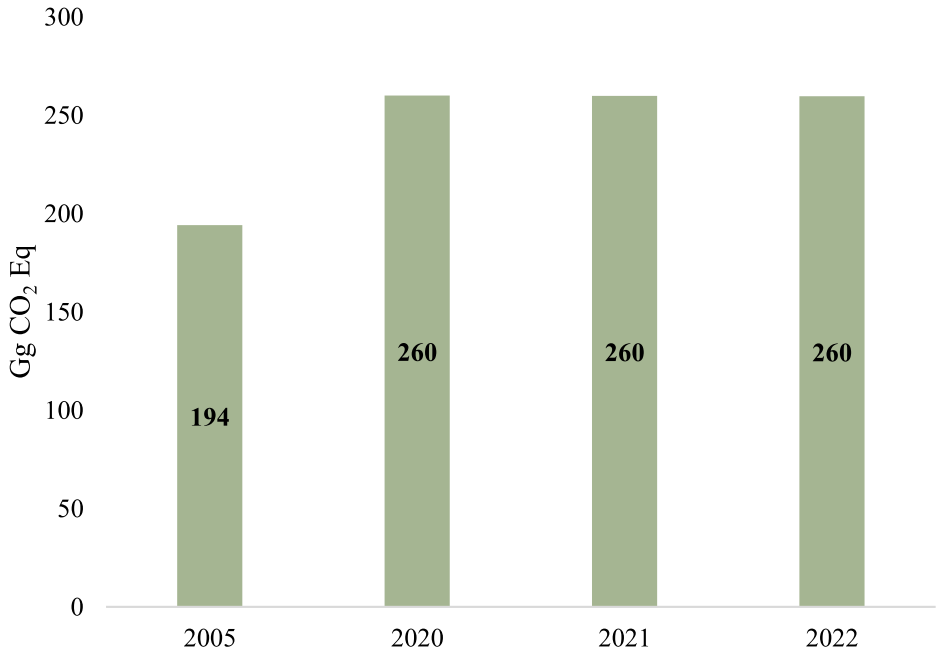


Figure 4.19 GHG emissions from Production of HFC-32 (2.B.9.b.v) in 2005, 2020-2022

Methodological issues

The IPCC 2006 Tier 1 methodology has been used to estimate the HFC-32 production. The HFC-32 production data is available for the period 2021 and 2022. This data is sourced from the Ozone Cell, Ministry of Environment, Forest, and Climate Change, Government of India who in turn have collated from producer companies in India. There is no production data available for 2005, but as per Ministry of Commerce some exports were made in that year. It is assumed that in 2005, export is equal to production (Ministry of Commerce and Industry, 2005). Activity data for the year 2020 is based on extrapolation of 2021 and 2022. The default emission factor of 0.04 is used from Table 3.28 A (Volume 3, Chapter 3, Page 3.28, IPCC 2019). The emission estimates indicate a rise from 194.276 kt CO_2-e in 2005 to 259.70 kt CO_2-e in 2022. HFC-32 emissions increased from 194.28 Gg CO_2-e in 2005 to 260.17 Gg CO_2-e in 2020, followed by a slight decline to 259.93 Gg CO_2-e in 2021 and 259.70 Gg CO_2-e in 2022.

Table 4.20 Activity data for Production of HFC-32 in t for 2005, 2020-2022

Source/Sink Categories	Unit	2005	2020	2021	2022
Production of HFC-32	Ton (t)	7174.15	9607.30	9598.75	9590.20

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

The default uncertainty associated with activity data is 1% for the HFC-134a production and default emission factor uncertainty of 50% is used from (Volume 3, Chapter 3, Page 3.106). uncertainty for the activity data has been taken to be 1% as per IPCC 2006 guidelines.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process

but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

4.3.10. Other (2.B.10)

Category description and background

4.3.10.1. Hydrogen production (2.B.10.a)

NE notation key is used as quantity of hydrogen production is not significant.

India's National Green Hydrogen Mission aims to produce 5 million metric tons of Hydrogen by 2030 for use in steel, fertiliser, shipping etc. Currently the focus is on establishing demand, building domestic electrolyzer manufacturing capacity, and implementing pilot projects to test and develop green hydrogen transition pathways, including establishment of regulations and standards to facilitate the growth of the green hydrogen sector.

Currently, grey hydrogen is produced in-house by industrial plants (refineries, fertiliser factories), so production and consumption are close, but detailed production numbers for sectors are seladom published publicly with high granularity. Hence due to the unavailability of the authentic data this category is reported as NE.

4.4. Metal Production (CRT 2.C)

The metal industry is a significant source of greenhouse gas emissions particularly within the Industrial Processes and Product Use (IPPU) sector. Due to national initiatives like "Make in India", and various other initiatives India has witnessed a gradually increasing pattern in metal sector, key sectors driving demand include construction, transportation, packaging and electrical industries. Government policies, infrastructure development, and renewable energy projects have further increased demand for certain sectors like aluminium, lead & zinc. The future looks promising with continued support and technological advancements ensuring sustained growth in the metal sector.

According to the IPCC, the metal industry encompasses emissions from the production process of metals, primarily due to the chemical transformation of the raw materials from which they are produced. These processes release substantial amounts of CO_2 and other greenhouse gases, contributing to global warming. The IPCC guidelines emphasize the importance of accurate emission estimation and reporting to develop effective mitigation strategies. Key processes in the metal industry include smelting, refining, and casting, each contributing differently to the overall emissions profile. Following are the major sub sectors of the metal industry:

- 4.4.1: Iron & steel production (2.C.1)
- 4.4.2: Ferro alloys production (2.C.2)
- 4.4.3: Aluminum Production (2.C.3)
- 4.4.4: Magnesium Production (2.C.4)
- 4.4.5: Lead Production (2.C.5)
- 4.4.6: Zinc Production (2.C.6)
- 4.4.7: Other (2.C.7)

In 2022, GHG emissions from these metal activities accounted for 9.90 % of total emissions from the Industrial Processes and Product Use (IPPU) sector, amounting to 27581 Gg CO_2 equivalent. Compared to 2005 levels, emissions from this category decreased by 25.14%. The key categories within this sector for India include CO_2 emissions from Aluminium, Ferro alloys and Magnesium production.

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

Category description

The iron and steel sector are a significant contributor to the Indian economy. The sector accounts for approximately 2% of India's GDP and employs around 2.5 million people directly and indirectly. Additionally, India is the second-largest producer of crude steel globally, contributing about 7% of the world's total crude steel production of. The iron & steel sector has a significant amount of emissions accounting from energy usage contributing to the overall national inventory boundary. For the BTR1 cycle, the subsequent emissions occurring from the IPPU boundary have been included in the energy sector. Hence the emissions accounted for are considered as IE for the 2.C.1 subsector and included in the energy sector.

4.4.2. Ferroalloys production (2.C.2.)

Category description

Ferroalloys are concentrated alloys of iron combined with metals like silicon, manganese, chromium, molybdenum, vanadium, and tungsten. These alloys are crucial in steel manufacturing, deoxidizing and modifying steel properties. Silicon metal, often grouped with ferroalloys, is used in aluminum alloys, silicone production, and electronics. The Ferroalloys production has seen a continuous growth due to its demand in steel production. The inclusion of ferroalloys enhances steel's strength, ductility, and resistance to fatigue and corrosion, making it ideal for structural applications requiring high strength and wear resistance. Steel is crucial in construction, automotive, and industrial machinery sectors. Ferroalloy production involves a metallurgical reduction process that emits significant carbon dioxide (CO_2). This process mixes raw ore, carbon materials, and slag-forming materials, heated to high temperatures. Common reductants include coal, coke, and bio-carbon sources like charcoal and wood. Emissions from coke production are accounted for in the Energy Sector. Electric submerged

arc furnaces, using graphite or Søderberg electrodes, generate heat through electric arcs and resistance. The carbon in electrodes captures oxygen from metal oxides, forming carbon monoxide (CO) and reducing ores to molten metals. Additionally, calcination of carbonate fluxes like limestone contributes to greenhouse gas emissions. Methane (CH_4) and nitrous oxide (N_2O) emissions also occur, accounting for up to 5% of CO_2 equivalent emissions from ferrosilicon and silicon-metal production.

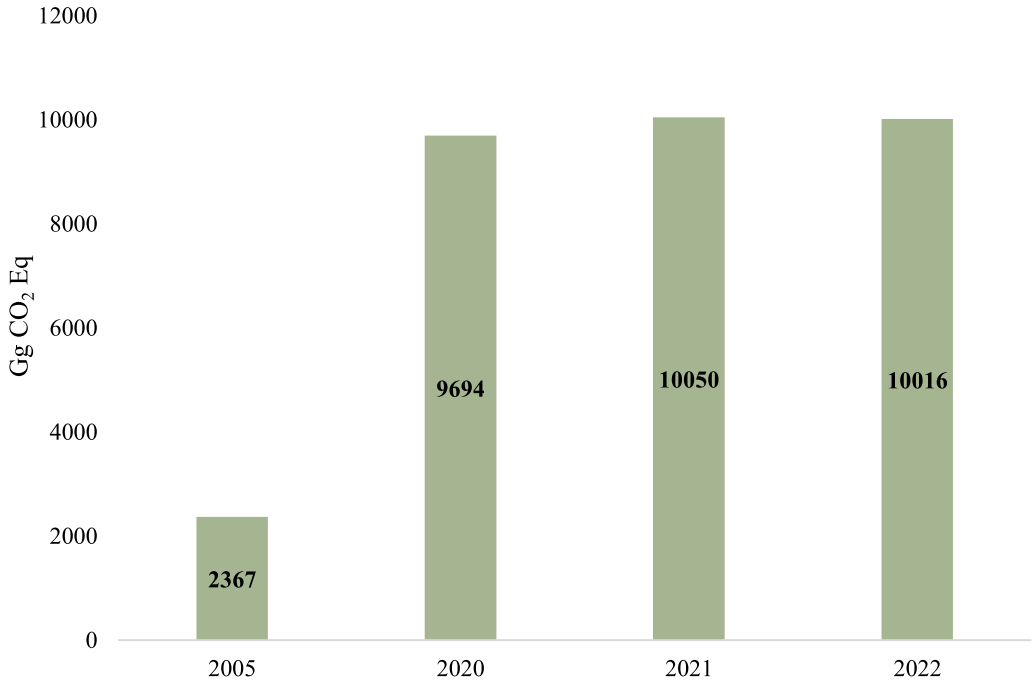


Figure 4.20 GHG emissions from Ferroalloys production (2.C.2.) in 2005, 2020-2022

Methodological issues

Ferroalloy production involves a metallurgical reduction process that emits significant carbon dioxide (CO_2) and some CH_4 emissions. For the estimation of CO_2 & CH_4 emissions from the ferro alloys production, Tier 1 methodology has been used. The IPCC Guidelines define an emission factor as the average rate at which a specific greenhouse gas is emitted from a particular source, relative to units of activity. For this inventory, 'emission factors' refer to parameters that do not need to be obtained from individual facility records. Instead, typical industry values can be used as acceptable substitutes when facility-specific data is unavailable. These factors usually represent material composition fractions or quantity ratios that are consistently within a well-defined range across numerous facilities in a manufacturing region.

Table 4.21 Activity data for Ferroalloys production in kt for 2005, 2020-2022

Source/Sink Categories	Unit	2005	2020	2021	2022
Ferroalloys production	kt	1558.62	4207.34	4368.68	4255.73

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

For uncertainty of emission factors, 5% uncertainty has been taken and for uncertainty of Activity data, 10% uncertainty has been taken, as per the IPCC guidance on uncertainty. The combined uncertainty is 11%. For activity data the same sources are used throughout the time series, from Mineral yearbook data published by the Indian bureau of mines, Ministry of Mines. To ensure the timeseries consistency, the activity data for 2020, 2021 & 2022 for the Ferro Chrome, Ferro Manganese & Ferro Silicon sub sectors are estimated passed on statistical

linear methodology. The emission factor is taken from 2006 IPCC guidelines. Therefore, CO_2 and CH_4 emissions from ferroalloys production has been estimated in a consistent manner throughout the time-series.

QA/QC and verification

The QA/QC process for the uncertainty analysis was carefully followed to ensure accuracy and reliability. The calculations were reviewed thoroughly, following IPCC Guidelines and best practices, and any issues or gaps were resolved. Stakeholders, including regulatory authorities, industry experts, and reviewers, were consulted to present the results and gather their feedback. This input was used to improve and refine the uncertainty estimates. The final analysis was documented clearly and prepared on time for inclusion in the GHG inventory report, ensuring all steps were completed properly and transparently.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

4.4.3. Aluminium Production (2.C.3)

Category description and background

The 2.C.3. Aluminium production category, which is part of the Metal industry and the wider IPPU sector, displays a complex and evolving emissions profile over the period from 2005 to 2022. In 2005, the category's emissions stood at 33361 $GgCO_2$ equivalent. By 2020, emissions had significantly dropped to 14,897 $GgCO_2$ equivalent. In subsequent years, emissions saw a slight rebound, rising to 16,436 $GgCO_2$ equivalent in 2021 and further to 17,017 $GgCO_2$ equivalent in 2022. In 2022, aluminium production accounted for 5.65% of the total emissions from the entire IPPU sector.

4.4.3.1. By-product Emissions (2.C.3.a)

Category description

The Tier 1 method for calculating CO_2 emissions has been considered since it incorporates broad cell technology characterizations (Prebake or Søderberg) as a lower order estimation of CO_2 emissions from aluminum. The process emissions are CO_2 emissions during the electrolytic reduction process where carbon anode (in Prebake cells) or paste (in Søderberg cells) is used to convert aluminium oxide to aluminium metal; and Perfluorocarbons (PFCs) emissions of CF_4 and C_2F_6 during anode effects; and CO, SO_2 and NMVOCs are also emitted in small quantity but not presented in this document. The IPCC Guidelines define an emission factor as the average rate at which a specific greenhouse gas is emitted from a particular source, relative to units of activity.

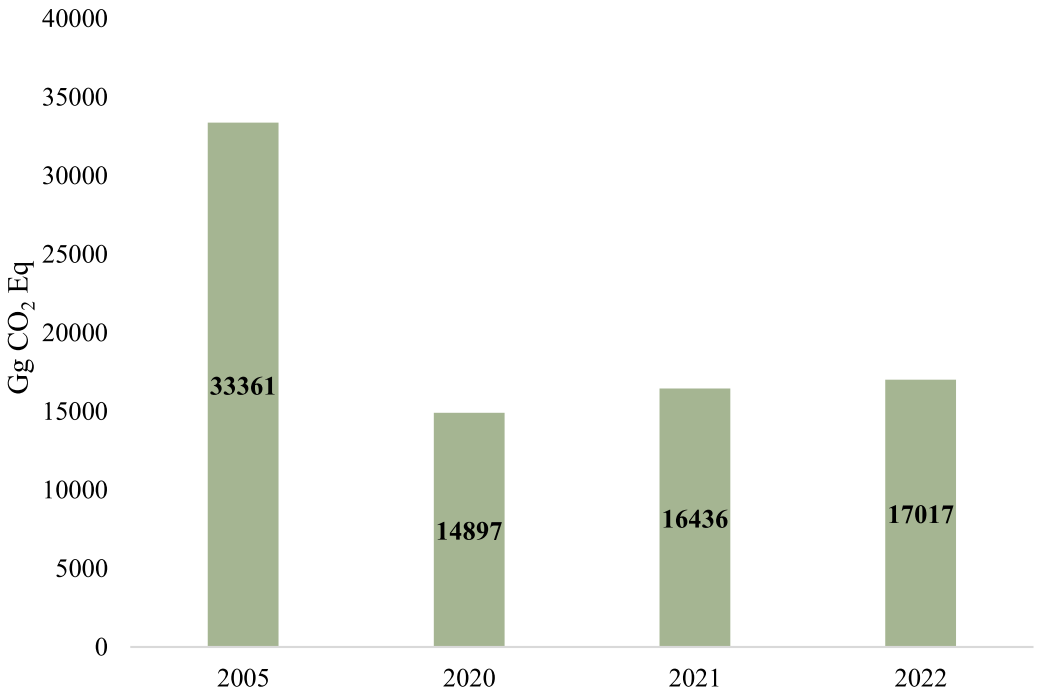


Figure 4.21 GHG emissions from By-product Emissions (2.C.3.a) in 2005, 2020-2022

Methodological issues

The aluminium production data for 2020, 2021, and 2022 was sourced from the Indian Minerals Yearbook, published by the Ministry of Mines, Indian Bureau of Mines. For 2005, production figures were obtained from the World Mineral Production report by the British Geological Survey. To determine the distribution of Soderberg and prebaked cell technology for 2005, an interpolation was performed using percentage distribution data from the Perfluorocarbon Emissions Reduction Programme (1990-2000), based on the years 1990, 1998, 1999, and 2000. Additionally, the 2019 anode survey results from the International Aluminium Institute (IAI) provided the most recent data on cell technology distribution. These data points were used to interpolate the 2005 distribution, resulting in an estimated 83% prebaked technology and the balance being Soderberg. For 2020, 2021, and 2022, a distribution of 95% prebaked and the remaining percentage in Soderberg was used, based on the results of the 2019 anode survey. The financial year aluminium production data is converted to calendar year before it is further processed.

Table 4.22 Activity data for By-product Emissions in t for 2005, 2020-2022

Source/Sink Categories	Unit	2005	2020	2021	2022
By-product Emissions	Ton (t)	1828606	3623200	3917275	4057405

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 (“Information on Flexibility”) of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

For uncertainty of emission factors, 10% uncertainty has been taken and for uncertainty of Activity data, 2% uncertainty has been considered as per the IPCC guidance on uncertainty. The combined uncertainty is 10%. For activity data two sources are referred- for 2005 value is considered from the World Mineral Statistics & Ministry of Mines provided data for the year 2013- 2022. The emission factor is referred from the IPCC 2006 guidelines.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

4.4.4. Magnesium Production (2.C.4)

Category description

Magnesium is crucial in manufacturing alloys for automotive and electronic applications, produced through primary and secondary methods. Primary production involves electrolysis or thermal reduction of carbonate minerals like dolomite, magnesite, carnallite, serpentine, brines, or seawater. The calcination of these raw materials as a pre-treatment step in electrolytic or thermal reduction results in CO_2 emissions. Secondary magnesium production involves recovering and recycling metallic magnesium from scrap materials such as machine cuttings, casting scraps, and furnace residues. SF_6 emissions from its use as a cover gas to prevent oxidation and burning of molten magnesium is also estimated.

Electrolysis involves the electrolysis of molten magnesium chloride to produce magnesium metal and chlorine gas. The process requires significant energy and results in emissions primarily from the use of electricity and the production of chlorine. This involves recycling magnesium from scrap. The process is less energy-intensive compared to primary production but still results in emissions from the smelting and refining processes. The economic downturn in early 2010, impacted production of magnesium globally. Magnesium production has noticed a gradual increase in magnesium production in last few years. Magnesium is a versatile metal with a wide range of applications across various industries due to its unique properties such as lightweight, high strength, and biocompatibility.

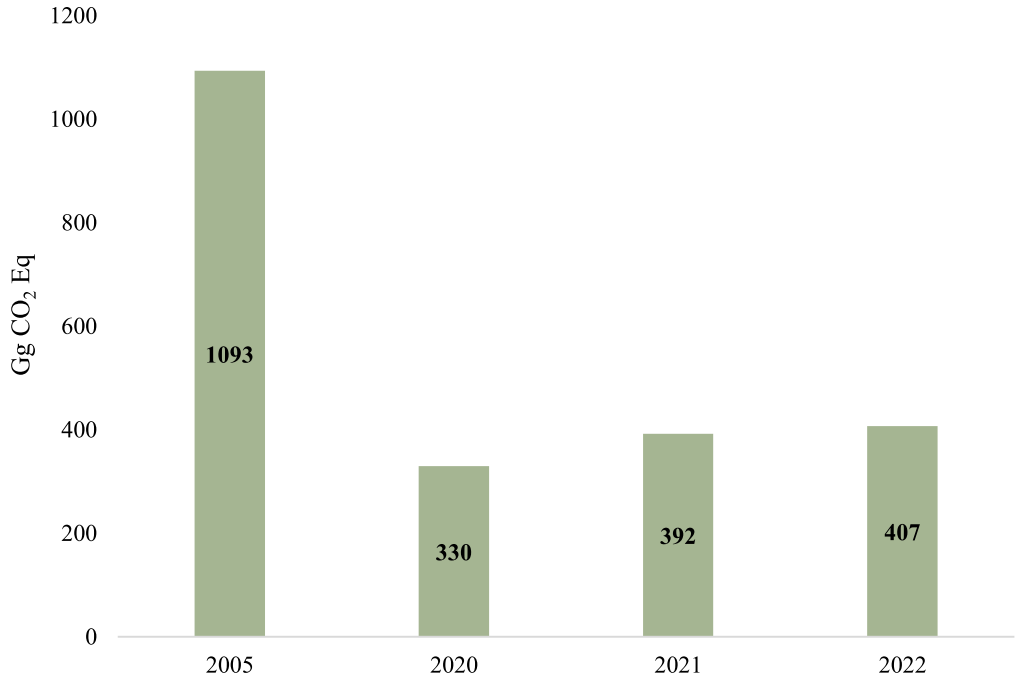


Figure 4.22 GHG emissions from Magnesium Production (2.C.4) in 2005, 2020-2022

Methodological issues

The Tier 1 method for calculating CO_2 emissions is considered. The Tier 1 method relies on national primary production data and knowledge of raw materials used in the country. The emissions from a casting process depend on the size and the type of cover gas system used for protection of molten magnesium. The emissions include SF_6, HFC-134a, FK 5-1-12 from the cover gases, emissions from decomposition of fluorinated products (eg., PFCs) and emissions from carrier gas.

Tier 1 methodology is used to estimate SF_6 emissions from magnesium casting and production. The assumption for the Tier 1 approach is that all SF_6 consumption in the magnesium industry segment is emitted as SF_6. In India, only one plant is operational that is producing magnesium with the total capacity of 200 ton. We have considered production equal to consumption/use. Bulk of the magnesium in use is imported. The emission factor for the SF_6 emission estimates from magnesium casting is taken to be 21 kg/ton.

Table 4.23 Activity data for Magnesium Production in t for 2005, 2020-2022

Source/Sink Categories	Unit	2005	2020	2021	2022
Magnesium Production (SF_6)	Ton (t)	200.00	200.00	200.00	200.00

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 (“Information on Flexibility”) of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

For uncertainty of Emission factors & Activity data is considered as 5% for both as per IPCC guidance on uncertainty. The combined uncertainty is 7%. For activity data Ministry of Mines provided data for the estimation & referred the Mineral Yearbook published by The Indian Bureau of Mines, Ministry of Mines. The emission factor is referred from the IPCC 2006 guidelines. Therefore, CO_2 emissions from Magnesium production have been estimated in a consistent manner throughout the time-series. For SF_6, the uncertainty for the activity data is taken to be 30% as per IPCC 2006 guidelines. The uncertainty for the emission factors is taken to be 5%. The uncertainty for the sector is ± 30.41%.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, (i) estimation of amount of magnesium die-casted annually which includes indigenous production, from recycled magnesium and from imports, (ii) research and development of country-specific emission factors, (iii) capacity-building initiatives for inventory compilers, and the (iv) exploration of higher-tier methodologies where feasible.

4.4.5. Lead Production (2.C.5)

Category description

It is produced through primary and secondary processes. With the rising demand from various national initiatives such as Make in India, National Solar Mission & growth in infrastructure development, lead production has witnessed a growth trajectory. Primary production involves extracting lead from ores, while secondary production recycles lead from scrapped lead-acid batteries. In developed countries, 78% of primary lead is produced via the sintering/smelting process, which includes sequential sintering and smelting steps, and 22% through direct smelting, which skips the sintering step.

In the sintering/smelting process, lead concentrates are blended with recycled sinter, limestone, silica, oxygen, and high-lead-content sludge to remove sulphur and volatile metals through combustion. This produces a sinter roast of lead oxide and other metallic oxides, resulting in SO_2 emissions and CO_2 emissions from the natural gas used for combustion. The sinter roast is then added to a blast furnace or Imperial Smelting Furnace with other ores, smelter by-products, and metallurgical coke. The coke reacts with air to form carbon monoxide (CO), which reduces the lead oxide, resulting in CO_2 emissions. The sintering process produces molten lead bullion.

In direct smelting, lead concentrates and other materials are fed directly into the furnace, bypassing the sintering step. CO_2 emissions from this process depend on the quantity of reducing agents (coal, metallurgical coke, and natural gas) and the type of furnace used. Various furnaces, such as Isasmelt-Ausmelt, Queneau-Schumann-Lurgi, Kaldo, and Kivcet, are employed for smelting. Direct smelting offers environmental and cost-saving benefits by avoiding the sintering process.

Secondary lead production processes recycled lead, mainly from scrapped lead-acid batteries. Batteries are either crushed with a hammer mill and added to the furnace with or without desulfurization or smelted whole. CO_2 emissions from secondary production depend on the quantity of reducing agents and the type of furnace used. Primary reducing agents include coal, natural gas, and metallurgical coke, while petroleum coke is used in electric resistance furnaces. Various furnaces, such as blast furnaces, Imperial Smelting furnaces, electric arc furnaces, electric resistance furnaces, reverberatory furnaces, Isasmelt furnaces, Queneau-Schumann-Lurgi furnaces, and Kivcet furnaces, are used for smelting batteries and other recycled scrap lead.

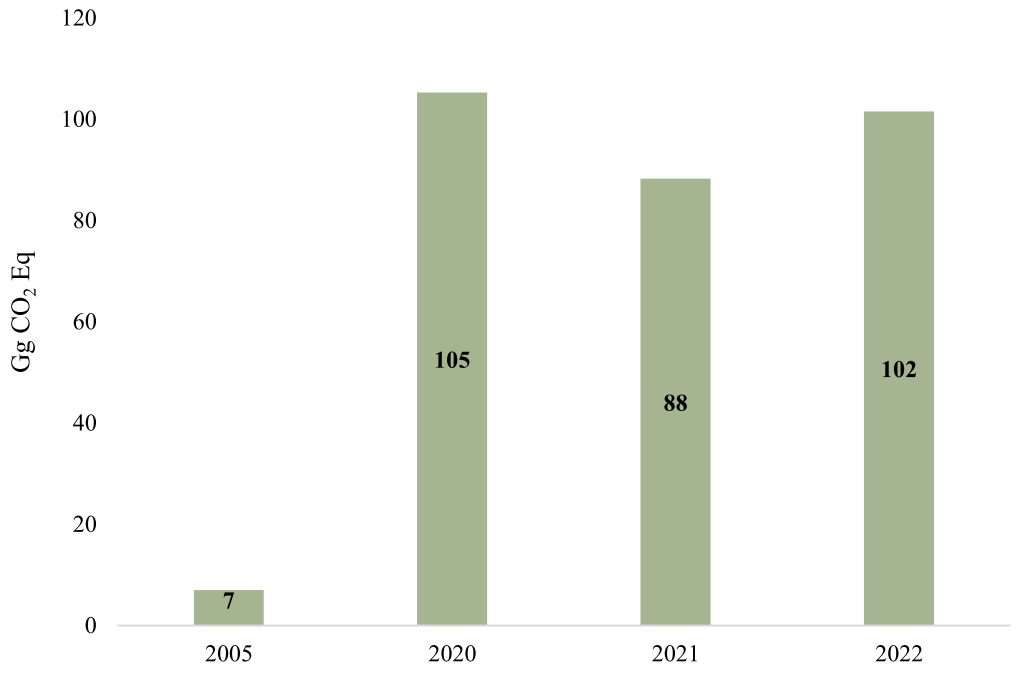


Figure 4.23 GHG emissions from Lead Production (2.C.5) in 2005, 2020-2022

Methodological issues

Tier -1 emission inventories for lead production were compiled using the following equation as given in the IPCC guideline.

Table 4.24 Activity data for Lead Production in kt for 2005, 2020-2022

Source/Sink Categories	Unit	2005	2020	2021	2022
Lead Production	kt	17.93	270.36	226.7	260.81

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

For uncertainty of emission factors, 50% uncertainty has been taken and for uncertainty of Activity data, 10% uncertainty has been considered. The combined uncertainty is 51%. For activity data Ministry of Mines provided data for the estimation & referred the Mineral Yearbook published by The Indian Bureau of Mines, Ministry of Mines. The emission factor is referred from the IPCC 2006 guidelines. Therefore, CO_2 emissions from the Zinc production have been estimated in a consistent manner throughout the time-series.

QA/QC and verification

The QA/QC process for the uncertainty analysis was carefully followed to ensure accuracy and reliability. The calculations were reviewed thoroughly, following IPCC Guidelines and best practices, and any issues or gaps were resolved. Stakeholders, including regulatory authorities, industry experts, and reviewers, were consulted to present the results and gather their feedback. This input was used to improve and refine the uncertainty estimates. The final analysis was documented clearly and prepared on time for inclusion in the GHG inventory report, ensuring all steps were completed properly and transparently.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

4.4.6. Zinc production (2.C.6)

Category description

Zinc is vital for industries like automobile, electrical, and hardware, produced through primary and secondary processes, each contributing to non-energy CO_2 emissions. Programs like "Make in India" have encouraged domestic production, leading to increased capacity for zinc production due to its demand in automobile industry, Renewable energy sector & Infrastructure sector. Electro-thermic Distillation: Roasted zinc concentrate is sintered and reduced by metallurgical coke in an electric retort furnace, emitting non-energy CO_2. Pyrometallurgical Process: Zinc and lead concentrates are smelted using metallurgical coke/coal, resulting in non-energy CO_2 emissions. Electrolytic Process: Zinc oxide is leached and electrolyzed without contributing to non-energy CO_2 emissions. Recovered zinc from flue dusts, sludges, and slags uses pyrometallurgical methods, including the Waelz Kiln and slag reduction, both utilizing carbon-based reductants at high temperatures. These processes result in non-energy CO_2 emissions, similar to primary smelting.

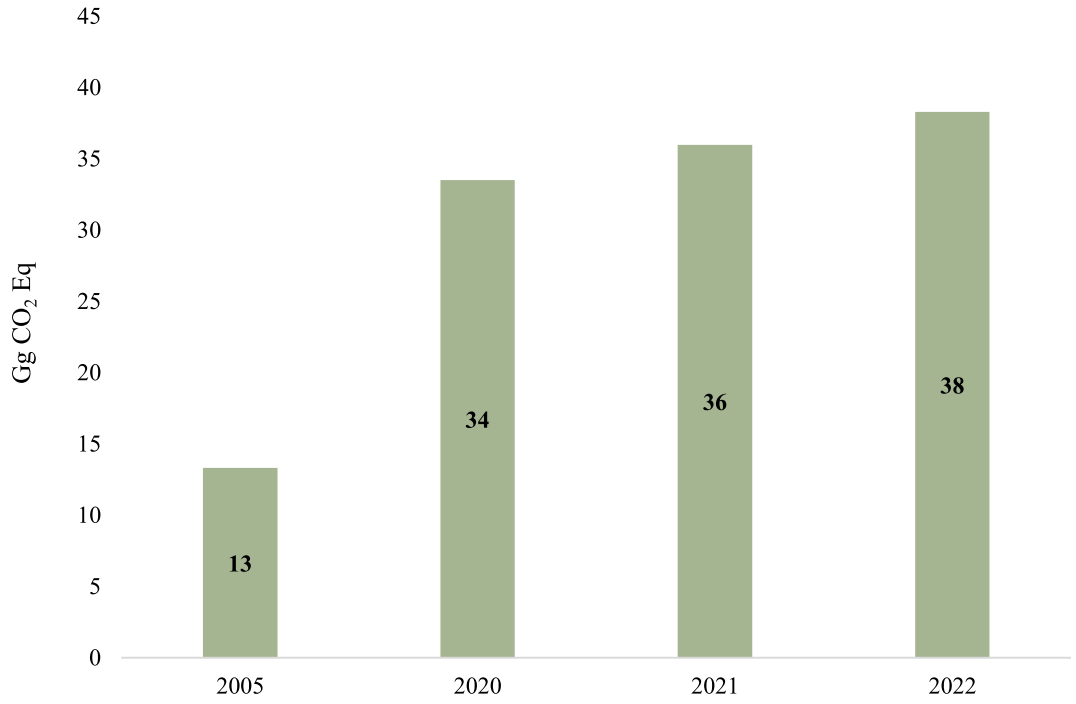


Figure 4.24 GHG emissions from Zinc production (2.C.6) in 2005, 2020-2022

Methodological issues

Zinc production's primary emission sources arise from the use of metallurgical coke and carbon-based reductants in high-temperature processes. Tier-1 emission inventories for zinc production were compiled using IPCC 2006 guidelines and 2019 refinements.

Table 4.25 Activity data for Zinc production in kt for 2005, 2020-2022

Source/Sink Categories	Unit	2005	2020	2021	2022
Zinc production	kt	281.75	708.25	760.75	809.75

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

For uncertainty of emission factors, 50% uncertainty has been considered and for uncertainty of Activity data, 10% uncertainty is considered as per the IPCC guidance on uncertainty. The combined uncertainty is 51%. For activity data Ministry of Mines provided data for the estimation & referred the Mineral Yearbook published by The Indian Bureau of Mines, Ministry of Mines. The emission factor is referred from the IPCC 2006 guidelines. Therefore, CO_2 emissions from Zinc production have been estimated in a consistent manner throughout the time-series.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

4.4.7. Other (2.C.7)

Category description and background

4.4.7.1. Rare earths production (2.C.7.a.)

NE notation key is used as the quantity of rare earth processed, refined, and separated in India is not significant. All processed rare-earth applications needed in India are mostly imported, despite the fact that India has a significant reserves of rare earth material.

PFC emissions associated with processing of rare earths is contingent upon the process that is being used to produce the same.

Planned improvements

Efforts are being made to collect information for reporting in BTR-3 onwards on processing, refining and separation process involved in India, including the amount of rare earth that is and would be processed each year.

4.5. Non-energy products from fuels and solvent use (CRT 2D)

Category description and background

In line with 2006 IPCC Guidelines and the 2019 amendment, this section deals with the following subsectors: Lubricant Use (2.D.1.) and Paraffin Wax Use (2.D.2.)

In 2022, GHG emissions from these non-energy product use activities accounted for 0.88 % of total emissions from the Industrial Processes and Product Use (IPPU) sector, amounting to 2456.12 Gg CO_2 Equivalent. Compared to 2005 levels, emissions from this category increased by 96.6 %. The key categories within this sector for India include CO_2 emissions from cement, lime, and glass production.

4.5.1. Lubricant use (2.D.1)

Category description

Lubricants are mostly used in industrial and transportation applications. Lubricants are produced either at refineries through separation from crude oil or at petrochemical facilities. CO_2 is emitted from the oxidation of lubricants and grease during use which is estimated and reported.

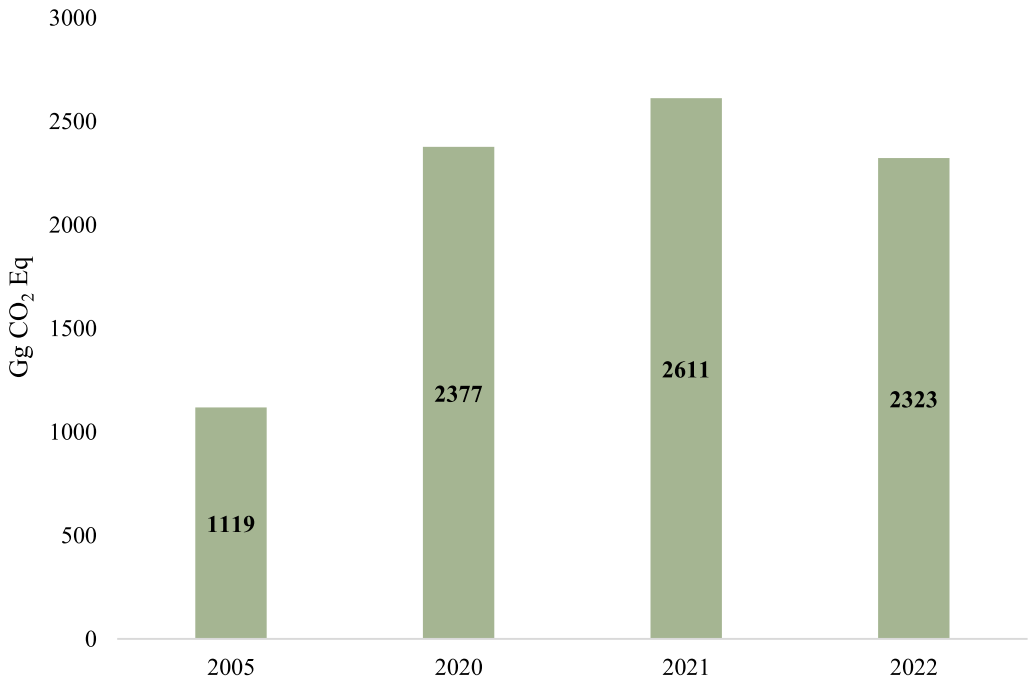


Figure 4.25 GHG emissions from Lubricant use (2.D.1) in 2005, 2020-2022

Methodological issues

Tier 1 methodology as per the 2006 IPCC Guidelines was used to estimate the CO_2 emissions. Emissions are calculated by multiplying the amount of lubricant consumed by the carbon content and oxidation during use (ODU) factor. Default emission factors mentioned for lubricant use in the 2006 IPCC guidelines were used to calculate the CO_2 emissions from lubricant use. The value taken for carbon content of lubricant is 20 tonne-C/TJ and value taken for Oxidized During Use (ODU) factor of lubricant is 0.2 respectively.

Table 4.26 Activity data for Lubricant use in kt for 2005, 2020-2022

Source/Sink Categories	Unit	2005	2020	2021	2022
Lubricant use	kt	1897.75	4031.00	4429.25	3940.00

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

For uncertainty of emission factors, +/-50% uncertainty has been taken and for uncertainty of Activity data, +/-20% uncertainty has been taken. The combined uncertainty is +/- 54%. For activity data the same sources are used throughout the time series, from Indian Petroleum and Natural gas statistics by Ministry of Petroleum and Natural Gas. The emission factor is taken from 2006 IPCC guidelines. Therefore, CO_2 emissions from lubricant use have been estimated in a consistent manner throughout the time-series.

QA/QC and verification

The QA/QC process for the uncertainty analysis was carefully followed to ensure accuracy and reliability. The calculations were reviewed thoroughly, following IPCC Guidelines and best practices, and any issues or gaps were resolved. Stakeholders, including regulatory authorities, industry experts, and reviewers, were consulted to present the results and gather their feedback. This input was used to improve and refine the uncertainty estimates. The final analysis was documented clearly and prepared on time for inclusion in the GHG inventory report, ensuring all steps were completed properly and transparently.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

4.5.2. Paraffin wax use (2.D.2)

Category description

Paraffin waxes are separated from crude oil during the production of light lubricating oils. Paraffin waxes are categorised by oil content and the amount of refinement. CO_2 is emitted from the oxidation of paraffin wax during use. Paraffin wax use result in the emission of CO_2 which is estimated and reported.

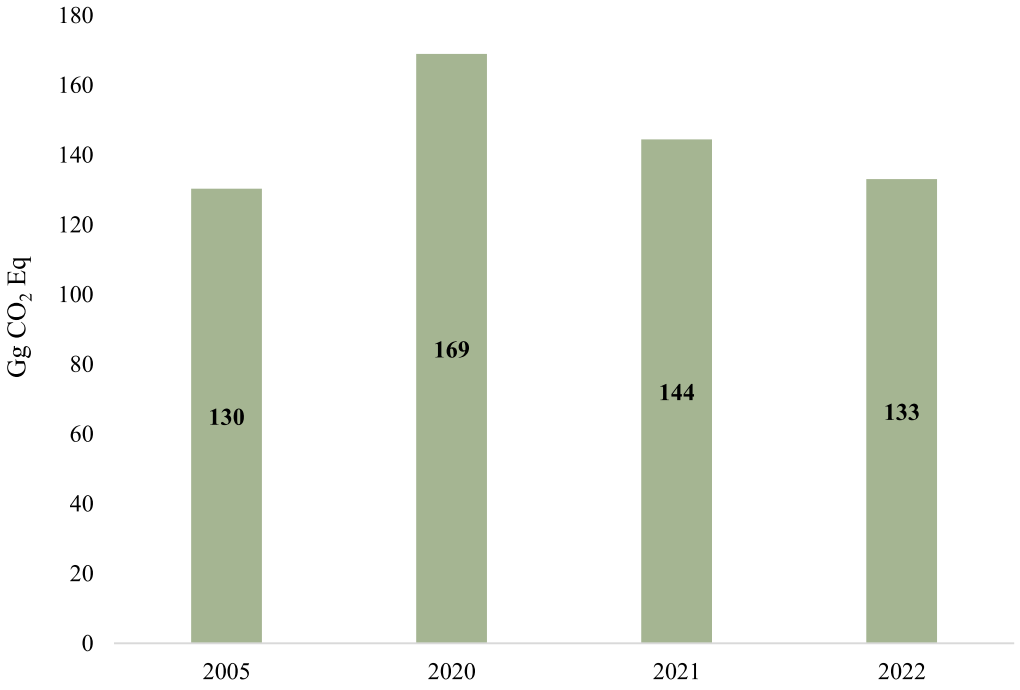


Figure 4.26 GHG emissions from Paraffin wax use (2.D.2) in 2005, 2020-2022

Methodological issues

Tier 1 methodology as per the 2006 IPCC Guidelines was used to estimate the CO_2 emissions. Emissions are calculated by multiplying the amount of paraffin wax consumed by the carbon content and oxidation during use ODU factor. Default emission factors mentioned for paraffin wax use in the 2006 IPCC guidelines were used to calculate the CO_2 emissions from paraffin wax use. The value taken for carbon content of paraffin wax is 20 tonne-C/TJ and value taken for ODU factor of paraffin wax is 0.2 respectively. The annual consumption of paraffin wax has been taken from the Indian Petroleum and Natural gas statistics by Ministry of Petroleum and Natural Gas.

Table 4.27 Activity data for Paraffin wax use in kt for 2005, 2020-2022

Source/Sink Categories	Unit	2005	2020	2021	2022
Paraffin wax use	kt	221.00	286.50	245.00	225.75

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

For uncertainty of emission factors, +/- 100% uncertainty has been taken and for uncertainty of Activity data, +/- 20% uncertainty has been taken. The combined uncertainty is +/- 102%. For activity data the same sources are used throughout the time series, from Indian Petroleum and Natural gas statistics by Ministry of Petroleum and Natural Gas. The emission factor is taken from 2006 IPCC guidelines. Therefore, CO_2 emissions from paraffin wax use have been estimated in a consistent manner throughout the time-series.

QA/QC and verification

The QA/QC process for the uncertainty analysis was carefully followed to ensure accuracy and reliability. The calculations were reviewed thoroughly, following IPCC Guidelines and best practices, and any issues or gaps were resolved. Stakeholders, including regulatory authorities, industry experts, and reviewers, were consulted

to present the results and gather their feedback. This input was used to improve and refine the uncertainty estimates. The final analysis was documented clearly and prepared on time for inclusion in the GHG inventory report, ensuring all steps were completed properly and transparently.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

4.5.3. Other (2.D.3)

Category description and background

4.5.3.1. Solvent use (2.D.3.a)

NE notation key is used as consumption of solvent is not significant.

There is no easily accessible publicly verified data for total solvent consumption by India. This will be examined further in subsequent BTRs.

4.5.3.2. Asphalt roofing (2.D.3.c)

NE notation key is used as consumption of asphalt is not significant.

Detailed production volumes (tonnes) of **asphalt roofing** made in India by domestic manufacturers is not quoted in any authentic sources. This will be examined further in subsequent BTRs.

4.6. Electronics industry (CRT 2.E)

Category description and background

The electronics industry emits both Fluorinated gases (FCs) that are gases at room temperature (FC gases) and fluorinated compounds that are liquids at room temperature (fluorinated liquids) which enter the atmosphere through evaporation. FC gases are used in two important steps of electronics manufacturing: (i) plasma etching and wafer cleaning (EWC) of silicon-containing materials and (ii) cleaning of the chamber walls of thin-film deposition (TFD) and diffusion tools after processing substrates. Electronic manufacturers also use fluorinated liquids as heat transfer fluids (HTFs) for temperature control during certain processes, as well as during testing of packaged semiconductor devices and during vapour phase reflow soldering of electronic components to circuit boards. The electronics manufacturers use N_2O as an input gas during TFD processes and for other N_2O-using manufacturing processes such as diffusion and dry removal of photoresist.

The subcategories that are considered for reporting in 2.E. Electronics Industry are as follows:

- 2.E.1 Integrated circuit or semiconductors
- 2.E.2 TFT flat panel display
- 2.E.3 Photovoltaics
- 2.E.4 Heat Transfer liquids
- 2.E.5 Others

4.6.1. Integrated circuit or semiconductor (2.E.1)

NO during the period of reporting.

Planned Improvement

India is in the process of producing semiconductors at industrial scale. It is envisaged that by BTR-3, data will be collated to report the relevant Fluorinated gas emissions from the starting year of production.

4.6.2. TFT flat panel display (2.E.2)

NO during the period of reporting.

The highly complex and capital-intensive steps of "cell" and "array" manufacturing is not done in India so far. However, design and development of display solutions for specialized use cases, such as automotive displays are done in very small quantities in India. Large scale production of TFTs (cell and array) are being set up in India, and they are slated to be operational only from 2026 onwards.

4.6.3. Photovoltaics (2.E.3)

Category description

The production of PV cells started in 1997 and continues till date. In 2005, consumption of CF_4 by PV cells in India was 0.31t. CF_4 is reported to have been used for etching and cleaning processes by major photovoltaic (PV) cell manufacturers in India till 2014.

Methodological issues

The Tier 1 methodology has been used to estimate the PFC emissions from this sector. The activity data is the total annual CF_4 consumption of gas received from all manufacturing units in India. This has been collated by the Ministry of New and Renewable Energy. IPCC default emission factor in terms of use rate of gas and the value of the fraction of gas remaining in the shipping container (heel) have been used as per Table 6.5, Chapter 6, IPCC 2006. In 2005 the CF_4 emissions were 1.29 Gg. CO_2 eq from the photovoltaics. CF_4 gas emissions is reported to be zero in 2020, 2021, and 2022.

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

Fluorinated compounds are mainly used for etching and cleaning processes where consumption is highly dependent on a number of process variables like concentration, temperature, time, etc. Different manufacturers optimize their processes differently. Some use one fluorinated compound while others use a different compound depending on their optimized process. In the complied data also, it is observed that while one manufacturer has used CF_4 in his process, others have not used this compound at all. Due to these factors, it is difficult to determine the uncertainty involved. Activity data is available for the entire time series, so no time series gaps occurring in this category.

QA/QC and verification

The annual consumption of CF_4 or non-consumption has been collated from all manufacturing units across India for the period 1997-2022 by the Ministry of New and Renewable Energy. The ministry has both production volumes of Solar photovoltaics from each company and the gas utilisation. Therefore, the data collated has gone through appropriate QA/QC procedures.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, (i) tracking the use of F gases by type for cleaning and etching of photovoltaics in India, (ii) assessment of emission per unit of production of photovoltaics, (iii) capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

4.6.4. Heat transfer fluid (2.E.4)

Category description and background

In the process of electronics manufacturing, fluorinated compounds are used for temperature control. These fluorinated compounds are released through evaporative losses during the cooling of process equipment, etc.

Not Estimated (NE) notation key is used as emissions could not be quantified due to lack of relevant data availability.

Planned improvements:

In next few years, it is planned to map F-gases used in heat transfer fluids in semi-conductor manufacturing if and when production starts in India.

4.6.5. Other (2.E.5)

4.6.5.1. Microelectromechanical systems (MEMS) (2.E.5.a)

Category description and background

Fluorinated compounds used in Microelectromechanical systems (MEMS) during their manufacturing process such as in plasma etching of silicon containing materials or in their cleaning process get emitted fugitively. Typical fluorinated gases in use may be CF_4, C_2F_6, C3F8, c-C4F8, c-C4F8O, C4F6, C5F8, CHF_3, CH_2F_2, NF_3, SF_6, and HTFs. MEMS manufacturers in India are electronic component manufactures.

By-product gases from MEMS manufacturing processes are reported as “NE” since the actual status of emissions from this source is unknown.

Emission estimates

Not Estimated (NE) notation key is used as emissions could not be quantified due to lack of relevant data availability.

Planned improvements:

It is proposed to develop the activity data base in the next 5 years in terms of data on HFC/PFC purchased amounts to use for cleaning electronic components and as solvents. The data would include the purchased amounts used for MEMS production.

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

Category description and background

Hydrofluorocarbons (HFCs) and to a limited extent Perfluorocarbons (PFCs) serve as alternatives to ozone depleting substances (ODS). The ODSs were phased out as a part of the Montreal Protocol to protect the Ozone layer. Current and expected application areas of HFCs and PFCs are:

- 2.F.1 Refrigeration and air conditioning
- 2.F.2 Foam Blowing agents
- 2.F.3 Fire Protection

- 2.F.4 Aerosols
- 2.F.5 Solvent cleaning
- 2.F.6 Others

Table 4.28 Summary of emission estimates from category 2F for 2005, 2020-2022

Year	2005	2020	2021	2022
Category	($GgCO_2$ equivalent)			
2.F. Product uses as substitutes for ODS	**1033**	**11746**	**16649**	**25397**
2.F.1. Refrigeration and air conditioning	550	10562	13395	15172
2.F.2. Foam blowing agents	149	600	638	1076
2.F.3. Fire protection	0	0	563	1634
2.F.4. Aerosols	334	583	1368	4131
2.F.5. Solvents	0	0	2	2
2.F.6. Other applications	0	0	683	3382

4.7.1. Refrigeration and air-conditioning (2.F.1)

Under refrigeration and air conditioning category, HFC emission from six subcategories including commercial refrigeration, domestic refrigeration, industrial refrigeration, transport refrigeration, mobile air-conditioning and stationary air-conditioning has been reported. Table 4.29 below indicates the subcategories and gases estimated from the same.

Table 4.29 Subcategories and Gases estimated for 2005, 2020-2022

Greenhouse Gas Source and Sink Categories	Gases Reported
2.F.1. Refrigeration and air-conditioning	
2.F.1.a. Commercial refrigeration	HFC-134a, R-404A, R-410A, R-407A
2.F.1.b. Domestic refrigeration	HFC-134a
2.F.1.c. Industrial refrigeration	R-404A, R-407C, R-410A
2.F.1.d. Transport refrigeration	R-404A
2.F.1.e. Mobile air-conditioning	HFC-134a, R-407C
2.F.1.f. Stationary air-conditioning	HFC-32, R-410A

4.7.1.1. Commercial refrigeration (2.F.1.a)

Category description

Commercial refrigeration equipment refers to a range of refrigeration systems and components that are used in commercial settings such as restaurants, supermarkets, convenience stores, and other food retail outlets to preserve and store perishable items such as food, beverages, and pharmaceuticals. This sector covers equipment's like Deep Freezers, Visi Coolers, Remote Condensing units, Water Coolers and includes cooling of Supermarkets/ Hypermarkets. For cooling and refrigeration, the commercial refrigeration units are charged with HCFC-22 and HFCs such as HFC-134a, R-404A, R-407A, and R410A. HCFC-22 (a non HFC) was extensively used as refrigerant across all equipment's before 2013. However, as India is a Party to Montreal Protocol, based on the decision of the 19th MOP (Meeting of Parties) in 2007, like all article 5 parties, India is phasing out use of HCFC-22 including its use in commercial refrigeration. The schedule for phasing out of HCFC-22 in India is as follows:

Base level:

- average of 2009 and 2010
- Freeze: 1January 2013
- 10% reduction: 1 January 2015

- 35% reduction: 1 January 2020
- 67.5% reduction: 1January 2025
- 100% reduction: 1 January 2030 with a service tail of 2.5% annual average during the period 2030-2040.

Only emission of HFCs is presented due to their use. The refrigerants are emitted from the equipment's during initial injection at the time of manufacturing, during their operational phase and at the end of life. In India, as per industry sources, the average lifetime of the commercial refrigerators is 8 years and there is no refrigerant left at the end of life (14). The following sections describe the methodology, activity data, and the emissions factors used to estimate the net emissions of HFC across the entire commercial refrigeration sector.

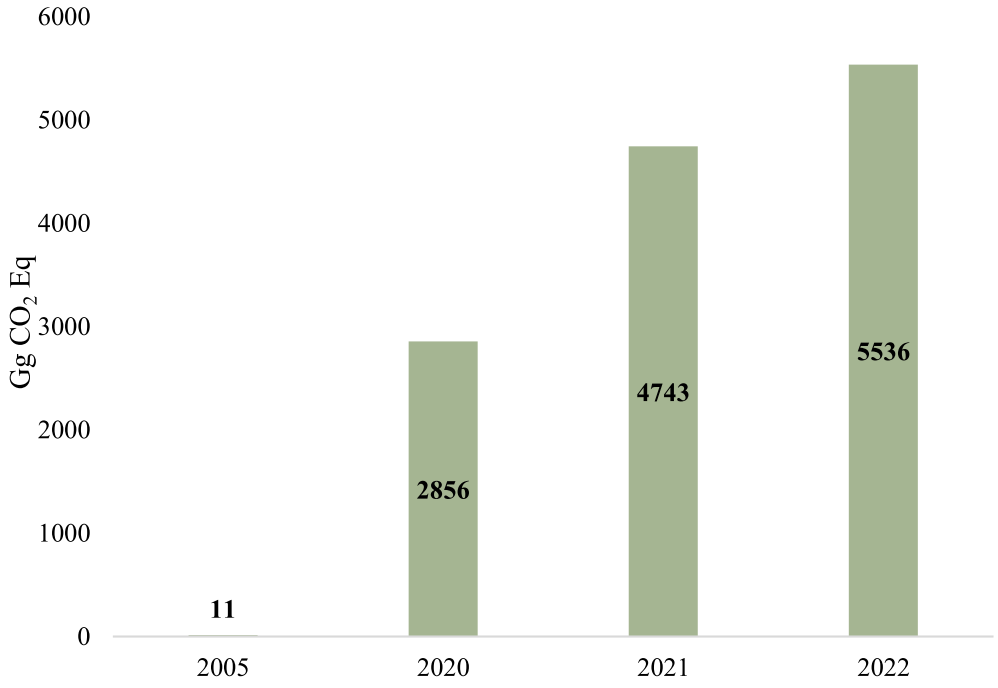


Figure 4.27 GHG emissions from Commercial refrigeration (2.F.1.a) in 2005, 2020-2022

4.7.1.1.a. Deep Freezers (2.F.1.a.i)

Category description

As per demand analysis for cooling sector in India 2027 published by Kumar et al, 2018, the refrigerant mix in deep freezers in 2017 was 65% HFC-134a, 20% R-404A, 5% R-744, and 10% R-407A/R-410A. By 2027 in a business-as-usual scenario, it is projected that the share would change to 50% HFC-134a, 10% R-404A, 10% R-744, and 30% R-407A/R-410A. A gradual change in share of refrigerants has been considered in our estimates using these projections for the years 2020, 2021 and 2022.

HCFC-22 was extensively used in deep freezers and other commercial refrigeration equipment's as refrigerants till 2013. The phaseout of HCFC-22 in deep freezers dipped to 90% in 2015, 65% in 2020 and further dip and is to be completely phased out by 2030.

The HFC emissions estimated from this category include HFC-134a, HFC-125, HFC-143a, and HFC-32 emitted from use of HFC-134a, R-404A, R-407A and R-410A in deep freezers.

Methodological issues

The Tier 1 methodology (IPCC 2006 guidelines) has been applied to estimate the HFC emissions from this sector. The formula used for the estimation is as follows:

$E_{total} = E_{charge} + E_{lifetime}$

Where

E_{total} : GHG emissionsrelated to the management of refrigerant containers

E_{charge} : GHG emissionsrelated to the refrigerant charge

$E_{lifetime}$: annual emissions from the banks of refrigerants during operation and servicing

End-of-life emissions is considered to be zero.

Emissions at the time of charging of new equipment is expressed as follows:

$$E_{charge,t} = M_t \, x \, \frac{k}{100}$$

where

$E_{charge,t}$: GHG emissionsduring system manufacture/assembly in year t, kg

Mt : amount of HFC charged into new equipment in year t, kg

K : emission factor of assembly losses of the HFC charged into new equipment, percent

The equation for estimating emissions during lifetime (operation and servicing) is expressed as follows:

$$E_{lifetime,t} = B_t \, x \, \frac{x}{100}$$

where

$E_{lifetime,t}$: amount of HFC emitted during system operation in year t, kg

Bt : amount of HFC banked in existing systems in year t, kg

x : annual emission rate (i.e., emission factor) of HFC of each sub application bank during operation accounting for average annual leakage and average annual emissions during servicing, percent.

Activity Data

The activity data in terms of units of Deep freezers sold for the year 2019–2022 is obtained from the CLASP Report, 2022. The compounded annual growth rate between 2019-2022 is used to back cast the units produced during the period 1990-2018.

The average initial refrigerant charge and types of F gases used is taken from Kumar et al, 2018. These data are further corroborated by the industry. During the period 2005-2022. the refrigerants used have transitioned from HCFC-22 to different HFCs (HFC-134a, R-404A and R-407A).

Country-specific emission factors are applied for estimating the initial and operational emissions of these gases from the commercial refrigeration sector. The country specific emissions factors have been established in consultation with the industry. The industry also has provided the lifetime range and confirmed that there is zero recovery, and no charge left at the end of life.

Table 4.30 indicates the HFC-134a emission for the years 2005, 2020, 2021 and 2022 from deep freezers. The HFC-134a emissions are sum of emissions from deep freezers exclusively containing HFC-134a as well as from deep freezers containing R-404A (contain 40% HFC-125 by mass), and R-407A (contains 4% R-134a by mass). Bulk of the emissions are from banked gas that remains in the equipment's during its lifetime. The total HFC-134a emissions have increased from 0.24 kt CO_2-e in 2005 to 44.97 ktCO_2-e in 2020, 52.11 ktCO_2-e in 2021 and 59.49 kt CO_2-e in 2022.

Table 4.30 Indices related to emissions of HFC-134a from Deep Freezers

Item	Unit	2005	2020	2021	2022
Total initial Charge of HFC-134a	T	1.10	106.49	114.10	121.25
HFC-134a Emission Factor for Initial Charge	%	2	2	2	2
Banked HFC -134a	T	3.27	649.30	756.11	866.72
HFC-134a Emission Factor for Operation	%	5	5	5	5
HFC-134a Recovery	%	0	0	0	0
HFC-134a Emission Factor for End of Life	%	0	0	0	0
HFC-134a Emissions from manufacturing	tons	0.02	2.13	2.28	2.42
HFC-134a Emissions during operation from banked gas	tons	0.16	32.46	37.81	43.34
Emissions from disposal	tons	0	0	0	0
Total HFC-134a Emissions (Manufacturing + Operation)	tons	0.19	34.59	40.09	45.76
GWP	No.	1300	1300	1300	1300
Emissions in CO_2 Eq	kt-CO_2 eq.	0.24	44.97	52.11	59.49

Table 4.31 presents the estimated emissions of HFC-125 from Deep Freezers that are charged R-404A containing 44% R-125 by mass. In 2005, the net HFC-125 emissions from deep freezers were only 0.135 kt CO_2-e. By 2020, emissions had increased substantially to 22.635 kt CO_2-e, followed by further growth to 27.075 kt CO_2-e in 2021 and 31.955 kt CO_2-e in 2022. The rise in emissions is directly related growth in demand of Deep freezers which are increasingly using R-04A and R-407A.

Table 4.31 Indices related to emissions of HFC-125 from Deep Freezers

Item	Unit	2005	2020	2021	2022
Total Initial Charge of HFC-125	t	0.23	24.91	28.07	31.36
Emission Factor for Initial Charge	%	2	2	2	2
Bank of HFC-125	t	0.76	132.84	159.59	189.06
Emission Factor for Operation	%	5	5	5	5
Amount of Recovery	%	0	0	0	0
Emission Factor for End of Life	%	0	0	0	0
Estimated emissions from manufacturing	t	0.005	0.498	0.561	0.627
Estimated emissions from banked gas during operation	t	0.04	6.64	7.98	9.45
Emissions from disposal	t	0	0	0	0
Total Emissions (Manufacturing + Operation)	t	0.04	7.14	8.54	10.08
GWP	No	3170	3170	3170	3170
Emissions in CO_2.Eq	kt-CO_2 eq.	0.14	22.63	27.07	31.95

Table 4.32 below presents HFC-32 emissions from deep freezers in 2005, 2020, 2021, and 2022. Emissions were negligible in 2005. A noticeable increase is observed by 2020, when emissions reached 1.606 kt CO_2 eq. This upward trend continued with 2.042 kt CO_2-e in 2021 and 2.561 kt CO_2-e in 2022 reflecting a consistent rise in the use of R-407A that contain 20% HFC-32 amongst other HFCs and that of R-410A that contains 50% HFC-32.

Table 4.32 Indices related to emissions of HFC-32 from Deep Freezers

Item	Unit	2005	2020	2021	2022
Initial Charge of HFC-32	t	0.10	10.14	12.41	14.91
Emission Factor for Initial Charge	%	2	2	2	2
Bank of HFC-32	t	0.36	43.38	55.36	69.69
Emission Factor for Operation	%	5	5	5	5
Recovery	%	0	0	0	0
Emission Factor for End of Life	%	0	0	0	0
Emissions from manufacturing	t	0.002	0.203	0.248	0.298
Emissions from stocks	t	0.02	2.17	2.77	3.48
Emissions from disposal	t	0	0	0	0
Total Emissions (Manufacturing + Operation)	t	0.02	2.37	3.02	3.78
GWP	No	677	677	677	677
Emissions in CO_2 Eq	kt-CO_2 eq	0.013	1.606	2.042	2.561

Table 4.33 presents HFC-143a emissions from Deep freezers that are charged with R-404A containing 4% HFC-143a. The HFC-143a emissions rose from 0.03 tons in 2005 to 4.93 tons in 2020 , 5.59 tons in 2021 and 6.24 tons in 2022. These are equivalent to 0.129 kt CO_2-e in 2005, 23.64 kt CO_2-e in 2020, 26.83 kt CO_2-e in 2021 and 29.93 kt CO_2-e in 2022.

The steady rise in HFC-143a emissions is in sync with R-404A use in deep freezers over the years.

Table 4.33 Indices related to emissions of HFC-143a from Deep Freezers

Item	Unit	2005	2020	2021	2022
Initial Charge of HFC-143a	t	0.16	14.00	14.25	14.40
Emission Factor for Initial Charge	%	2	2	2	2
Bank of HFC-143a	t	0.47	92.92	106.10	118.95
Emission Factor for Operation	%	5	5	5	5
Recovery	%	0	0	0	0
Emission Factor for End of Life	%	0	0	0	0
Emissions from manufacturing	t	0.003	0.280	0.285	0.288
Emissions from stocks	t	0.02	4.65	5.31	5.95
Emissions from disposal	t	0	0	0	0
Total Emissions (Manufacturing + Operation)	t	0.03	4.93	5.59	6.24
GWP	No	4800	4800	4800	4800
Emissions in CO_2 Eq	kt-CO_2 eq.	0.129	23.644	26.833	29.930

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty and Time-series Consistency

For estimating the uncertainty associated with emission factor, the upper limit of 30% for electrical equipment, from the 2006 IPCC Guidelines has been applied for both production and use phases.

The time series has been created using surrogate data for the years in which the deep freezer unit data is not available. Details are provided in the section on activity data.

QA/QC and Verification

Quality Assurance

The calculations and the document produced has gone through 2 levels of review, one was a peer review, and the other has been a review by the project co-lead and the lead respectively to ensure adherence to the methodology used for undertaking the estimations and related assumptions.

Quality Control

The QC was ensured through the following activities:

QC Activity	Procedures
Checking the assumptions and criteria for the selection of activity data and emission factors	• National level activity data of production of deep freezers are obtained from the various sources ensuring high data accuracy and reliability for the years. • Emission factors as applicable have been obtained from Refrigeration and Air Conditioning Association.
Checking for transcription errors in input data and reference	• Bibliographical data references are cited in the internal documentation for the sector. • For transcription errors, activity data and EF used for refrigeration and air conditioning are cross-checked.
Check that parameter and emission units are correctly recorded and that appropriate conversion factors are used	• The accuracy of parameter units and their labels on the calculation sheets is verified from the beginning to the end of the calculations. • We have ensured that the conversion factors are correctly applied during the verification process.
Check those emissions and removals are calculated correctly	• Verified that the right GWP was applied to the emission data when converting each individual's GHG emissionsto CO_2 equivalent.
Checking for consistency in data between categories	• The data used in sub applications for Refrigeration and Air conditioning are checked for their consistency in the emission calculations.
Check that uncertainties in emissions are estimated and calculated correctly	• The accuracy and completeness of the uncertainty assessments are evaluated.
Reviewing the internal documentation and archiving	• The activity data and emission factor used in the inventory creation process are maintained to enable subsequent assessment.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

4.7.1.1.b. Visi Coolers (2.F.1.a. ii)

Category description

The commercial beverage coolers also known as visi-coolers, are coolers with a transparent glass front doors used for storing bottled or canned/packaged beverages for sale in retail outlets. Visi-coolers do not have a freezer and are meant to cool all contents uniformly to the same specified temperature range. Visi-coolers are used by grocery stores, restaurants, and supermarkets that sell packaged beverages.

The India Cooling Action Plan (ICAP) states that the commercial refrigeration sector, including commercial beverage coolers, is "poised to grow 2-fold in the next decade and 6-fold in the subsequent decade. The report also states that commercial beverage coolers had a market size of 0.3 million units in 2017– 2018.

The following sections describe the methodology, activity data, and the emissions factors used to estimate the net emissions of HFC from Visi coolers.

Methodological issues

Emission quantification method

The Tier 1 methodology has been used to estimate the HFC emissions from this sector. The formula used for the estimation is as follows

$E_{total,t} = E_{charge,t} + E_{lifetime,t}$

Where

$E_{total,t}$: GHG emissionsrelated to the management of refrigerant containers

$E_{charge,t}$: GHG emissionsrelated to the refrigerant charge

$E_{lifetime,t}$: annual emissions from the banks of refrigerants during operation and servicing

Note that there being no end-of-life emissions, Eend-of-life is considered to be zero. Hence not included in the formula above.

Emissions at the time of charging of new equipment is expressed as follows:

$$E_{charge,t} = M_t \, x \, \frac{k}{100}$$

where

$E_{charge,t}$: GHG emissionsduring system manufacture/assembly in year t, kg

Mt : amount of HFC charged into new equipment in year t, kg

K : emission factor of assembly losses of the HFC charged into new equipment, percent

The equation for estimating emissions during lifetime (operation and servicing) is expressed as follows:

$$E_{lifetime,t} = B_t \, x \, \frac{x}{100}$$

where

$E_{lifetime,t}$: amount of HFC emitted during system operation in year t, kg

Bt : amount of HFC banked in existing systems in year t, kg

x : annual emission rate (i.e., emission factor) of HFC of each sub application bank during operation accounting for average annual leakage and average annual emissions during servicing, percent.

Activity Data

For the period 1999–2009, number of visi-cooler units sold is sourced from the CLASP Report, 2014. The activity data for visi-coolers for the period 2017 and 2021 is sourced from CLASP Report (2024). The number unit sold in 2022 is obtained from the Demand Analysis Report 2027 projections available through 2027. Number of units for 2010-2016 were developed using CAGR between 2009 and 2017.

Emission Factor

Country-specific emission factors are applied for estimating the initial and operational emissions of these gases from the commercial refrigeration sector. The country specific emissions factors have been established in consultation with the industry. The industry also provided the lifetime range and confirmed that there is zero recovery, and no charge left at the end of life.

In Visi coolers, use of HCFC-22 has been progressively decreasing as it will be completely phased out by 2030. The industry has alternatively shifted to HFCs such as HFC-134a, R-404A (44% HFC-125, 52% HFC-143a, 4% HFC-134a), R-407A (20% HFC-32, 40% HFC-125a, and 40% HFC-134a), and R-410A (50% HFC-32 and 50% HFC-125) depending on application and energy efficiency considerations.

As per Demand Analysis for Cooling by Sector in India in 2027 (Kumar et. al, 2018), the refrigerant mix of visi-coolers as of 2017 was 70% HFC-134a, 20% R-404A, and 10% R-407A/R-410A. By 2027, in a BAU scenario this share will become - 60% HFC-134a, 5% R-404A and 35% R407A/R410A. Using this data the number of visi-coolers in 2020, 201 and 2022 have been estimated.

Emission Estimates

Table 4.34 shows HFC-134a emissions from visi coolers. In 2005, emissions were relatively low at 0.59 emissions for the years 2005, 2020, 2021, and 2022. Emissions were very low in 2005, at just 0.046 kt CO_2-e. A sharp increase is observed by 2020, reaching 33.94 kt CO_2-e. This growth continued with 38.20 kt CO_2-e in 2021 and further to 42.36 kt CO_2-e in 2022. The data reflects a steady and substantial increase in HFC-134a emissions over time.

Table 4.34 Indices related to emissions of HFC-134a from visi cooler

Item	Unit	2005	2020	2021	2022
Initial Charge of HFC-134a	t	1.87	74.76	77.45	80.77
Emission Factor for Initial Charge	%	5	5	5	5
Bank of HFC-134a	t	7.16	447.35	510.20	570.95
Emission Factor for Operation	%	5	5	5	5
Recovery	%	0	0	0	0
Emission Factor for End of Life	%	0	0	0	0
Emissions from manufacturing	t	0.09	3.74	3.87	4.04
Emissions from stocks	t	0.36	22.37	25.51	28.55
Emissions from disposal	t	0	0	0	0
Total Emissions (Manufacturing + Operation)	t	0.45	26.11	29.38	32.59
GWP	No	1300	1300	1300	1300
Emissions in CO_2.Eq	kt-CO_2 eq.	0.587	33.937	38.197	42.361

Table 4.35 below presents HFC-125 emission from visi coolers for the years 2005, 2020, 2021, and 2022. In 2005, emissions were as low as 0.543 kt CO_2-e. By 2020, emissions increased significantly to 16.460 kt CO_2 eq, and this upward trend continued with 18.815 kt CO_2-e emissions in 2021 and 21.265 kt CO_2-e emissions in 2022.

Table 4.35 Indices related to emissions of HFC-125 from visi cooler

Item	Unit	2005	2020	2021	2022
Initial Charge of HFC-125	t	0.62	15.63	16.87	18.29
Emission Factor for Initial Charge	%	5	5	5	5
Bank of HFC-125	t	2.81	88.22	101.84	115.87
Emission Factor for Operation	%	5	5	5	5
Recovery	%	0	0	0	0
Emission Factor for End of Life	%	0	0	0	0
Emissions from manufacturing	t	0.03	0.78	0.84	0.91
Emissions from stocks	t	0.14	4.41	5.09	5.79
Emissions from disposal	t	0	0	0	0
Total Emissions (Manufacturing + Operation)	t	0.17	5.19	5.94	6.71
GWP	No	3170	3170	3170	3170
Emissions in CO_2.Eq	kt-CO_2 eq.	0.543	16.460	18.815	21.265

Table 4.36 presents HFC-32 emissions from visi coolers. In 2005, the emissions were very low at just 0.056 kt CO_2-e. By 2020, emissions had risen significantly to 1.072 kt CO_2-e, reflecting increased usage. This trend continued with 1.289 kt CO_2-e in 2021 and 1.546 kt CO_2-e in 2022. The data shows a consistent increase in emissions over the years.

Table 4.36 Indices related to emissions of HFC-32 from visi cooler

Item	Unit	2005	2020	2021	2022
Initial Charge of HFC-32	t	0.27	5.41	6.41	7.64
Emission Factor for Initial Charge	%	5	5	5	5
Bank of HFC-32	t	1.38	26.27	31.66	38.03
Emission Factor for Operation	%	5	5	5	5
Recovery	%	0	0	0	0
Emission Factor for End of Life	%	0	0	0	0
Emissions from manufacturing	t	0.01	0.27	0.32	0.38
Emissions from stocks	t	0.07	1.31	1.58	1.90
Emissions from disposal	t	0	0	0	0
Total Emissions (Manufacturing + Operation)	t	0.08	1.58	1.90	2.28
GWP	No	677	677	677	677
Emissions in CO_2.Eq	kt-CO_2 eq.	0.056	1.072	1.289	1.546

Table 4.37 below presents HFC-143a emissions from visi coolers. Emissions were relatively low in 2005, at 0.504 kt CO_2-e. A significant increase was observed by 2020, with emissions reaching 18.156 kt CO_2-e. The upward trend continued in 2021, rising to 19.986 kt CO_2-e, and further to 21.541 kt CO_2-e in 2022, indicating growing use of HFC-143a during this period.

Table 4.37 Indices related to emissions of HFC-143a from visi cooler

Item	Unit	2005	2020	2021	2022
Initial Charge of HFC-143a	t	0.42	10.26	10.20	10.00
Emission Factor for Initial Charge	%	5	5	5	5
Bank of HFC-143a	t	1.68	65.39	73.07	79.75
Emission Factor for Operation	%	5	5	5	5
Recovery	%	0	0	0	0
Emission Factor for End of Life	%	0	0	0	0
Emissions from manufacturing	t	0.02	0.51	0.51	0.50
Emissions from stocks	t	0.08	3.27	3.65	3.99
Emissions from disposal	t	0	0	0	0
Total Emissions (Manufacturing + Operation)	t	0.10	3.78	4.16	4.49
GWP	No	4800	4800	4800	4800
Emissions in CO_2.Eq	kt-CO_2 eq.	0.504	18.156	19.986	21.541

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty and Time-series Consistency

For estimating the uncertainty associated with emission factor, the upper limit of 30% for electrical equipment, from the 2006 IPCC Guidelines has been applied for both production and use phases.

The time series has been created using surrogate data for the years in which the visi coolers unit data is not available. Details are provided in the section on activity data.

QA/QC and Verification

The calculations and the document produced has gone through 2 levels of review, one was a peer review and the other has been a review by the project co-lead and the lead respectively to ensure adherence to the methodology used for undertaking the estimations and related assumptions.

The QC was ensured through the following activities:

QC Activity	Procedures
Checking the assumptions and criteria for the selection of activity data and emission factors	• National level activity data of production of deep freezers are obtained from the various sources ensuring high data accuracy and reliability for the years. • Emission factors as applicable have been obtained from Refrigeration and Air Conditioning Association.
Checking for transcription errors in input data and reference	• Bibliographical data references are cited in the internal documentation for the sector. • For transcription errors, activity data and EF used for refrigeration and air conditioning are cross-checked.
Check that parameter and emission units are correctly recorded and that appropriate conversion factors are used	• The accuracy of parameter units and their labels on the calculation sheets is verified from the beginning to the end of the calculations. • We have ensured that the conversion factors are correctly applied during the verification process.
Check those emissions and removals are calculated correctly	• Verified that the right GWP was applied to the emission data when converting each individual's GHG emissionsto CO_2 equivalent.
Checking for consistency in data between categories	• The data used in sub applications for Refrigeration and Air conditioning are checked for their consistency in the emission calculations.
Check that uncertainties in emissions are estimated and calculated correctly	• The accuracy and completeness of the uncertainty assessments are evaluated.
Reviewing the internal documentation and archiving	• The activity data and emission factor used in the inventory creation process are maintained to enable subsequent assessment.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

4.7.1.1.c. Remote Condensing Unit (2.F.1.a. iii)

Category description

As per demand analysis for Cooling by Sector in India in 2027 (Kumar et al, 2018 (17)), as of 2017 the remote condensing units refrigerant mix was 70% HFC-134a, 20% R-404A, 5% R-744, and 5% R-407A/R-410A. The report further projects that by 2027 in a business-as-usual scenario the share will change to 60% HFC-134a, 5% R-404A, 10% R744, and 25% R407A/R410A. in 2005, however, HCFC-22 was extensively used as a charging gas, which in later years has been phased down, and the sector has shifted alternatively to HFC based refrigerants.

Methodological issues

The Tier 1 methodology has been used to estimate the HFC emissions from this sector. The formula used for the estimation is as follows

$E_{total,t} = E_{charge,t} + E_{lifetime,t}$

Where

$E_{total,t}$: GHG emissionsrelated to the management of refrigerant containers

$E_{charge,t}$: GHG emissionsrelated to the refrigerant charge

$E_{lifetime,t}$: annual emissions from the banks of refrigerants during operation and servicing

Note that there being no end-of-life emissions, Eend-of-life is considered to be zero. Hence not included in the formula above.

Emissions at the time of charging of new equipment is expressed as follows:

$$E_{charge,t} = M_t \, x \, \frac{k}{100}$$

where

$E_{charge,t}$: GHG emissionsduring system manufacture/assembly in year t, kg

Mt : amount of HFC charged into new equipment in year t, kg

K : emission factor of assembly losses of the HFC charged into new equipment, percent

The equation for estimating emissions during lifetime (operation and servicing) is expressed as follows:

$$E_{lifetime,t} = B_t \, x \, \frac{x}{100}$$

where

$E_{lifetime,t}$: amount of HFC emitted during system operation in year t, kg

Bt : amount of HFC banked in existing systems in year t, kg

x : annual emission rate (i.e., emission factor) of HFC of each sub application bank during operation accounting for average annual leakage and average annual emissions during servicing, percent.

Activity Data

As per the report on Demand Analysis for Cooling by Sector in India in 2027published by Kumar et al, 2018, in 2017 there were about 0.04 million units and they are projected to grow at the rate of 10%–15% by 2027. Using this growth rate the units sold in 2020, 2021 and 2022 have been estimated. To estimate values prior to 2017, decelerating growth rates of 10%, 5%, and 3% were applied across successive ten-year intervals. The said report also provides the initial charging rate per unit and life times which have been further corroborated by the industry.

Emission Factor

Country-specific emission factors is applied for estimating the initial and operational emissions of these gases from the commercial refrigeration sector. The country specific emissions factors have been established in consultation with the industry. The industry also provided the lifetime range and confirmed that there is zero recovery, and no charge left at the end of life.

Emission Estimates

HFC-134a, HFC-143a, HFC-125 and HFC32 are estimated from remote condensing units due to use of R134A, R404A, R744, R407A/R410A. The gas R404A contains R-134a (4% by weight), R-125 (44% by weight), and R-143a (52% by weight). R-744 is refrigerant grade CO_2. R407A contains 20% R-32, 40% R-125, and 40% R-134a by weight. R410A constitutes of 50% R-32 and 50% R-125 by weight.

Table 4.38 below presents total HFC-134a emissions from remote condensing units in India for the years 2005, 2020, 2021, and 2022. Emissions were relatively low in 2005, at 0.984 kt CO_2-e. By 2020, a significant increase brought emissions to 45.617 kt CO_2-e. This upward trend continued, reaching 53.470 kt CO_2-e in 2021, and further increased to 62.131 kt CO_2-e in 2022, reflecting a substantial rise in the use of HFC-134a over the years.

Table 4.38 Indices related to emissions of HFC-134a from remote condensing unit

Item	Unit	2005	2020	2021	2022
Initial Charge of HFC-134a	t	2.95	113.58	126.91	143.16
Emission Factor for Initial Charge	%	5	5	5	5
Bank of HFC-134a	t	12.18	588.22	695.71	812.70
Emission Factor for Operation	%	5	5	5	5
Recovery	%	0	0	0	0
Emission Factor for End of Life	%	0	0	0	0
Emissions from manufacturing	t	0.15	5.68	6.35	7.16
Emissions from stocks	t	0.61	29.41	34.79	40.63
Emissions from disposal	t	0	0	0	0
Total Emissions (Manufacturing + Operation)	t	0.76	35.09	41.13	47.79
GWP	no.	1300	1300	1300	1300
Emissions in CO_2-e	Kt CO_2- e.	0.984	45.617	53.470	62.131

Table 4.39 below presents the total HFC-125 emissions from remote condensing units for the years 2005, 2020, 2021 and 2022. In 2005, emissions were recorded at a relatively low level of 0.837 kt CO_2-e. A significant increase occurred by 2020, reaching 18.698 kt CO_2-e. The trend continued upward in 2021 to 22.171 kt CO_2-e, and further to 26.167 kt CO_2-e in 2022. This pattern indicates a steady growth in HFC-125 emissions over the observed period.

Table 4.39 Indices related to emissions of HFC-125 from remote condensing unit

Item	Unit	2005	2020	2021	2022
Total HFC-125 charged in the year of production	t	0.29	6.54	7.56	8.80
Average initial refrigerant charge	kg	3	3	3	3
Initial Charge of HFC-125	t	0.87	19.63	22.69	26.39
Emission Factor for Initial Charge	%	5	5	5	5
Bank of HFC-125	t	4.41	98.34	117.19	138.69
Emission Factor for Operation	%	5	5	5	5
Recovery	%	0	0	0	0
Emission Factor for End of Life	%	0	0	0	0
Emissions from manufacturing	t	0.04	0.98	1.13	1.32
Emissions from stocks	t	0.22	4.92	5.86	6.93
Emissions from disposal	t	0	0	0	0
Total Emissions (Manufacturing + Operation)	t	0.26	5.90	6.99	8.25
GWP	No	3170	3170	3170	3170
Emissions in CO_2.Eq	kt-CO_2 eq.	0.837	18.698	22.171	26.167

Table 4.40 below presents total HFC-32 emissions from remote condensing units for the years 2005, 2020, 201 and 2022. In 2005, emissions were relatively low at 0.078 kt CO_2-e., increasing steadily over the years. By 2020, emissions had reached 0.810 kt CO_2-e., followed by 1.042 kt CO_2-e. in 2021, and further rising to 1.358 kt CO_2-e. in 2022.

Table 4.40 Indices related to emissions of HFC-32 from remote condensing unit

Item	Unit	2005	2020	2021	2022
Total HFC-32 charged in the year of production	t	0.10	1.55	2.06	2.76
Average initial refrigerant charge	kg	3	3	3	3
Initial Charge of HFC-32	t	0.31	4.65	6.18	8.27
Emission Factor for Initial Charge	%	5	5	5	5

Item	Unit	2005	2020	2021	2022
Bank of HFC-32	t	2.00	19.28	24.60	31.86
Emission Factor for Operation	%	5	5	5	5
Recovery	%	0	0	0	0
Emission Factor for End of Life	%	0	0	0	0
Emissions from manufacturing	t	0.02	0.23	0.31	0.41
Emissions from stocks	t	0.10	0.96	1.23	1.59
Emissions from disposal	t	0	0	0	0
Total Emissions (Manufacturing + Operation)	t	0.12	1.20	1.54	2.01
GWP	No	677	677	677	677
Emissions in CO_2.Eq	kt-CO_2 eq.	0.078	0.810	1.042	1.358

Table 4.41 presents the total HFC-143a emissions from remote condensing units for the years 2005, 2020, 2021, and 2022. Emissions were relatively low in 2005 at 0.843 kt CO_2-e., but by 2020, they had significantly increased to 24.853 kt CO_2-e. This upward trend continued with emissions reaching 28.541 kt CO_2-e. in 2021 and 32.252 kt CO_2-e. in 2022.

Table 4.41 Indices related to emissions of HFC-143a from remote condensing unit

Item	Unit	2005	2020	2021	2022
Total HFC-143a charged in the year of production	t	0.22	5.38	5.81	6.21
Average initial refrigerant charge	kg	3	3	3	3
Initial Charge of HFC-143a	t	0.66	16.13	17.43	18.62
Emission Factor for Initial Charge	%	5	5	5	5
Bank of HFC-143a	t	2.85	87.42	101.50	115.76
Emission Factor for Operation	%	5	5	5	5
Recovery	%	0	0	0	0
Emission Factor for End of Life	%	0	0	0	0
Emissions from manufacturing	t	0.03	0.81	0.87	0.93
Emissions from stocks	t	0.14	4.37	5.07	5.79
Emissions from disposal	t	0	0	0	0
Total Emissions (Manufacturing + Operation)	t	0.18	5.18	5.95	6.72
GWP	No	4800	4800	4800	4800
Emissions in CO_2.Eq	kt-CO_2 eq.	0.843	24.853	28.541	32.252

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty and Time-series Consistency

For estimating activity data uncertainty for production and use phase, a 10% value from the Tier 2 method for the metal industry, as outlined in the 2006 IPCC Guidelines has been applied. For estimating the uncertainty associated with emission factor, the upper limit of 30% for electrical equipment, from the 2006 IPCC Guidelines has been applied for both production and use phases.

The time series has been created using surrogate data for the years in which the remote condensing unit data is not available. Details are provided in the section on activity data.

QA/QC and Verification

The calculations and the document produced has gone through two levels of review, one was a peer review and the other has been a review by the project co-lead and the lead respectively to ensure adherence to the methodology used for undertaking the estimations and related assumptions.

The QC was ensured through the following activities:

QC Activity	Procedures
Checking the assumptions and criteria for the selection of activity data and emission factors	• National level activity data of production of remote condensing unit are obtained from the various sources ensuring high data accuracy and reliability for the years. • Emission factors as applicable have been obtained from Refrigeration and Air Conditioning Association.
Checking for transcription errors in input data and reference	• Bibliographical data references are cited in the internal documentation for the sector. • For transcription errors, activity data and EF used for refrigeration and air conditioning are cross-checked.
Check that parameter and emission units are correctly recorded and that appropriate conversion factors are used	• The accuracy of parameter units and their labels on the calculation sheets is verified from the beginning to the end of the calculations. • We have ensured that the conversion factors are correctly applied during the verification process.
Check those emissions and removals are calculated correctly	• Verified that the right GWP was applied to the emission data when converting each individual's GHG emissionsto CO_2 equivalent.
Checking for consistency in data between categories	• The data used in sub applications for Refrigeration and Air conditioning are checked for their consistency in the emission calculations.
Check that uncertainties in emissions are estimated and calculated correctly	• The accuracy and completeness of the uncertainty assessments are evaluated.
Reviewing the internal documentation and archiving	• The activity data and emission factor used in the inventory creation process are maintained to enable subsequent assessment.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

4.7.1.1.d. Water Coolers (2.F.1.a. iv)

Category description

As per demand analysis for Cooling by Sector in India in 2027 (Kumar et al, 2018 (17)), in 2017, refrigerant mix in water coolers was 70% HFC-134a, 20% R-404A, 5% R-744, and 5% with R-407A and R-410A. By 2027 it is projected that the share will change to 60% HFC-134a, 5% R-404A, 10% R-744, and 25% R407A and R410A. In earlier years HCFC-22 was used as a refrigerant in water coolers. However, HCFC-22 has been progressively phased down, and alternatively HFCs and natural refrigerants depending on application and energy efficiency considerations are being used.

The following sections describe the methodology, activity data, and the emissions factors used to estimate the net emissions of HFC across the entire commercial refrigeration sector.

Methodological issues

Tier 1 methodology has been used to estimate the HFC emissions from this sector. The formula used for the estimation is as follows

$$E_{total,t} = E_{charge,t} + E_{lifetime,t}$$

Where

$E_{total,t}$: GHG emissionsrelated to the management of refrigerant containers

$E_{charge,t}$: GHG emissionsrelated to the refrigerant charge

$E_{lifetime,t}$: annual emissions from the banks of refrigerants during operation and servicing

Note that there being no end-of-life emissions, Eend-of-life is considered to be zero. Hence not included in the formula above.

Emissions at the time of charging of new equipment is expressed as follows:

$$E_{charge,t} = M_t \, x \, \frac{k}{100}$$

where

$E_{charge,t}$: GHG emissionsduring system manufacture/assembly in year t, kg

Mt : amount of HFC charged into new equipment in year t, kg

K : emission factor of assembly losses of the HFC charged into new equipment, percent

The equation for estimating emissions during lifetime (operation and servicing) is expressed as follows:

$$E_{lifetime,t} = B_t \, x \, \frac{x}{100}$$

where

$E_{lifetime,t}$: amount of HFC emitted during system operation in year t, kg

Bt : amount of HFC banked in existing systems in year t, kg

x : annual emission rate (i.e., emission factor) of HFC of each sub application bank during operation accounting for average annual leakage and average annual emissions during servicing, percent.

Activity Data

The activity data in the form of units of water cooler's in stocks is sourced from various reports. For the period 1999–2009, it is sourced from the CLASP Report (2014). For 2017 the data is obtained from Demand Analysis for Cooling by Sector in India in 2027 report. The number of units for the period 2018–2022 were derived based on the projections available for the period 2017-2027 in the same report. For the gap period 2010-2016 the number of units were estimated by interpolating the data by applying CAGR between 2009 and 2017.

Demand Analysis for cooling by sector in India 2027 published by Kumar et al, 2018 provides information on average initial refrigerant charge and types of F gases used. These data are further corroborated by the industry.

Emission Factor

Country-specific emission factors are applied for estimating the initial and operational emissions of these gases from the commercial refrigeration sector. The country specific emissions factors have been established in consultation with the industry. The industry also provided the lifetime range and confirmed that there is zero recovery, and no charge left at the end of life.

Emission Estimates

Table 4.42 presents total HFC-134a emissions data for the years 2005, 2020, 2021, and 2022. Emissions were minimal in 2005, recorded at just 0.547 kt CO_2-e., but increased substantially over the following years. By 2020, emissions had reached 40.752 kt CO_2-e., followed by a rise to 46.548 kt CO_2-e. in 2021 and 52.207 kt CO_2-e. in 2022. The data reflects a sharp upward trend, indicative of expanding usage of HFC-134a over time.

Table 4.42 Indices related to emissions of HFC-134a from water coolers

Item	Unit	2005	2020	2021	2022
Initial Charge of HFC-134a	t	1.73	96.15	99.83	103.72
Emission Factor for Initial Charge	%	5	5	5	5
Bank of HFC-134a	t	6.69	530.81	616.29	699.48
Emission Factor for Operation	%	5	5	5	5
Recovery	%	0	0	0	0
Emission Factor for End of Life	%	0	0	0	0
Emissions from manufacturing	t	0.09	4.81	4.99	5.19
Emissions from stocks	t	0.33	26.54	30.81	34.97
Emissions from disposal	t	0	0	0	0
Total Emissions (Manufacturing + Operation)	t	0.42	31.35	35.81	40.16
GWP	No	1300	1300	1300	1300
Emissions in CO_2.Eq	kt-CO_2 eq.	0.547	40.752	46.548	52.207

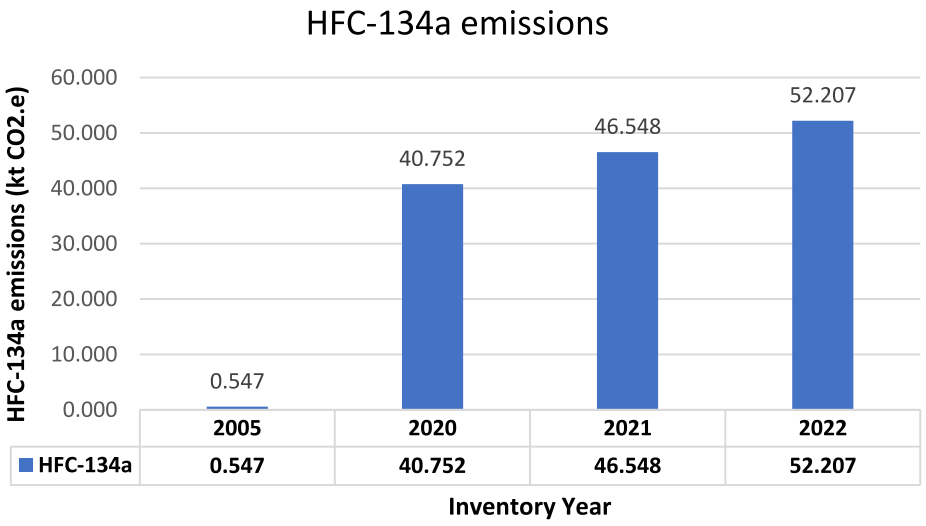


Figure 4.28 HFC-143a emissions estimates from water coolers

Table 4.43 provides the HFC-125 emissions data for the years 2005, 2020, 2021, and 2022. Emissions were relatively low in 2005 at 0.460 kt CO_2-e., but rose significantly to 16.639 kt CO_2-e. by 2020. This growth trend continued, with emissions reaching 19.213 kt CO_2-e. in 2021 and 21.838 kt CO_2-e. in 2022, reflecting the increasing reliance on HFC-125 in relevant sectors.

Table 4.43 Indices related to emissions of HFC-125 from water coolers

Item	Unit	2005	2020	2021	2022
Total HFC-125 charged in the year of production	t	0.85	27.70	29.74	31.87
Average initial refrigerant charge	kg	0.6	0.6	0.6	0.6
Initial Charge of HFC-125	t	0.51	16.62	17.85	19.12
Emission Factor for Initial Charge	%	5	5	5	5
Bank of HFC-125	t	2.40	88.36	103.38	118.66
Emission Factor for Operation	%	5	5	5	5
Recovery	%	0	0	0	0
Emission Factor for End of Life	%	0	0	0	0
Emissions from manufacturing	t	0.03	0.83	0.89	0.96
Emissions from stocks	t	0.12	4.42	5.17	5.93

Item	Unit	2005	2020	2021	2022
Emissions from disposal	t	0	0	0	0
Total Emissions (Manufacturing + Operation)	t	0.15	5.25	6.06	6.89
GWP	No	3170	3170	3170	3170
Emissions in CO_2.Eq	kt-CO_2 eq.	0.460	16.639	19.213	21.838

Table 4.44 presents the total HFC-32 emissions due to use of various refrigerants in water coolers for the years 2005, 2020, 2021, and 2022. In 2005, emissions were minimal at 0.042 kt CO_2-e. However, by 2020, emissions had sharply increased to 0.715 kt CO_2-e., indicating rising usage. The growth continued in the following years, reaching 0.889 kt CO_2-e. in 2021 and 1.104 kt CO_2-e. in 2022.

Table 4.44 Indices related to emissions of HFC-32 from water coolers

Item	Unit	2005	2020	2021	2022
Total HFC-32 charged in the year of production	t	0.30	6.57	8.10	9.99
Average initial refrigerant charge	kg	0.6	0.6	0.6	0.6
Initial Charge of HFC-32	t	0.18	3.94	4.86	5.99
Emission Factor for Initial Charge	%	5	5	5	5
Bank of HFC-32	t	1.07	17.19	21.41	26.61
Emission Factor for Operation	%	5	5	5	5
Recovery	%	0	0	0	0
Emission Factor for End of Life	%	0	0	0	0
Emissions from manufacturing	t	0.01	0.20	0.24	0.30
Emissions from stocks	t	0.05	0.86	1.07	1.33
Emissions from disposal	t	0	0	0	0
Total Emissions (Manufacturing + Operation)	t	0.06	1.06	1.31	1.63
GWP	No	677	677	677	677
Emissions in CO_2.Eq	kt-CO_2 eq.	0.042	0.715	0.889	1.104

Table 4.45 below presents total HFC-143a emissions from water coolers for the years 2005, 2020, 2021, and 2022. Emissions were very low in 2005, at just 0.469 kt CO_2-e. By 2020, they had surged to 22.170 kt CO_2-e., indicating a significant rise in usage of HFC-143a. This upward trend continued in 2021 with emissions increasing to 24.878 kt CO_2-e., and further to 27.244 kt CO_2-e. in 2022, reflecting ongoing usage of HFC-143a in this sector.

Table 4.45 Indices related to emissions of HFC-143a from water coolers

Item	Unit	2005	2020	2021	2022
Item	Unit	2005	2020	2021	2022
Initial Charge of HFC-143a	t	0.39	13.66	13.71	13.49
Emission Factor for Initial Charge	%	5	5	5	5
Bank of HFC-143a	t	1.57	78.72	89.95	100.03
Emission Factor for Operation	%	5	5	5	5
Recovery	%	0	0	0	0
Emission Factor for End of Life	%	0	0	0	0
Emissions from manufacturing	t	0.02	0.68	0.69	0.67
Emissions from stocks	t	0.08	3.94	4.50	5.00
Emissions from disposal	t	0	0	0	0
Total Emissions (Manufacturing + Operation)	t	0.10	4.62	5.18	5.68
GWP	No	4800	4800	4800	4800
Emissions in CO_2.Eq	kt-CO_2 eq.	0.469	22.170	24.878	27.244

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty and Time-series Consistency

For estimating the uncertainty associated with emission factor, the upper limit of 30% for electrical equipment, from the 2006 IPCC Guidelines has been applied for both production and use phases.

The time series has been created using surrogate data for the years in which the water coolers data is not available. Details are provided in the section on activity data.

QA/QC and Verification

The calculations and the document produced has gone through two levels of review, one was a peer review and the other has been a review by the project co-lead and the lead respectively to ensure adherence to the methodology used for undertaking the estimations and related assumptions.

The QC was ensured through the following activities:

QC Activity	Procedures
Checking the assumptions and criteria for the selection of activity data and emission factors	• National level activity data of production of remote condensing unit are obtained from the various sources ensuring high data accuracy and reliability for the years. • Emission factors as applicable have been obtained from Refrigeration and Air Conditioning Association.
Checking for transcription errors in input data and reference	• Bibliographical data references are cited in the internal documentation for the sector. • For transcription errors, activity data and EF used for refrigeration and air conditioning are cross-checked.
Check that parameter and emission units are correctly recorded and that appropriate conversion factors are used	• The accuracy of parameter units and their labels on the calculation sheets is verified from the beginning to the end of the calculations. • We have ensured that the conversion factors are correctly applied during the verification process.
Check those emissions and removals are calculated correctly	• Verified that the right GWP was applied to the emission data when converting each individual's GHG emissionsto CO_2 equivalent.
Checking for consistency in data between categories	• The data used in sub applications for Refrigeration and Air conditioning are checked for their consistency in the emission calculations.
Check that uncertainties in emissions are estimated and calculated correctly	• The accuracy and completeness of the uncertainty assessments are evaluated.
Reviewing the internal documentation and archiving	• The activity data and emission factor used in the inventory creation process are maintained to enable subsequent assessment.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category. Not applicable.

4.7.1.1.f. Supermarket/Hypermarket (2.F.1.a.v)

Category description

In Supermarket/Hypermarket HCFC-22 has been progressively phased down, and the sector has shifted towards alternatives such as HFC-134a, R-404A, R-410A, R-407A and natural refrigerants like R-744 depending on application and energy efficiency considerations. As of 2017, as per Kumar et al, 2017, the refrigerant mix in supermarket and hyper markets were 70% R404A, 30% R407A/R410A. By 2027 the share is projected to shift to 50% R404A, 10% R744, 40% R407A/R410A.

The following sections describe the methodology, activity data, and the emissions factors used to estimate the net emissions of HFC across the entire commercial refrigeration sector.

Methodological issues

The Tier 2a methodology has been used to estimate the HFC emissions from this sector. The formula used for the estimation is as follows

$E_{total,t} = E_{charge,t} + E_{lifetime,t}$

Where

$E_{total,t}$: GHG emissionsrelated to the management of refrigerant containers

$E_{charge,t}$: GHG emissionsrelated to the refrigerant charge

$E_{lifetime,t}$: annual emissions from the banks of refrigerants during operation and servicing

Note that there being no end-of-life emissions, Eend-of-life is considered to be zero. Hence not included in the formula above.

Emissions at the time of charging of new equipment is expressed as follows:

$$E_{charge,t} = M_t \, x \, \frac{k}{100}$$

where

$E_{charge,t}$: GHG emissionsduring system manufacture/assembly in year t, kg

Mt : amount of HFC charged into new equipment in year t, kg

K : emission factor of assembly losses of the HFC charged into new equipment, percent

The equation for estimating emissions during lifetime (operation and servicing) is expressed as follows:

$$E_{lifetime,t} = B_t \, x \, \frac{x}{100}$$

where

$E_{lifetime,t}$: amount of HFC emitted during system operation in year t, kg

Bt : amount of HFC banked in existing systems in year t, kg

x : annual emission rate (i.e., emission factor) of HFC of each sub application bank during operation accounting for average annual leakage and average annual emissions during servicing, percent.

Activity Data

The supermarket/hypermarket units in India was obtained from multiple sources. Data for the years 2006 and 2016 was sourced from Statista.The number of supermarkets for 2022 was compiled by taking into account the number of supermarkets/hypermarkets that have been opened across the country under different brand names, the list of which is available at their respective annual statements/web sites. In 1990, it is noted that there was

only one supermarket in India, namely Super Bazaar located in Connaught Place, New Delhi.

Demand Analysis for cooling by sector in India 2027 published by Kumar et al, 2018 provides information on average initial refrigerant charge and types of F gases used. These data are further corroborated by the industry.

Emission Factor

Country-specific emission factors of HFC134a, HFC125, HFC32 and HFC143a are applied for estimating the initial and operational emissions of these gases from the commercial refrigeration sector. The country specific emissions factors have been established in consultation with the industry. The industry also provided the lifetime range and confirmed that there is zero recovery, and no charge left at the end of life.

Emission Estimates

Table 4.46 presents total HFC-134a emissions for the years 2005, 2020, 2021, and 2022. Emissions were very low in 2005, at just 0.046 kt CO_2-e. By 2020, they had surged to 121.222 kt CO_2-e., indicating a substantial rise in usage. This upward trend continued in 2021 with emissions increasing to 150.347 emissions for the years 2005, 2020, 2021, and 2022. Emissions were very low in 2005, at just 0.046 kt CO_2-e, and further to 183.044 emissions for the years 2005, 2020, 2021, and 2022. Emissions were very low in 2005, at just 0.046 kt CO_2-e. in 2022.

Table 4.46 Indices related to emissions of HFC-134a from supermarket/hypermarket

Item	Unit	2005	2020	2021	2022
Initial Charge of HFC-134a	t	0.23	359.77	409.96	467.52
Emission Factor for Initial Charge	%	5	5	5	5
Bank of HFC-134a	t	0.48	1505.19	1903.07	2348.55
Emission Factor for Operation	%	5	5	5	5
Recovery	%	0	0	0	0
Emission Factor for End of Life	%	0	0	0	0
Emissions from manufacturing	t	0.01	17.99	20.50	23.38
Emissions from stocks	t	0.02	75.26	95.15	117.43
Emissions from disposal	T	0	0	0	0
Total Emissions (Manufacturing + Operation)	t	0.04	93.25	115.65	140.80
GWP	no.	1300	1300	1300	1300
Emissions in CO_2.Eq	kt-CO_2 eq.	0.046	121.222	150.347	183.044

Table 4.47 below presents HFC-125 emissions for the years 2005, 2020, 2021, and 2022. From 2.089 kt CO_2-e HFC emissions in 2005, the HFC emissions have surged to 1550.93 kt CO_2-e in 2020, 1857.685 kt CO_2-e in 2021 and 2189 ktCO_2-e in 2022 indicating the robust growth of this sector along the years.

Table 4.47 Indices related to emissions of HFC-125 from supermarket/hypermarket

Item	Unit	2005	2020	2021	2022
Initial Charge of HFC-125	T	4.07	1687.77	1878.85	2093.43
Emission Factor for Initial Charge	%	5	5	5	5
Bank of HFC-125	T	9.11	8095.15	9841.57	11717.85
Emission Factor for Operation	%	5	5	5	5
Recovery	%	0	0	0	0
Emission Factor for End of Life	%	0	0	0	0
Emissions from manufacturing	T	0.20	84.39	93.94	104.67
Emissions from stocks	T	0.46	404.76	492.08	585.89
Emissions from disposal	T	0	0	0	0
Total Emissions (Manufacturing + Operation)	T	0.66	489.15	586.02	690.56
GWP	No	3170	3170	3170	3170
Emissions in CO_2.Eq	kt-CO_2 eq.	2.089	1550.593	1857.686	2189.088

Table 4.48 below presents HFC-32 emissions from super markets for the years 2005, 2020, 2021, and 2022. Emissions were negligible in 2005, at just 0.180 kt CO_2-e emissions in 2005. By 2020, HFC-125 emissions increased to 82.052 kt CO_2-e. In 2021, HFC-125 emissions grew to 101.195 kt CO_2-e in and to 122.953 kt CO_2-e by 2022.

Table 4.48 Indices related to emissions of HFC-32 from supermarket/hypermarket

Item	Unit	2005	2020	2021	2022
Initial Charge of HFC-32	t	1.56	453.93	526.15	609.86
Emission Factor for Initial Charge	%	5	5	5	5
Bank of HFC-32	t	3.77	1970.05	2463.38	3022.44
Emission Factor for Operation	%	5	5	5	5
Recovery	%	0	0	0	0
Emission Factor for End of Life	%	0	0	0	0
Emissions from manufacturing	t	0.08	22.70	26.31	30.49
Emissions from stocks	t	0.19	98.50	123.17	151.12
Emissions from disposal	t	0	0	0	0
Total Emissions (Manufacturing + Operation)	t	0.27	121.20	149.48	181.61
GWP	No	677	677	677	677
Emissions in CO_2.Eq	kt-CO_2 eq.	0.180	82.052	101.195	122.953

Table 4.49 below presents HFC-143a emissions from super markets/Hyper markets for the years 2005, 2020, 2021, and 2022. HFC-143a emissions from this segment has increased from 2.227 kt CO_2-e in 2005 to 1909.577 kt CO_2-e in 2020, 2250 kt CO_2-e in 2021 and 2606.26 kt CO_2-e in 2022.

Table 4.49 Indices related to emissions of HFC-143a from supermarket/hypermarket

Item	Unit	2005	2020	2021	2022
Initial Charge of HFC-143a	t	2.98	1304.90	1420.98	1547.39
Emission Factor for Initial Charge	%	5	5	5	5
Bank of HFC-143a	t	6.30	6651.67	7956.81	9311.88
Emission Factor for Operation	%	5	5	5	5
Recovery	%	0	0	0	0
Emission Factor for End of Life	%	0	0	0	0
Emissions from manufacturing	t	0.15	65.25	71.05	77.37
Emissions from stocks	t	0.32	332.58	397.84	465.59
Emissions from disposal	t	0	0	0	0
Total Emissions (Manufacturing + Operation)	t	0.46	397.83	468.89	542.96
GWP	No	4800	4800	4800	4800
Emissions in CO_2.Eq	kt-CO_2 eq.	2.227	1909.577	2250.671	2606.226

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty and Time-series Consistency

Uncertainty

For estimating the uncertainty associated with emission factor, the upper limit of 30% for electrical equipment, from the 2006 IPCC Guidelines has been applied for both production and use phases.

Time-series Consistency

The time series has been created using surrogate data for the years in which the no of supermarket/hypermarket unit data is not available. Details are provided in the section on activity data.

QA/QC and Verification

The calculations and the document produced has gone through 2 levels of review, one was a peer review and the other has been a review by the project co-lead and the lead respectively to ensure adherence to the methodology used for undertaking the estimations and related assumptions.

The QC was ensured through the following activities:

QC Activity	Procedures
Checking the assumptions and criteria for the selection of activity data and emission factors	• National level activity data of production of remote condensing unit are obtained from the various sources ensuring high data accuracy and reliability for the years. • Emission factors as applicable have been obtained from Refrigeration and Air Conditioning Association.
Checking for transcription errors in input data and reference	• Bibliographical data references are cited in the internal documentation for the sector. • For transcription errors, activity data and EF used for refrigeration and air conditioning are cross-checked.
Check that parameter and emission units are correctly recorded and that appropriate conversion factors are used	• The accuracy of parameter units and their labels on the calculation sheets is verified from the beginning to the end of the calculations. • We have ensured that the conversion factors are correctly applied during the verification process.
Check those emissions and removals are calculated correctly	• Verified that the right GWP was applied to the emission data when converting each individual's GHG emissionsto CO_2 equivalent.
Checking for consistency in data between categories	• The data used in sub applications for Refrigeration and air conditioning are checked for their consistency in the emission calculations.
Check that uncertainties in emissions are estimated and calculated correctly	• The accuracy and completeness of the uncertainty assessments are evaluated.
Reviewing the internal documentation and archiving	• The activity data and emission factor used in the inventory creation process are maintained to enable subsequent assessment.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

4.7.1.1. Domestic refrigeration (2.F.1.b)

Category description

CFC-12 was used from the beginning as refrigerant till 2010 in domestic refrigerators in India. As India is a signatory to the Montreal Protocol (Article 5 country), its CFC-12 phase out policy began in 2005. In 2005, fifty percent of CFC-12 usage was phased out, by 2007 the phaseout was 85% and by 2010, 100% phaseout of CFC-12 was achieved. Consequently, India has stopped using CFC-12 in 2010 in refrigerators. Since then, the refrigerator industry in India has started using HFC-134a, and from 2022 complete transition to HC-600a has taken place in this sector.

HFC used as refrigerants is emitted from the equipment's during initial injection, during its operational phase and at the end of life. In India, the average lifetime of the refrigerators as per the industry is 12 years and there is no refrigerant left at the end of life. The following sections describe the methodology, activity data, and the emissions factors used to estimate the net emissions of HFC-134a across the entire refrigeration sector.

Methodological issues

The Tier 1 methodology has been used to estimate the HFC emissions from this sector. The formula used for the estimation is as follows

$E_{total,t} = E_{charge,t} + E_{lifetime,t}$

Where

$E_{total,t}$: GHG emissionsrelated to the management of refrigerant containers

$E_{charge,t}$: GHG emissionsrelated to the refrigerant charge

$E_{lifetime,t}$: annual emissions from the banks of refrigerants during operation and servicing

Note that there being no end-of-life emissions, End-of-life is considered to be zero. Hence not included in the formula above.

Refrigerant charge emissions of new equipment

$$E_{charge,t} = M_t \, x \, \frac{k}{100}$$

$E_{charge,t}$: GHG emissionsduring system manufacture/assembly in year t, kg

Mt : amount of HFC charged into new equipment in year t, kg

K : emission factor of assembly losses of the HFC charged into new equipment, percent

Emissions during lifetime (operation and servicing)

$$E_{lifetime,t} = B_t \, x \, \frac{x}{100}$$

$E_{(lifetime,t)} = B_t*x/100$

$E_{lifetime,t}$: amount of HFC emitted during system operation in year t, kg

Bt : amount of HFC banked in existing systems in year t, kg

x : annual emission rate (i.e., emission factor) of HFC of each sub application bank during operation accounting for average annual leakage and average annual emissions during servicing, percent.

The activity data is the number of domestic refrigerators produced and sold in the county. The data was obtained from the Bureau of Energy Efficiency (BEE), Government of India. It collected the data under its SLP (Star Labelling Programme). The data available is in terms of number of Frost Free and Direct Cool refrigerators for the financial years 2018-19 to 2023-24. The data was subsequently converted into the calendar year format. Due to the limited availability of data, for earlier years, percentage of households with refrigerators in both rural and urban areas was used as a surrogate data available from India's household consumption survey reports. This surrogate data was interpolated and the resulting CAGR was used to get the entire series of refrigerator production to estimate the banked HFC for the required period. Further, the average refrigerant charge that goes into the refrigerators was obtained from the industry and the gases that are being used for charging were also confirmed.

Country-specific emission factors are applied for estimating the initial and operational emissions of HFC-134a from the domestic refrigeration sector. The country specific emissions factors have been established in consultation with the industry. The industry also provided the lifetime range and confirmed that there is zero recovery, and no charge left at the end of life. Due to voluntary phaseout policy of the refrigerator industry in India, HFC-134a use in new refrigerators in 2022 has become zero and is replaced by HC-600a as per our survey. The GWP of HFC-134a is 1300 and that of HC-600a is only 3. It must be noted that, the banked HFC-134a gas continues to lead to HFC-134a emissions from this category even in 2022.

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

For estimating the uncertainty associated with emission factor, the upper limit of 30% for electrical equipment, from the 2006 IPCC Guidelines has been applied for both production and use phases. The time series has been created using surrogate data for the years in which the refrigeration production data is not available. The surrogate data used is based on sample survey carried out by the ministry of statistics and programme implementation. Details are provided in the section on activity data.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

4.7.1.2. Industrial refrigeration (2.F.1.c)

The Industrial refrigeration sector comprises of refrigeration systems employed in manufacturing and process industries. Industrial refrigeration is mostly utilized in: (a) processing and storage of food and beverages, and (b) production of petrochemicals, chemicals, and pharmaceuticals to manage heat, protect equipment and chemicals, and maintain optimal operating conditions. The industrial refrigeration industry can be categorises as follws based on their wide diversity of cooling requirements in terms of temperature level, cooling demand, and processing methods

- Cold storage
- Packhouses
- Ripening chambers and
- Chillers

Many industrial systems are enormous, requiring several megawatts of cooling power and requiring several tonnes of refrigerant. However, many firms use a variety of small and medium-sized refrigeration systems, therefore not all industrial systems are large.

HCFC-22 was used extensively in all the above-mentioned applications in India till the decision to phase out the same came into effect as India is a party to the Montreal Protocol (MOP). India's Phasing out policy for HCFC-22 has been discussed in the first paragraph of the category description in the commercial refrigeration section.

4.7.1.3.a. Cold storage (2.F.1.c.i)

This category includes cold storages, pack-houses, ripening chambers, and reefer vehicles.

Category description

Cold storage (Bulk) is an environment-controlled warehousing space with multiple chambers intended for bulk storage of perishable items used for storing for long duration. Is generally an independent refrigerated warehouse. The cooling capacity of a cold storage varies between 228 to 402 kW.

In 2017, cold storage refrigerant mix was 5% R- 134a, 10% HCFC-22, 10% R-404A and 75% R-717 (Kumar et al, 2017). The share is projected to shift to 5% R- 134a, 10% R-404A, and 85% R-717 with complete phasing out of R-22.depending on application and energy efficiency considerations.

HFC used as refrigerants is emitted from the equipment's during initial injection, during its operational phase and at the end of life. In India, the average lifetime of the commercial refrigerators as per the industry is 20 years and there is no refrigerant left at the end of life.

Methodological issues

Tier 1 methodology has been used to estimate the HFC emissions from this sector. The formula used for the estimation is as follows

$E_{total,t} = E_{charge,t} + E_{lifetime,t}$

Where

$E_{total,t}$: GHG emissionsrelated to the management of refrigerant containers

$E_{charge,t}$: GHG emissionsrelated to the refrigerant charge

$E_{lifetime,t}$: annual emissions from the banks of refrigerants during operation and servicing

Note that there being no end-of-life emissions, Eend-of-life is considered to be zero. Hence not included in the formula above.

Emissions at the time of charging of new equipment is expressed as follows:

$$E_{charge,t} = M_t \, x \, \frac{k}{100}$$

where

$E_{charge,t}$: GHG emissionsduring system manufacture/assembly in year t, kg

Mt : amount of HFC charged into new equipment in year t, kg

K : emission factor of assembly losses of the HFC charged into new equipment, percent

The equation for estimating emissions during lifetime (operation and servicing) is expressed as follows:

$$E_{lifetime,t} = B_t \, x \, \frac{x}{100}$$

where

$E_{lifetime,t}$: amount of HFC emitted during system operation in year t, kg

Bt : amount of HFC banked in existing systems in year t, kg

x : annual emission rate (i.e., emission factor) of HFC of each sub application bank during operation accounting for average annual leakage and average annual emissions during servicing, percent.

Activity Data

The activity data in terms of number of units of cold storage for the years 2001 to 2022 was sourced from Indiastat. The value for 1986 was obtained from the publication Cold Chain Development in India – Modernization of the Infrastructure of Cold Storage of Perishables. Data for the years 1990 to 2001 was interpolated using the CAGR (CAGR) for the period 1986 and 2001.

Additionally, the average refrigerant charge used in these appliances was obtained directly from industry sources, and the types of gases used for charging were also verified through industry consultation.

Emission Factor

Country-specific emission factors of HFC134a, HFC-125 and HFC143a are applied for estimating the initial and operational emissions of these gases from the Industrial refrigeration sector. The country specific emissions factors have been established in consultation with the industry. The industry also provided the lifetime range and confirmed that there is zero recovery, and no charge left at the end of life.

Emission Estimates

Table 4.50 below presents HFC-134a emissions for the years 2005, 2020, 2021, and 2022. Emissions were relatively low in 2005, at 38.937 kt CO_2-e in 2005. Over the next 15 years, HFC-134a emissions from cold storage category in India has risen to 249.335 kt CO_2-e in 2020, to 268.79 kt CO_2-e in 2021 and 288.585 kt CO_2-e in 2022.

Table 4.50 Indices related to emissions of HFC-134a from cold storage

Item	Unit	2005	2020	2021	2022
Initial Charge of HFC-134a	t	77.84	339.05	340.68	347.48
Emission Factor at Initial Charge stage	%	5	5	5	5
Bank of HFC-134a	t	521.18	3496.87	3793.61	4092.29
Emission Factor for Operation	%	5	5	5	5
Recovery	%	0	0	0	0
Emission Factor for End of Life	%	0	0	0	0
Emissions from manufacturing	t	3.89	16.95	17.03	17.37
Emissions from stocks	t	26.06	174.84	189.68	204.61
Emissions from disposal	t	0	0	0	0
Total Emissions (Manufacturing + Operation)	t	29.95	191.80	206.71	221.99
GWP	no.	1300	1300	1300	1300
Emissions in CO_2.Eq	Kt CO_2-e	38.937	249.335	268.729	288.585

Further, Table 4.51 presents HFC-125 emissions from Cold storage sector in the years 2005, 2020, 2021, and 2022. HFC-125 emissions were 34.637 kt CO_2-e. Compared to 2005, there is a increase in HFC-125 emissions from this category to 468.964 kt CO_2-e in 2020, 523.375 kt CO_2-e in 2021 and to 577.373 kt CO_2-e in 2022.

Table 4.51 Indices related to emissions of HFC-125 from cold storage

Item	Unit	2005	2020	2021	2022
Initial Charge of HFC-125	t	36.84	352.81	356.30	358.09
Emission Factor for Initial Charge	%	5	5	5	5
Bank of HFC-125	t	181.69	2605.95	2945.75	3284.64
Emission Factor for Operation	%	5	5	5	5
Recovery	%	0	0	0	0
Emission Factor for End of Life	%	0	0	0	0
Emissions from manufacturing	t				

Item	Unit	2005	2020	2021	2022
	1.84	17.64	17.81	17.90	
Emissions from stocks	t	9.08	130.30	147.29	164.23
Emissions from disposal	t	0	0	0	0
Total Emissions (Manufacturing + Operation)	t	10.93	147.94	165.10	182.14
GWP	No	3170	3170	3170	3170
Emissions in CO_2.Eq	kt-CO_2 eq.	34.637	468.964	523.375	577.373

Table 4.52 below presents the HFC-143a emissions from cold storage sector in India for the years 2005, 2020, 2021, and 2022. In 2005, HFC-143a emissions from cold storage sector stood at 61.983 kt CO_2-e for the years 2005, 2020, 2021, and 2022. By 2020, HFC-134a emissions had risen sharply to 839.213 kt CO_2-e. The HFC-134a emissions further rose to 936.581 kt CO_2-e and 1033.211 kt CO_2-e by 2021 and 2022 respectively.

Table 4.52 Indices related to emissions of HFC-143a from cold storage

Item	Unit	2005	2020	2021	2022
Initial Charge of HFC-143a	t	43.53	416.96	421.08	423.20
Emission Factor for Initial Charge	%	5	5	5	5
Bank of HFC-143a	t	214.73	3079.76	3481.34	3881.85
Emission Factor for Operation	%	5	5	5	5
Recovery	%	0	0	0	0
Emission Factor for End of Life	%	0	0	0	0
Emissions from manufacturing	t	2.18	20.85	21.05	21.16
Emissions from stocks	t	10.74	153.99	174.07	194.09
Emissions from disposal	t	0	0	0	0
Total Emissions (Manufacturing + Operation)	t	12.91	174.84	195.12	215.25
GWP	No	4800	4800	4800	4800
Emissions in CO_2.Eq	kt-CO_2 eq.	61.983	839.213	936.581	1033.211

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty and Time-series Consistency

For estimating the uncertainty associated with emission factor, the upper limit of 30% for electrical equipment, from the 2006 IPCC Guidelines has been applied for both production and use phases.

The time series has been created using surrogate data for the years in which the cold storage data is not available. Details are provided in the section on activity data.

QA/QC and Verification

The calculations and the document produced has gone through two levels of review, one was a peer review and the other has been a review by the project co-lead and the lead respectively to ensure adherence to the methodology used for undertaking the estimations and related assumptions.

The QC was ensured through the following activities:

QC Activity	Procedures
Checking the assumptions and criteria for the selection of activity data and emission factors	• National level activity data of production of cold storage are obtained from the various sources ensuring high data accuracy and reliability for the years. • Emission factors as applicable have been obtained from Refrigeration and Air Conditioning Association.
Checking for transcription errors in input data and reference	• Bibliographical data references are cited in the internal documentation for the sector. • For transcription errors, activity data and EF used for refrigeration and air conditioning are cross-checked.
Check that parameter and emission units are correctly recorded and that appropriate conversion factors are used	• The accuracy of parameter units and their labels on the calculation sheets is verified from the beginning to the end of the calculations. • We have ensured that the conversion factors are correctly applied during the verification process.
Check those emissions and removals are calculated correctly	• Verified that the right GWP was applied to the emission data when converting each individual's GHG emissionsto CO_2 equivalent.
Checking for consistency in data between categories	• The data used in sub applications for Refrigeration and Air conditioning are checked for their consistency in the emission calculations.
Check that uncertainties in emissions are estimated and calculated correctly	• The accuracy and completeness of the uncertainty assessments are evaluated.
Reviewing the internal documentation and archiving	• The activity data and emission factor used in the inventory creation process are maintained to enable subsequent assessment.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

4.7.1.3.b. Packhouses (2.F.1.c.ii)

Category description

A typical pack-house consists of various operations such as sorting, grading, washing, drying, weighing, packaging, pre-cooling and staging, among others. Refrigerants are used in packhouses during pre-cooling and staging phases of the processes involved in packhouses. The entire set of activities is also known as preconditioning the produce for market connectivity.

The share of refrigerants used in Packhouses in India were 35% HFC-134a, 35% R-404A, and 30% HCFC-22 (Kumar et al, 2017). By 2027 the share of refrigerants in this category are projected to shift to 70% HFC-134a 25% R-404A and only 5% R-22 will remain.

HFC used as refrigerants is emitted from the equipment's during initial injection, during its operational phase and at the end of life. In India, the average lifetime of the commercial refrigerators as per the industry is 20 years and there is no refrigerant left at the end of life. The following sections describe the methodology, activity data, and the emissions factors used to estimate the net emissions of HFC across the entire Industrial refrigeration sector.

Methodological issues

Emission quantification method

The Tier 1 methodology has been used to estimate the HFC emissions from this sector. The formula used for the estimation is as follows

$$E_{total,t} = E_{charge,t} + E_{lifetime,t}$$

Where

$E_{total,t}$: GHG emissionsrelated to the management of refrigerant containers

$E_{charge,t}$: GHG emissionsrelated to the refrigerant charge

$E_{lifetime,t}$: annual emissions from the banks of refrigerants during operation and servicing

Note that there being no end-of-life emissions, Eend-of-life is considered to be zero. Hence not included in the formula above.

Emissions at the time of charging of new equipment is expressed as follows:

$$E_{charge,t} = M_t \, x \, \frac{k}{100}$$

where

$E_{charge,t}$: GHG emissionsduring system manufacture/assembly in year t, kg

Mt : amount of HFC charged into new equipment in year t, kg

K : emission factor of assembly losses of the HFC charged into new equipment, percent

The equation for estimating emissions during lifetime (operation and servicing) is expressed as follows:

$$E_{lifetime,t} = B_t \, x \, \frac{x}{100}$$

where

$E_{lifetime,t}$: amount of HFC emitted during system operation in year t, kg

Bt : amount of HFC banked in existing systems in year t, kg

x : annual emission rate (i.e., emission factor) of HFC of each sub application bank during operation accounting for average annual leakage and average annual emissions during servicing, percent.

Activity Data

The activity data for packhouses was sourced from the Ozone Cell's Cold Chain Report for the year 2020, and from the website of Agricultural & Processed Food Products Export Development Authority (APEDA) for 2024, which lists recognized packhouses in the country. The data was back casted for the period 2005 to 2019 using CAGR for the period 2020 and 2024. The year 2005 is chosen as the starting point for calculations, as the Grapenet system was introduced during 2005–2006 for the 1st time, marking the beginning of systematic packhouse establishment in India.

Additionally, the average refrigerant charge used in these appliances was obtained directly from industry sources, and the types of gases used for charging were also verified through industry consultation.

Emission Factor

Country-specific emission factors is applied for estimating the initial and operational emissions of these gases from the Industrial refrigeration sector. The country specific emissions factors have been established in consultation with the industry. The industry also provided the lifetime range and confirmed that there is zero recovery, and no charge left at the end of life.

Emission Estimates

Table 4.53 presents HFC-134a emissions from packhouses in India for the years 2005, 2020, 2021, and 2022. In 2005, emissions were minimal at 0.002 kt CO_2-e. By 2020, HFC-134a emissions from packhouses in India rose to 1.003 kt CO_2-e. This upward trajectory of HFC-134a emissions from this sector continued, reaching 1.242 kt CO_2-e in 2021, and 1.499 kt CO_2-e in 2022.

Table 4.53 Indices related to emissions of HFC-134a from packhouses

Item	Unit	2005	2020	2021	2022
Initial Charge of HFC-134a	t	0.02	3.21	3.45	3.70
Emission Factor for Initial Charge	%	5	5	5	5
Bank of HFC-134a	t	0.02	12.22	15.67	19.36
Emission Factor for Operation	%	5	5	5	5
Recovery	%	0	0	0	0
Emission Factor for End of Life	%	0	0	0	0
Emissions from manufacturing	t	0.00	0.16	0.17	0.18
Emissions from stocks	t	0.00	0.61	0.78	0.97
Emissions from disposal	t	0	0	0	0
Total Emissions (Manufacturing + Operation)	t	0.00	0.77	0.96	1.15
GWP	No	1300	1300	1300	1300
Emissions in CO_2.Eq	kt-CO_2 eq.	0.002	1.003	1.242	1.499

Table 4.54 presents total HFC-125 emissions from packhouses in India for the years 2005, 2020, 2021, and 2022. In 2005, emissions were extremely low at 0.0018 kt CO_2-e By 2020, HFC-125 emissions had increased sharply to 0.8663 kt CO_2-e. In 2021, it further rose to 1.0167 kt CO_2-e. By 2022 the HFC-125 emissions from packhouses further rose to 1.1627 kt CO_2-e.

Table 4.54 Indices related to emissions of HFC-125 from packhouses

Item	Unit	2005	2020	2021	2022
Initial Charge of HFC-125	T	0.01	1.01	0.98	0.95
Emission Factor for Initial Charge	%	5	5	5	5
Bank of HFC-125	T	0.01	4.46	5.44	6.39
Emission Factor for Operation	%	5	5	5	5
Recovery	%	0	0	0	0
Emission Factor for End of Life	%	0	0	0	0
Emissions from manufacturing	T	0.00	0.05	0.05	0.05
Emissions from stocks	T	0.00	0.22	0.27	0.32
Emissions from disposal	T	0	0	0	0
Total Emissions (Manufacturing + Operation)	T	0.00	0.27	0.32	0.37
GWP	No	3170	3170	3170	3170
Emissions in CO_2.Eq	kt-CO_2 eq.	0.002	0.866	1.017	1.163

Table 4.55 presents the emissions of total HFC-143a emission from packhouses in the years 2005, 2020, 2021, and 2022. HFC-143a emissions in 2005 was 0.003 kt CO_2-e. It rose to 1.550 kt CO_2-e in 2020 and to 1.819 and 2.081 kt CO_2-e respectively in the years 2021 and 2022.

Table 4.55 Indices related to emissions of HFC-143a from packhouses

Item	Unit	2005	2020	2021	2022
Initial Charge of HFC-143a	t	0.01	1.19	1.16	1.12
Emission Factor for Initial Charge	%	5	5	5	5
Bank of HFC-143a	t	0.01	5.27	6.42	7.55
Emission Factor for Operation	%	5	5	5	5
Recovery	%	0	0	0	0
Emission Factor for End of Life	%	0	0	0	0
Emissions from manufacturing	t	0.00	0.06	0.06	0.06

Item	Unit	2005	2020	2021	2022
Emissions from stocks	t	0.00	0.26	0.32	0.38
Emissions from disposal	t	0	0	0	0
Total Emissions (Manufacturing + Operation)	t	0.00	0.32	0.38	0.43
GWP	No	4800	4800	4800	4800
Emissions in CO_2.Eq	kt-CO_2 eq.	0.003	1.550	1.819	2.081

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty and Time-series Consistency

For estimating the uncertainty associated with emission factor, the upper limit of 30% for electrical equipment, from the 2006 IPCC Guidelines has been applied for both production and use phases.

The time series has been created using surrogate data for the years in which the packhouses unit data is not available. Details are provided in the section on activity data.

QA/QC and Verification

The calculations and the document produced has gone through 2 levels of review, one was a peer review and the other has been a review by the project co-lead and the lead respectively to ensure adherence to the methodology used for undertaking the estimations and related assumptions.

The QC was ensured through the following activities:

QC Activity	Procedures
Checking the assumptions and criteria for the selection of activity data and emission factors	• National level activity data of production of cold storage are obtained from the various sources ensuring high data accuracy and reliability for the years. • Emission factors as applicable have been obtained from Refrigeration and Air Conditioning Association.
Checking for transcription errors in input data and reference	• Bibliographical data references are cited in the internal documentation for the sector. • For transcription errors, activity data and EF used for refrigeration and air conditioning are cross-checked.
Check that parameter and emission units are correctly recorded and that appropriate conversion factors are used	• The accuracy of parameter units and their labels on the calculation sheets is verified from the beginning to the end of the calculations. • We have ensured that the conversion factors are correctly applied during the verification process.
Check those emissions and removals are calculated correctly	• Verified that the right GWP was applied to the emission data when converting each individual's GHG emissionsto CO_2 equivalent.
Checking for consistency in data between categories	• The data used in sub applications for Refrigeration and Air conditioning are checked for their consistency in the emission calculations.
Check that uncertainties in emissions are estimated and calculated correctly	• The accuracy and completeness of the uncertainty assessments are evaluated.
Reviewing the internal documentation and archiving	• The activity data and emission factor used in the inventory creation process are maintained to enable subsequent assessment.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category. Not applicable.

4.7.1.3.c. Ripening Chambers (2.F.1.c.iii)

Category description

Ripening chamber constitute a series of chambers and is a front-end facility in the cold-chain, designed to function for controlled and hygienic ripening of certain fresh produce. In India, these are used extensively for ripening bananas, mangoes, papayas, other citrus fruits, and some vegetables.

As per Kumar et al, 2017, the share of refrigerants used in ripening chambers in India were 35% HFC-134a, 35% R-404A, and 30% HCFC-22. By 2027 the share of refrigerants in this category are projected to shift to 70% HFC-134a 25% R-404A and only 5% R-22 will remain.

HFC used as refrigerants is emitted from the equipment's during initial injection, during its operational phase and at the end of life. In India, the average lifetime of the commercial refrigerators as per the industry is 20 years and there is no refrigerant left at the end of life . The following sections describe the methodology, activity data, and the emissions factors used to estimate the net emissions of HFC across the entire Industrial refrigeration sector.

Methodological issues

Emission quantification method

The Tier 1 methodology has been used to estimate the HFC emissions from this sector. The formula used for the estimation is as follows

$E_{total,t} = E_{charge,t} + E_{lifetime,t}$

Where

$E_{total,t}$: GHG emissionsrelated to the management of refrigerant containers

$E_{charge,t}$: GHG emissionsrelated to the refrigerant charge

$E_{lifetime,t}$: annual emissions from the banks of refrigerants during operation and servicing

Note that there being no end-of-life emissions, Eend-of-life is considered to be zero. Hence not included in the formula above.

Emissions at the time of charging of new equipment is expressed as follows:

$$E_{charge,t} = M_t \, x \, \frac{k}{100}$$

where

$E_{charge,t}$: GHG emissionsduring system manufacture/assembly in year t, kg

Mt : amount of HFC charged into new equipment in year t, kg

K : emission factor of assembly losses of the HFC charged into new equipment, percent

The equation for estimating emissions during lifetime (operation and servicing) is expressed as follows:

$$E_{lifetime,t} = B_t \, x \, \frac{x}{100}$$

where

$E_{lifetime,t}$: amount of HFC emitted during system operation in year t, kg

Bt : amount of HFC banked in existing systems in year t, kg

x : annual emission rate (i.e., emission factor) of HFC of each sub application bank during operation accounting for average annual leakage and average annual emissions during servicing, percent.

Activity Data

The activity data for ripening chambers was sourced from the All India Cold-chain Infrastructure Capacity – Assessment of Status & Gap report (2015) for the year 2015 and from the India Cooling Action Plan (ICAP, 2019). For the year 2017 and 2027 it was sourced from the Cooling Demand Analysis Report for India for the year 2027. For the remaining years, data was interpolated. Additionally, the average refrigerant charge used in these appliances was obtained directly from industry sources, and the types of gases used for charging were also verified through industry consultation.

Emission Factor

Country-specific emission factors are applied for estimating the initial and operational emissions of these gases from the Industrial refrigeration sector. The country specific emissions factors have been established in consultation with the industry. The industry also provided the lifetime range and confirmed that there is zero recovery, and no charge left at the end of life.

Emission Estimates

Table 4.56 presents the estimated emissions of total HFC-134a emissions for the years 2005, 2020, 2021, and 2022. HFC-134a emissions were very low in 2005, at just 0.069 kt CO_2-e . By 2020, HFC-134a emissions rose to 6.261 kt CO_2-e 2021, 7.981 kt CO_2-e in 2021 and 10.125 kt CO_2-e in 2022.

Table 4.56 Indices related to emissions of HFC-134a from ripening chambers

Item	Unit	2005	2020	2021	2022
Initial Charge of HFC-134a	t	0.23	17.76	22.14	27.59
Emission Factor for Initial Charge	%	5	5	5	5
Bank of HFC-134a	t	0.84	78.56	100.65	128.18
Emission Factor for Operation	%	5	5	5	5
Recovery	%	0	0	0	0
Emission Factor for End of Life	%	0	0	0	0
Emissions from manufacturing	t	0.01	0.89	1.11	1.38
Emissions from stocks	t	0.04	3.93	5.03	6.41
Emissions from disposal	t	0	0	0	0
Total Emissions (Manufacturing + Operation)	t	0.05	4.82	6.14	7.79
GWP	no.	1300	1300	1300	1300
Emissions in CO_2.Eq	kt-CO_2 eq.	0.069	6.261	7.981	10.125

Table 4.57 below presents total HFC-125 emissions from ripening chambers in India. HFC-125 emissions in 2005 were 0.049 kt CO_2-e . By 2020, HFC-125 emissions from ripening chambers rose to 6.313 kt CO_2-e 2021, in 2021 to 8.089 kt CO_2-e and in 2022 to 10.302 kt CO_2-e.

Table 4.57 Indices related to emissions of HFC-125 from ripening chambers

Item	Unit	2005	2020	2021	2022
Initial Charge of HFC-125	t	0.07	7.51	9.37	11.67
Emission Factor for Initial Charge	%	5	5	5	5
Bank of HFC-125	t	0.24	32.31	41.67	53.32
Emission Factor for Operation	%	5	5	5	5
Recovery	%	0	0	0	0
Emission Factor for End of Life	%	0	0	0	0

Item	Unit	2005	2020	2021	2022
Emissions from manufacturing	t	0.00	0.38	0.47	0.58
Emissions from stocks	t	0.01	1.62	2.08	2.67
Emissions from disposal	t	0	0	0	0
Total Emissions (Manufacturing + Operation)	t	0.02	1.99	2.55	3.25
GWP	No	3170	3170	3170	3170
Emissions in CO_2.Eq	kt-CO_2 eq.	0.049	6.313	8.089	10.302

Table 4.58 below presents the total HFC-143a emissions from ripening chambers in India for the years 2005, 2020, 2021, and 2022. The HFC-143a emissions were 0.0088 kt CO_2-e in 2005. By 2020, HFC-125 emissions rose to 11.297 kt CO_2-e, in 2021 to 14.475 kt CO_2-e in and to 18.435 kt CO_2-e in 2022.

Table 4.58 Indices related to emissions of HFC-143a from ripening chambers

Item	Unit	2005	2020	2021	2022
Initial Charge of HFC-143a	t	0.09	8.88	11.07	13.80
Emission Factor for Initial Charge	%	5	5	5	5
Bank of HFC-143a	t	0.28	38.19	49.24	63.02
Emission Factor for Operation	%	5	5	5	5
Recovery	%	0	0	0	0
Emission Factor for End of Life	%	0	0	0	0
Emissions from manufacturing	t	0.00	0.44	0.55	0.69
Emissions from stocks	t	0.01	1.91	2.46	3.15
Emissions from disposal	t	0	0	0	0
Total Emissions (Manufacturing + Operation)	t	0.02	2.35	3.02	3.84
GWP	No	4800	4800	4800	4800
Emissions in CO_2.Eq	kt-CO_2 eq.	0.088	11.297	14.475	18.435

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 (“Information on Flexibility”) of this Biennial Transparency Report.

Uncertainty and Time-series Consistency

For estimating the uncertainty associated with emission factor, the upper limit of 30% for electrical equipment, from the 2006 IPCC Guidelines has been applied for both production and use phases.

The time series has been created using surrogate data for the years in which the ripening chambers data is not available. Details are provided in the section on activity data.

QA/QC and Verification

The calculations and the document produced has gone through 2 levels of review, one was a peer review and the other has been a review by the project co-lead and the lead respectively to ensure adherence to the methodology used for undertaking the estimations and related assumptions.

The QC was ensured through the following activities:

QC Activity	Procedures
Checking the assumptions and criteria for the selection of activity data and emission factors	• National level activity data of production of cold storage are obtained from the various sources ensuring high data accuracy and reliability for the years. • Emission factors as applicable have been obtained from Refrigeration and Air Conditioning Association.
Checking for transcription errors in input data and reference	• Bibliographical data references are cited in the internal documentation for the sector. • For transcription errors, activity data and EF used for refrigeration and air conditioning are cross-checked.
Check that parameter and emission units are correctly recorded and that appropriate conversion factors are used	• The accuracy of parameter units and their labels on the calculation sheets is verified from the beginning to the end of the calculations. • We have ensured that the conversion factors are correctly applied during the verification process.
Check those emissions and removals are calculated correctly	• Verified that the right GWP was applied to the emission data when converting each individual's GHG emissionsto CO_2 equivalent.
Checking for consistency in data between categories	• The data used in sub applications for Refrigeration and Air conditioning are checked for their consistency in the emission calculations.
Check that uncertainties in emissions are estimated and calculated correctly	• The accuracy and completeness of the uncertainty assessments are evaluated.
Reviewing the internal documentation and archiving	• The activity data and emission factor used in the inventory creation process are maintained to enable subsequent assessment.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

4.7.1.3.d. Chillers (2.F.1.c.iv)

Category description

The chillers are used extensively in retail, hospitality and infrastructure. The chiller market is driven by rapid industrialization, urbanization and increasing need for cooling solutions across various sectors such as manufacturing, HVAC and health care. Chillers as per the technological requirements are available as Screw, Scroll and Centrifugal chillers.

As per the Demand Analysis for Cooling by Sector in India in 2027 report (Kumar et. al., 2020 (17)), all screw chillers in 2017 were charged with HFC-134a. The scroll chillers had 95% share of R-410A and 5% R-407C. The centrifugal chillers had 90% HFC-134a, and 10% R-123 (a type of HCFC). This report projects that by 2027, the share of R-134a will be 70% in screw chillers and the rest will be R-513A. The scroll chillers will have only R-410A. The centrifugal chiller will have 60% HFC-134a, 10% R-513A, 10% R514A and 20% R1233zd. However, HFC-32 is now replacing R-410A in the market. These refrigerant shares have been determined through India's HCFC phase out schedule, refrigerant preferences of key market players, and refrigerants used in top selling models. These trends of refrigerant use have been taken into account while estimating the HFC emissions from this category.

The gases used as refrigerant is emitted from the equipment's during initial injection, during its operational phase and at the end of life. As per the industry, in India, the average lifetime is 20 years and there is no refrigerant left at the end of life [16].

The following sections describe the methodology, activity data, and the emissions factors used to estimate the net emissions of HFC across the entire Industrial refrigeration sector.

Methodological issues

Emission quantification method

The Tier 1 methodology has been used to estimate the HFC emissions from this sector. The formula used for the estimation is as follows

$E_{total,t} = E_{charge,t} + E_{lifetime,t}$

Where

$E_{total,t}$: GHG emissionsrelated to the management of refrigerant containers

$E_{charge,t}$: GHG emissionsrelated to the refrigerant charge

$E_{lifetime,t}$: annual emissions from the banks of refrigerants during operation and servicing

Note that there being no end-of-life emissions, Eend-of-life is considered to be zero. Hence not included in the formula above.

Emissions at the time of charging of new equipment is expressed as follows:

$$E_{charge,t} = M_t \, x \, \frac{k}{100}$$

where

$E_{charge,t}$: GHG emissionsduring system manufacture/assembly in year t, kg

Mt : amount of HFC charged into new equipment in year t, kg

K : emission factor of assembly losses of the HFC charged into new equipment, percent

The equation for estimating emissions during lifetime (operation and servicing) is expressed as follows:

$$E_{lifetime,t} = B_t \, x \, \frac{x}{100}$$

where

$E_{lifetime,t}$: amount of HFC emitted during system operation in year t, kg

Bt : amount of HFC banked in existing systems in year t, kg

x : annual emission rate (i.e., emission factor) of HFC of each sub application bank during operation accounting for average annual leakage and average annual emissions during servicing, percent.

Activity Data

The activity data for chillers was obtained from various sources (UNEP, 2006; Kumar et al., 2020 and CLASP. the average refrigerant charge used in these appliances was obtained directly from industry sources and the types of gases used for charging were also verified through industry consultation.

Emission Factor

Country-specific emission factors of HFC-134a, HFC-125, and HFC-32 are used for estimating the initial and operational emissions of these gases from the Industrial refrigeration sector. The country specific emissions factors have been established in consultation with the industry. The industry also provided the lifetime range and confirmed that there is zero recovery, and no charge left at the end of life.

Emission Estimates

Table 4.59 presents the emissions of HFC-134a from chillers in India for the years 2005, 2020, 2021, and 2022. In 2005, the HFC-134a emissions were minimal at just 1.06 kt CO_2-e., reflecting limited use. By 2020, emissions

increased to 160.99 kt CO_2-e., highlighting a significant rise in the use of HFC-134a. The upward trend continued, with emissions reaching 191.33 kt CO_2-e and to 225.08 kt CO_2-e. in 2022.

Table 4.59 Indices related to emissions of HFC-134a from chillers

Item	Unit	2005	2020	2021	2022
Initial Charge of HFC-134a	t	15.65	1758.44	1957.61	2180.93
Emission Factor for Initial Charge	%	2	2	2	2
Bank of HFC-134a	t	50.19	8867.18	10802.76	12951.97
Emission Factor for Operation	%	1	1	1	1
Recovery	%	0	0	0	0
Emission Factor for End of Life	%	0	0	0	0
Emissions from manufacturing	t	0.31	35.17	39.15	43.62
Emissions from stocks	t	0.50	88.67	108.03	129.52
Emissions from disposal	t	0	0	0	0
Total Emissions (Manufacturing + Operation)	t	0.81	123.84	147.18	173.14
GWP	no.	1300	1300	1300	1300
Emissions in CO_2.Eq	kt-CO_2 eq.	1.059	160.993	191.334	225.080

Table 4.60 below presents the estimated emissions of HFC-125 from chillers for the years 2005, 2020, 2021, and 2022. In 2005, HFC-125 emissions from chillers was 0.13 kt CO_2-e indicating the presence of low volumes of chillers in the market. However, emissions rose to 18.14 kt CO_2-e., marking a significant rise in chiller stocks in 2020. In 2021, the HFC-125 emissions rose to 21.97 kt CO_2-e and to 21,970 kt CO_2-e in 2022.

Table 4.60 Indices related to emissions of HFC-125 from chillers

Item	Unit	2005	2020	2021	2022
Initial Charge of HFC-125	t	0.75	80.00	93.89	110.19
Emission Factor for Initial Charge	%	2	2	2	2
Bank of HFC-125	t	2.48	412.15	505.29	614.42
Emission Factor for Operation	%	1	1	1	1
Recovery	%	0	0	0	0
Emission Factor for End of Life	%	0	0	0	0
Emissions from manufacturing	t	0.02	1.60	1.88	2.20
Emissions from stocks	t	0.02	4.12	5.05	6.14
Emissions from disposal	t	0	0	0	0
Total Emissions (Manufacturing + Operation)	t	0.04	5.72	6.93	8.35
GWP	No.	3170	3170	3170	3170
Emissions in CO_2.Eq	kt-CO_2 eq.	0.126	18.137	21.970	26.463

Table 4.61 present the emissions of HFC-32 from chillers for the years 2005, 2020, 2021 and 2022. In 2005, HFC-32 emissions were negligible at 0.03 kt CO_2-e. By 2020, HFC-32 emissions increased 3.87 kt CO_2-, in 2021 to 4.68 kt CO_2-e and in 2022 to 5.64 kt CO_2-e.

Table 4.61 Indices related to emissions of HFC-32 from chillers

Item	Unit	2005	2020	2021	2022
Initial Charge of HFC-32	t	0.75	79.89	93.78	110.08
Emission Factor for Initial Charge	%	2	2	2	2
Bank of HFC-32	t	2.46	411.29	504.32	613.35
Emission Factor for Operation	%	1	1	1	1
Recovery	%	0	0	0	0

Item	Unit	2005	2020	2021	2022
Emission Factor for End of Life	%	0	0	0	0
Emissions from manufacturing	t	0.01	1.60	1.88	2.20
Emissions from stocks	t	0.02	4.11	5.04	6.13
Emissions from disposal	t	0	0	0	0
Total Emissions (Manufacturing + Operation)	t	0.04	5.71	6.92	8.34
GWP	no.	677	677	677	677
Emissions in CO_2.Eq	kt-CO_2 eq.	0.027	3.866	4.684	5.643

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty and Time-series Consistency

For estimating the uncertainty associated with emission factor, the upper limit of 30% for electrical equipment, from the 2006 IPCC Guidelines has been applied for both production and use phases.

The time series has been created using surrogate data for the years in which the chillers unit data is not available. Details are provided in the section on activity data.

QA/QC and Verification

The calculations and the document produced has gone through 2 levels of review, one was a peer review and the other has been a review by the project co-lead and the lead respectively to ensure adherence to the methodology used for undertaking the estimations and related assumptions.

The QC was ensured through the following activities:

QC Activity	Procedures
Checking the assumptions and criteria for the selection of activity data and emission factors	• National level activity data of production of cold storage are obtained from the various sources ensuring high data accuracy and reliability for the years. • Emission factors as applicable have been obtained from Refrigeration and Air Conditioning Association.
Checking for transcription errors in input data and reference	• Bibliographical data references are cited in the internal documentation for the sector. • For transcription errors, activity data and EF used for refrigeration and air conditioning are cross-checked.
Check that parameter and emission units are correctly recorded and that appropriate conversion factors are used	• The accuracy of parameter units and their labels on the calculation sheets is verified from the beginning to the end of the calculations. • We have ensured that the conversion factors are correctly applied during the verification process.
Check those emissions and removals are calculated correctly	• Verified that the right GWP was applied to the emission data when converting each individual's GHG emissionsto CO_2 equivalent.
Checking for consistency in data between categories	• The data used in sub applications for Refrigeration and Air conditioning are checked for their consistency in the emission calculations.
Check that uncertainties in emissions are estimated and calculated correctly	• The accuracy and completeness of the uncertainty assessments are evaluated.
Reviewing the internal documentation and archiving	• The activity data and emission factor used in the inventory creation process are maintained to enable subsequent assessment.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

4.7.1.3. Transport refrigeration (2.F.1.d)

Category description

This sector comprises refrigeration systems utilized across different modes of transport, primarily for transporting frozen or chilled food and beverage products. Transport refrigeration can be categorized into the following three sub-sectors:

a) Road refrigerant containers in vans, trucks, and trailers

b) Intermodal containers, commonly known as reefer containers

c) Ships, which encompass refrigerated cargo vessels, fishing vessels, and passenger liners

In this section we have only considered reefers. Reefers vehicles as road transport vehicles with a fixed insulated body equipped with active refrigeration designed for environment-controlled carriage of products. The existing number of road reefer transportation vehicles was obtained from various sources and domain expert interviews. It is estimated that 800 to 1000 road reefer transportation vehicles are added each year. The growth of reefer vehicles is in direct proportion with the growth of pack-houses.

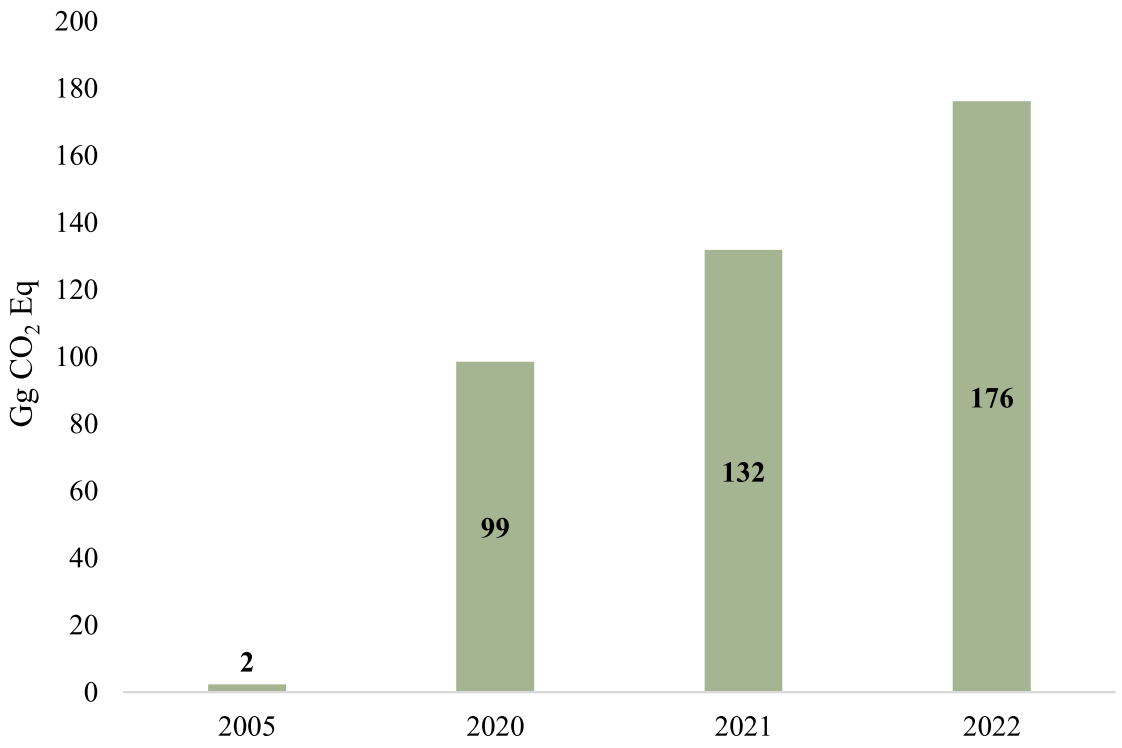


Figure 4.29 GHG emissions from Transport refrigeration (2.F.1.d) in 2005, 2020-2022

4.7.1.4.a. Reefers (2.F.1.d.i)

Category description

As of 2017 as per the Demand Analysis for Cooling by Sector in India in 2027 report (Kumar et al, 2017), the share of refrigerants in reefers in India was 35% HFC-134a , 40% R-404A, 20% was HCFC-22 and only 5% was R-407/R410a. In a BAU scenario, by 2027 the share is projected to become 50% R-134a, 30% R-404A, 5%

HCFC-22 and 15% R-407/R410a.

HFC used as refrigerants in reefers is emitted from the equipment's during initial injection, during its operational phase and at the end of life. In India, the average lifetime of the commercial refrigerators as per the industry is 8 years and there is no refrigerant left at the end of life. following sections describe the methodology, activity data, and the emissions factors used to estimate the net emissions of HFC across the entire Industrial refrigeration sector.

Methodological issues

Emission quantification method

The Tier 1 methodology has been used to estimate the HFC emissions from this sector. The formula used for the estimation is as follows

$E_{total,t} = E_{charge,t} + E_{lifetime,t}$

Where

$E_{total,t}$: GHG emissionsrelated to the management of refrigerant containers

$E_{charge,t}$: GHG emissionsrelated to the refrigerant charge

$E_{lifetime,t}$: annual emissions from the banks of refrigerants during operation and servicing

Note that there being no end-of-life emissions, Eend-of-life is considered to be zero. Hence not included in the formula above.

Emissions at the time of charging of new equipment is expressed as follows:

$$E_{charge,t} = M_t \, x \, \frac{k}{100}$$

where

$E_{charge,t}$: GHG emissionsduring system manufacture/assembly in year t, kg

Mt : amount of HFC charged into new equipment in year t, kg

K : emission factor of assembly losses of the HFC charged into new equipment, percent

The equation for estimating emissions during lifetime (operation and servicing) is expressed as follows:

$$E_{lifetime,t} = B_t \, x \, \frac{x}{100}$$

where

$E_{lifetime,t}$: amount of HFC emitted during system operation in year t, kg

Bt : amount of HFC banked in existing systems in year t, kg

x : annual emission rate (i.e., emission factor) of HFC of each sub application bank during operation accounting for average annual leakage and average annual emissions during servicing, percent.

Activity Data

The activity data for the number of reefer trucks in the year 2010 is obtained from the CEEW Report . For 2015, data is sourced from the Cold Chain Assessment Report (NCCD, 2015) . The 2022 activity data, in terms of reefer trucks, is taken from the India Cooling Action Plan (ICAP). Missing values for the intervening years have been estimated using the CAGR of years that are available.

Additionally, the average refrigerant charge used in these appliances was obtained directly from industry sources, and the types of gases used for charging were also verified through industry consultation.

Emission Factor

HFC-134a, HFC-125 and HFC143a country-specific emission factors are applied for estimating the initial and operational emissions of these gases from the Industrial refrigeration sector. The country specific emissions factors have been confirmed through literature review and in consultation with the industry. The industry also provided the lifetime range and confirmed that there is zero recovery, and no charge left at the end of life.

Emission Estimates

Table 4.62 below presents HFC-134a emissions for the years 2005, 2020, 2021, and 2022. In 2005, HFC-134a emissions from reefer trucks was 0.64 kt CO_2-e. In next 15 years that is in 2020, it increased to 23.13 kt CO_2-e, in 2021 to 31.12 kt CO_2-e and in 202022 it rose to 42 kt CO_2-e. The rise in emissions is in sync with the growth in economy.

Table 4.62 Indices related to emissions of HFC-134a from reefer trucks

Item	Unit	2005	2020	2021	2022
Initial Charge of HFC-134a	T	1.32	55.28	74.91	101.51
Emission Factor for Initial Charge	%	5	5	5	5
Bank of HFC-134a	T	5.74	200.41	269.20	363.11
Emission Factor for Operation	%	7.5	7.5	7.5	7.5
Recovery	%	0	0	0	0
Emission Factor for End of Life	%	0	0	0	0
Emissions from manufacturing	T	0.07	2.76	3.75	5.08
Emissions from stocks	T	0.43	15.03	20.19	27.23
Emissions from disposal	T	0	0	0	0
Total Emissions (Manufacturing + Operation)	T	0.50	17.80	23.94	32.31
GWP	No	1300	1300	1300	1300
Emissions in CO_2.Eq	kt-CO_2 eq.	0.64	23.13	31.12	42.00

Table 4.63 below presents HFC-125 emissions from use of refrigerants in reefer trucks for the years 2005, 2020, 2021, and 2022. Emissions in 0.82 kt CO_2-e., indicating limited use. By 2020, emissions had increased to 30.912 kt CO_2-e, reflecting greater use of HFC-125 in refrigerant blends. The upward trend continued in 2021, with emissions rising to 42.096 kt CO_2-e and further increasing to 57.142 kt CO_2-e in 2022.

Table 4.63 Indices related to emissions of HFC-125 from reefer trucks

Item	Unit	2005	2020	2021	2022
Initial Charge of HFC-125	t	0.66	31.53	42.59	57.19
Emission Factor for Initial Charge	%	5	5	5	5
Bank of HFC-125	t	2.99	108.99	148.67	202.22
Emission Factor for Operation	%	7.5	7.5	7.5	7.5
Recovery	%	0	0	0	0
Emission Factor for End of Life	%	0	0	0	0
Emissions from manufacturing	t	0.033	1.577	2.129	2.859
Emissions from stocks	t	0.22	8.17	11.15	15.17
Emissions from disposal	t	0	0	0	0
Total Emissions (Manufacturing + Operation)	t	0.26	9.75	13.28	18.03
GWP	No	3170	3170	3170	3170
Emissions in CO_2.Eq	kt-CO_2 eq.	0.82	30.91	42.10	57.14

Table 4.64 below presents emissions of HFC-32 (kt CO_2-e) from reefers for the years 2005, 2020, 2021, and 2022. In 2005, emissions from reefers is estimated to be 0.077 kt CO_2-e, indicating low early-stage penetration of the gas as refrigerant in this sector. By 2020, HFC-32 emissions have risen to 1.462 kt CO_2-e, showing the

gradual adoption of HFC-32 in air conditioning systems as a lower-GWP alternative. This growth continued in 2021, with emissions rising to 2.259 kt CO_2-e, and further to 3.423 kt CO_2-e. in 2022.

Table 4.64 Indices related to emissions of HFC-32 from reefer trucks

Item	Unit	2005	2020	2021	2022
Initial Charge of HFC-32	T	0.24	8.75	13.27	19.47
Emission Factor for Initial Charge	%	5	5	5	5
Bank of HFC-32	T	1.36	22.96	35.64	54.43
Emission Factor for Operation	%	7.5	7.5	7.5	7.5
Recovery	%	0	0	0	0
Emission Factor for End of Life	%	0	0	0	0
Emissions from manufacturing	T	0.012	0.438	0.664	0.973
Emissions from stocks	T	0.10	1.72	2.67	4.08
Emissions from disposal	T	0	0	0	0
Total Emissions (Manufacturing + Operation)	T	0.11	2.16	3.34	5.06
GWP	No	677	677	677	677
Emissions in CO_2.Eq	kt-CO_2 eq.	0.077	1.462	2.259	3.423

Table 4.65 below presents total HFC-143a emissions from reefers for the years 2005, 2020, 2021, and 2022. In 2005, emissions were relatively low at 0.811 kt CO_2-e. By 2020, emissions had risen substantially to 43.065 kt CO_2-e, signalling a rise in the use of HFC-143a in refrigerant blends. This rising trend in emissions continued in 2021, reaching 56.403 kt CO_2-e., and further rose to 73.576 kt CO_2-e. in 2022.

Table 4.65 Indices related to emissions of HFC-143a from reefer trucks

Item	Unit	2005	2020	2021	2022
Initial Charge of HFC-143a	t	0.49	26.92	34.65	44.58
Emission Factor for Initial Charge	%	5	5	5	5
Bank of HFC-143a	t	1.93	101.68	133.58	174.66
Emission Factor for Operation	%	7.5	7.5	7.5	7.5
Recovery	%	0	0	0	0
Emission Factor for End of Life	%	0	0	0	0
Emissions from manufacturing	t	0.024	1.346	1.732	2.229
Emissions from stocks	t	0.14	7.63	10.02	13.10
Emissions from disposal	t	0	0	0	0
Total Emissions (Manufacturing + Operation)	t	0.17	8.97	11.75	15.33
GWP	No	4800	4800	4800	4800
Emissions in CO_2 -e	Kt CO_2 -e	0.811	43.065	56.403	73.576

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 (“Information on Flexibility”) of this Biennial Transparency Report.

Uncertainty and Time-series Consistency

For estimating the uncertainty associated with emission factor, the upper limit of 30% for electrical equipment, from the 2006 IPCC Guidelines has been applied for both production and use phases.

The time series has been created using surrogate data for the years in which the no of reefer unit data is not available. Details are provided in the section on activity data.

QA/QC and Verification

The calculations and the document produced has gone through 2 levels of review, one was a peer review and the other has been a review by the project co-lead and the lead respectively to ensure adherence to the methodology used for undertaking the estimations and related assumptions.

The QC was ensured through the following activities:

QC Activity	Procedures
Checking the assumptions and criteria for the selection of activity data and emission factors	• National level activity data of production of cold storage are obtained from the various sources ensuring high data accuracy and reliability for the years. • Emission factors as applicable have been obtained from Refrigeration and Air Conditioning Association.
Checking for transcription errors in input data and reference	• Bibliographical data references are cited in the internal documentation for the sector. • For transcription errors, activity data and EF used for refrigeration and air conditioning are cross-checked.
Check that parameter and emission units are correctly recorded and that appropriate conversion factors are used	• The accuracy of parameter units and their labels on the calculation sheets is verified from the beginning to the end of the calculations. • We have ensured that the conversion factors are correctly applied during the verification process.
Check those emissions and removals are calculated correctly	• Verified that the right GWP was applied to the emission data when converting each individual's GHG emissionsto CO_2 equivalent.
Checking for consistency in data between categories	• The data used in sub applications for Refrigeration and Air conditioning are checked for their consistency in the emission calculations.
Check that uncertainties in emissions are estimated and calculated correctly	• The accuracy and completeness of the uncertainty assessments are evaluated.
Reviewing the internal documentation and archiving	• The activity data and emission factor used in the inventory creation process are maintained to enable subsequent assessment.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

4.7.1.4. Mobile air-conditioning (2.F.1.e)

Category description

This category only includes car air-conditioning. Indian cars were using CFC-12 since the time air-conditioned cars were introduced in early 1990s. And the industry switched to HFC-134a from 1995 onwards. Hundred percent use of HFC-134a is reported by the industry since 2010 which is in sync with India's Phasing out policy for CFC-12 discussed in the first paragraph of the category description in the domestic refrigeration section.

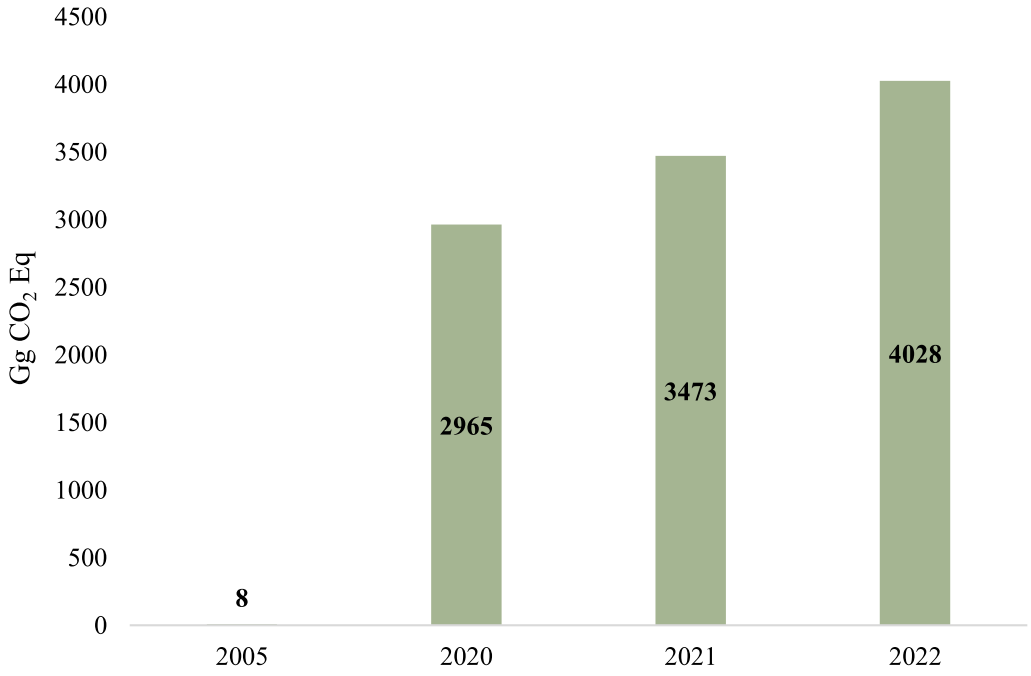


Figure 4.30 GHG emissions from Mobile air-conditioning (2.F.1.e) in 2005, 2020-2022

Methodological issues

HFC-134a used as refrigerants in mobile AC is emitted when it is injected, during operation and during end of life. In India, the average lifetime of the mobile air conditioning for cars as per the industry is taken to be 15 years and there is no refrigerant left at the end of life. The following sections describe the activity data, the emissions factors and the methodology used to estimate the net emissions of HFC-134a across the entire air conditioning sector. IPCC Tier 1 methodology has been used to estimate the HFC emissions from this sector.

The activity data represents domestic sales (production + imports – exports) of cars in India and was sourced from the Society of Indian Automobile Manufacturers (SIAM). This data, covering domestic sales, production, and export of cars available for the financial years 1994-95 to 2023-24, was subsequently converted to a calendar year format for further analysis. Further, the average refrigerant charge that goes into the AC was obtained from the industry and the gases that are being used for charging were also confirmed. See Table 22 detailing the activity data.

Country-specific emission factors have been applied for estimating the initial and operational emissions of HFC-134a from the mobile air conditioning sector. The country specific emissions factors have been established in consultation with the industry. The industry also provided the lifetime range of 15 years coinciding with the scrapping policy of the government. It seems that some companies do undertake recovery of the refrigerant but initial charge left being reported as zero, the net end of life emissions also become zero.

The HFC-134a emissions from mobile air-conditioning have risen from 2.63 Gg CO_2-e in 2005 to 292.68 Gg CO_2 Equivalent in 2022. This is likely to decrease in next few years when substitutes of HFCs such as HFO-1234yf with very low or zero GWP become commercially available at affordable cost with co-benefits of higher energy efficiency. The values increased substantially from 2.64 GgCO_2.e in 2005 to 261.92 GgCO_2 equivalent in 2020, with further growth to 275.75 GgCO_2 equivalent in 2021 and 292.69 GgCO_2 equivalent in 2022.

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 (“Information on Flexibility”) of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

For estimating the uncertainty associated with emission factor, the upper limit of 30% for electrical equipment, from the 2006 IPCC Guidelines has been applied for both production and use phases. The data was obtained from the Society of Indian Automobile Manufacturers (SIAM), which provided detailed information on domestic sales, production, and export figures of cars from their annual reports for the financial years 1994-95 to 2023-24. This data was then adjusted to fit the calendar year format for time series consistent analysis.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

Recalculations

4.7.1.5. Stationary air-conditioning (2.F.1.f)

Category description

HCFC-22 was used as refrigerant in residential Air Conditioners (AC). India being a signatory to the Montreal Protocol (Article 5 country), successfully met the 2013 target of freeze of HCFC production and consumption and 10% phase- out targets of HCFCs in 2015[12]. Against the phase out target of 35% of production and consumption of HCFCs from the baseline as on 1.1.2020, India achieved 44%, due to the pro-active measures taken by the country in the Implementation of HPMP Stage-II. However, R-410a (50% HFC-32 and 50% HFC-125) was also used simultaneously but in fewer number of equipment's. As the phaseout of HCFC-22 is in progress, R-410a is being widely used in this sector but its usage started reducing 2017 onwards. HFC-32 has also been introduced in 2013 but its use became more common in early 2020s. Meanwhile R-290, a hydrocarbon also has taken inroads in the sector.

HFC used as refrigerants is emitted from the equipment's during initial injection, during its operational phase and at the end of life. In India, the average lifetime of the residential AC as per the industry is 10 years and there is no refrigerant left at the end of life15. The following sections describe the activity data, the emissions factors and the methodology used to estimate the net emissions of HFC-32 and HFC-125 emissions from the residential air conditioning sector.

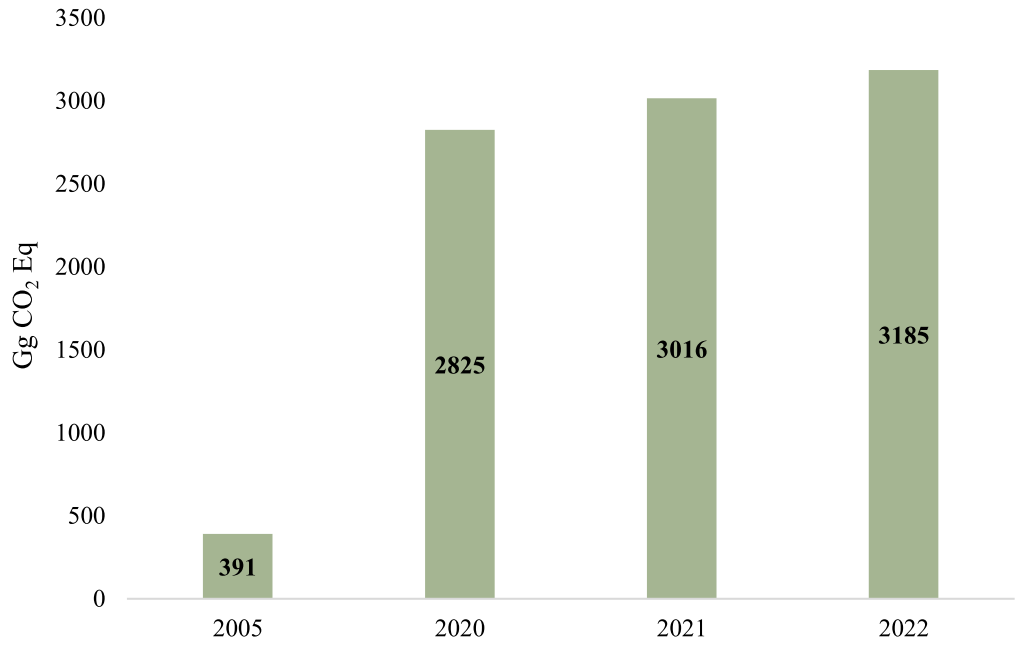


Figure 4.31 GHG emissions from Stationary air-conditioning (2.F.1.f) in 2005, 2020-2022

Methodological issues

The Tier 1 methodology has been used to estimate the HFC emissions from this sector. The formula for the same is as follows

$E_{total,t} = E_{charge,t} + E_{lifetime,t}$

$E_{total,t}$: GHG emissionsrelated to the management of refrigerant containers

$E_{charge,t}$: GHG emissionsrelated to the refrigerant charge

$E_{lifetime,t}$: annual emissions from the banks of refrigerants during operation and servicing

Note that there being no end-of-life emissions, Eend-of-life is considered to be zero. Hence not included in the formula above.

Refrigerant charge emissions of new equipment

$$E_{charge,t} = M_t \, x \, \frac{k}{100}$$

$E_{charge,t}$: GHG emissionsduring system manufacture/assembly in year t, kg

Mt : amount of HFC charged into new equipment in year t , kg

K : emission factor of assembly losses of the HFC charged into new equipment, percent

Emissions during lifetime (operation and servicing)

$$E_{lifetime,t} = B_t \, x \, \frac{x}{100}$$

$E_{lifetime,t}$: amount of HFC emitted during system operation in year t, kg

Bt : amount of HFC banked in existing systems in year t , kg

x : annual emission rate (i.e., emission factor) of HFC of each sub application bank during operation accounting for average annual leakage and average annual emissions during servicing, percent.

The activity data is the number of Residential AC produced and sold in the county. The data was obtained from the Bureau of Energy Efficiency (BEE), GoI. The data provided was in terms of fixed and variable speed air conditioner for the financial years 2018-19 to 2023-24. Data is gathered under BEE's Standard and Labelling (S&L) programme. The data was subsequently converted into the calendar year format. Due to the limited availability of data, we applied the compound annual growth rate (CAGR) of the industry to derive the entire series of air conditions produced. Further, the average refrigerant charge that goes into the refrigerators was obtained from the industry and the gases that are being used for charging were also confirmed. India phased out the use of HCFC-22 in 2016, subsequently adopting HFC-32 and R410A. The transition has now progressed to R290.

Country-specific emission factors have been applied for estimating the initial and operational emissions of HFC from the residential AC sector. The country specific emissions factors have been established in consultation with the industry. The industry also provided the lifetime range and confirmed that there is zero recovery, and no charge left at the end of life. The total emissions of HFC-32 and HFC-125 from this sector has increased significantly between 2005 and 2022. However, will decrease as HFC's get replaced by hydrocarbons and other cooling gases that have very small or zero GWPs.

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

For estimating activity data uncertainty for production and use phase, a 10% value from the Tier 2 method for the metal industry, as outlined in the 2006 IPCC Guidelines has been applied. For estimating the uncertainty associated with emission factor, the upper limit of 30% for electrical equipment, from the 2006 IPCC Guidelines has been applied for both production and use phases.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

Recalculations

4.7.2. Foam blowing agents (2.F.2)

Category description and background

In the foam industry, blowing agents are used to expand the plastic matrix before it solidifies, resulting in foam products. The final density of the foam depends on the type and amount of blowing agent used, as well as the processing conditions applied. Before 2010, CFC-11 was widely used as a blowing agent for foam. After the phase-out of CFCs, HCFC-141b became common in this role. However, India successfully phased out HCFC-141b from the foam sector in 2020. Alternatives to HCFC-141b in foam manufacturing include hydrocarbons (such as cyclopentane and n-pentane), modified water-blown formulations, supercritical carbon dioxide, methyl formate, HFOs, and high-GWP HFCs. The division of foams into open-cell or closed-cell relates to the way in which blowing agent is lost from the products.

4.7.2.1. Closed cells (2.F.2.a)

Category description

Closed-cell foam, only a small portion of emissions is released during manufacturing. The majority of emissions happen gradually during the in-use phase and are frequently not discharged until the end of life, during decommissioning. As a result, emissions from closed-cell foams may persist for at least 50 years from the date of manufacturing. HFCs are emitted. HFC-245fa is emitted as a result of foam blowing agent use.

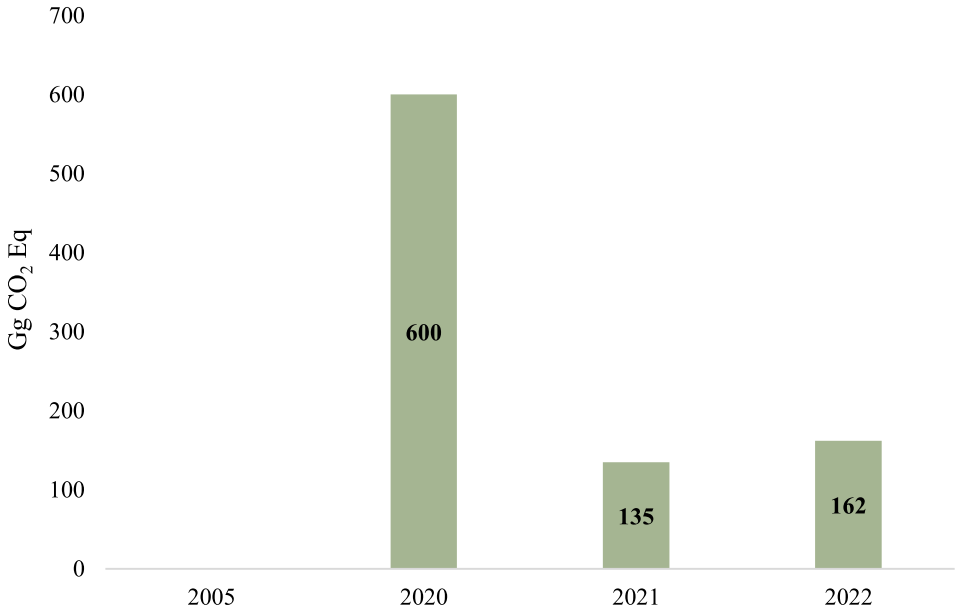


Figure 4.32 GHG emissions from Closed cells (2.F.2.a) in 2005, 2020-2022

Methodological issues

The Tier 1 methodology has been used to estimate the HFC emissions from this sector. The formula for the same is as follows

Emissionst = Mt • EFFYL + Bankt • EFAL

Emissionst = emissions from closed-cell foam in year t, tonnes

Mt = total HFC used in manufacturing new closed-cell foam in year t, tonnes

EFFYL = first year loss emission factor, fraction

Bankt = HFC charge blown into closed-cell foam manufacturing between year t and year t-n, tonnes

EFAL = annual loss emission factor, fraction

The activity data used is the consumption of HFC-245fa and HFC-365mfc received from Ozone cell, Ministry of Environment, Forest climate change for the years 2021 and 2022. For the closed-cell consumption of HFC-245fa, we considered 45% of the activity data based on the report from the Indian Polyurethane Association. The default emission factor of closed cell is taken from IPCC 2006 guidelines, volume 3, chapter 7, Table 7.7 has been used. The Emissions for HFC-245fa of 2021 and 2022 are 11.34 and 21.63 $GgCO_2$ equivalent. The emissions for HFC-365mfc are 1.54 $GgCO_2$ equivalent. Not estimated (NE) notation key is used as the activity data for foam blowing agent for closed-cell applicants for the years 2005 and 2020 are unavailable due to lack of resources and technical constraints.

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

For the uncertainties of the emissions for both manufacturing and use, the 2006 IPCC Guidelines value of 50% was used.

QA/QC and verification

In QC procedure the data and parameters used for the emission inventory preparation are checked for its integrity, correctness, relevance and completeness. Activity data was checked with inventory compliers to compare the data by different producers and distributors. The outliers, if any were also investigated. As outlined in the IPCC Good Practice Guidance, ensuring quality assurance involves carefully reviewing the inventory to assess its accuracy and identifying areas where improvements can be made to enhance its overall quality., The emission calculations are reviewed by the internal team who are not directly involved in the inventory preparation.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

4.7.2.2. Open cells (2.F.2.b)

Category description

In open-cell foam, emissions of HFCs used as blowing agents are expected to occur primarily during the manufacturing process and shortly afterward. Open-cell foams are utilized in applications such as cushioning for household furniture, mattresses, automotive seating, and moulded products like car steering wheels and office furniture. HFCs are emitted. HFC-245fa is emitted as a result of foam blowing agent use.

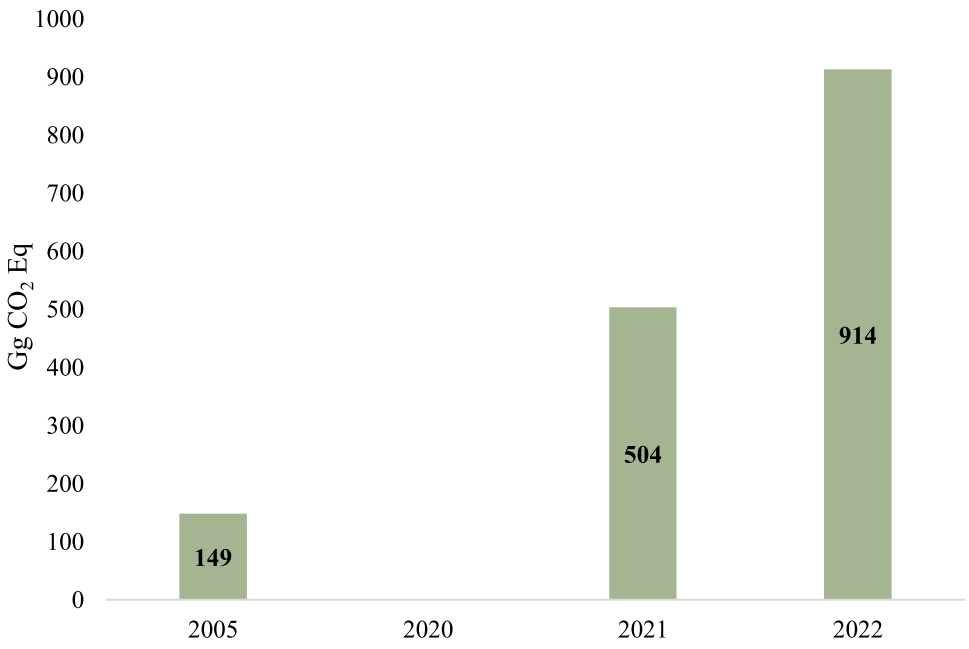


Figure 4.33 GHG emissions from Open cells (2.F.2.b) in 2005, 2020-2022

Methodological issues

The Tier 1 methodology has been used to estimate the HFC emissions from this sector. The activity data used is the consumption of HFC-245fa received from Ozone cell, Ministry of Environment, Forest climate change for the years 2021 and 2022. For the open-cell consumption of HFC-245fa, we considered 55% of the activity data based on the report from the Indian Polyurethane Association. The default emission factor of closed cell is taken from IPCC 2006 guidelines, volume 3, chapter 7, Table 7.7 has been used. The Emissions for HFC-245fa of 2021 and 2022 are 277.10 and 502.50 $GgCO_2eq$. Not estimated (NE) notation key is used as the activity data for foam blowing agent for open-cell applicants for the years 2005 and 2020 are unavailable due to lack of resources and technical constraints.

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

A quantitative uncertainty analysis for this category was conducted using the Tier 1 approach from the 2006 IPCC Guidelines. For the uncertainties of the emissions for both manufacturing and use, the 2006 IPCC Guidelines value of 50% was used. For each category and gas, a detailed analysis is conducted for the starting and latest reporting years, highlighting the main contributors to overall uncertainty. Time-series consistency is a cornerstone of the inventory process. For the reported years, consistent methodologies and data sources have been applied to the greatest extent possible to ensure that trends reflect actual changes in emissions.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

4.7.3. Fire protection (2.F.3)

Category description

Fire protection (fire suppression) equipment that uses HFCs and/or PFCs as partial replacements for halons includes portable (streaming) units and fixed (flooding) systems. Although actual emissions from the fire protection sub-sector are expected to be minimal, its use, primarily in stand-by fire protection, is generally non-emissive and continues to grow. This creates an accumulating reserve of potential future emissions.

Methodological issues

The activity data was the consumption data of HFC-236fa collated from Ozone Cell, Ministry of Environment, Forest and Climate Change. There are still no findings on the emission factor of HFC extinguishing agents when using them. The default emission factor from literature in IPCC 2006 Guidelines, Volume 3, Chapter 7 was used. The emissions for HFC-236fa of 2021 and 2022 are 171.77 and 211.60 $GgCO_2$ equivalent.

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

A quantitative uncertainty analysis for this category was conducted using the Tier 1 approach from the 2006 IPCC Guidelines. The uncertainty for the activity data has been taken to be 15% as per IPCC 2006 guidelines. The uncertainty for the emission factors was taken to be 2% as per IPCC 2006 guidelines. For each category and gas, a detailed analysis is conducted for the starting and latest reporting years, highlighting the main contributors to overall uncertainty. Time-series consistency is a cornerstone of the inventory process. For the reported years, consistent methodologies and data sources have been applied to the greatest extent possible to ensure that trends reflect actual changes in emissions.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

4.7.4. Aerosols (2.F.4)

Category description and background

Most aerosol products use hydrocarbons (HC) as propellants, but a small portion includes HFCs and PFCs as propellants or solvents. Emissions from aerosols typically occur soon after production, averaging six months after sale; however, the time between manufacturing and sale can vary significantly depending on the specific application. During aerosol use, 100 percent of the chemical is released.

4.7.4.1. Metered dose inhalers (2.F.4.a)

Category description

HFCs are emitted from the manufacturing and use of metered dose inhalers (MDIs).

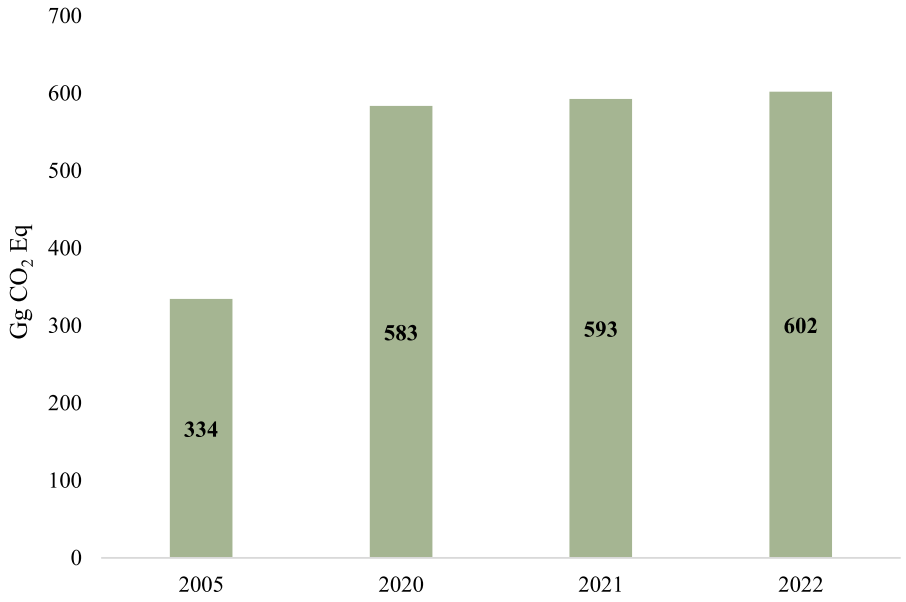


Figure 4.34 GHG emissions from Metered dose inhalers (2.F.4.a) in 2005, 2020-2022

Methodological issues

The Tier 1 methodology has been used to estimate the HFC emissions from this sector. Total consumption of HFC-227ea is allocated to this category. Consumption data is collated from Ozone Cell, Ministry of Environment, Forest, Climate change. Emission factor as per IPCC 2006 it is default emission factor of 50% of the initial charge per year.

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

For the uncertainties of the emission factors, 0% was applied for all production, use and disposal, due to the fact that the number of emissions is equal to the number of aerosols used. For the uncertainties of the activity data, the 10% value of the Tier 2 method for metal industry in the 2006 IPCC Guidelines was applied for all production, use, and disposal.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

4.7.4.2. Other (please specify) (2.F.4.b)

4.7.5. Solvents (2.F.5)

Category description

HFC/PFC solvents are primarily applied in areas like Precision cleaning, Electronics cleaning, Metal cleaning, and Deposition applications. HFCs are typically utilized as an azeotrope or blended form in solvent cleaning. The most commonly used HFC solvent is HFC-43-10mee, with some usage of HFC-365mfc, HFC-245fa (in aerosol solvents), and heptafluorocyclopentane.

Methodological issues

The Tier 1 methodology has been used to estimate the HFC emissions from this sector. The activity data available is the consumption of HFC-43-10mee from Ozone Cell, Ministry of Environment, Forest and Climate Change. Emission factor as per IPCC, 2006 it is default emission factor of 50% of the initial charge per year. Half of the chemical charge escapes within first year and the remaining charge escapes second year.

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

For the uncertainties of the HFC emission factors, -5% to +5% was applied. For the uncertainties of the activity data, the 10% value of the Tier 2 method for metal industry in the 2006 IPCC Guidelines was applied.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

4.7.6. Other applications (10) (2.F.6)

Category description and background

HFCs and PFCs encompass a wide variety of gases with properties that make them suitable for numerous niche applications. They are primarily used in fields such as electronics testing, heat transfer, dielectric fluids, medical applications, and various emerging technologies. Emission rates from these applications vary significantly, ranging from nearly 100% in the year of use to as low as 1% per year. Among these gases, HFC-134a is the most commonly used.

Methodological issues

Emission quantification Method

The Tier 1 methodology has been used to estimate the HFC emissions from this sector. The formula for the same is as follows

Emissionst = St • EF + St–1 • (1– EF)

where

Emissions = emissions in year t, tonnes

St = quantity of HFC and PFC sold in year t, tonnes

St–1 = quantity of HFC and PFC sold in year t–1, tonnes

EF = emission factor (= fraction of chemical emitted during the first year), fraction

Activity Data

Quantification of HFC-134a for these applications together is done by subtracting the net HFC-134a utilisation in other categories from the national level consumption of HFC-134a reported by the ozone cell for the years 2021 and 2022.

Emission Factor

Emission factor as per IPCC,2006 it is default emission factor of 50% of the initial charge per year. Half of the chemical charge escapes within first year and the remaining charge escapes second year.

Emission Estimates

The emissions of HFC-134a is estimated to be 682.87 and 3382.11 kt CO_2-e in 2021 and 2022 respectively. The details of consumption, emission factor, emissions in the 1st year of injection, emission from banked gas etc. are all indicated in Table 119.

Table 4.66: HFC-134a emissions from other applications

Item	Unit	2005	2020	2021	2022
HFC- 134a Consumption	T	NE	NE	1050.58	4677.9595
Emission factor during first Year	%	50	50	50	50
Emissions during first year of HFC-134a	T	NE	NE	525.29	2338.97975
HFC-134a consumption previous year	T	NE	NE	0	525.29
Emission factor	%	50	50	50	50
Bank Emissions HFC-134a	T	NE	NE	0	262.645
Emissions HFC-134a	T	NE	NE	525.29	2601.62475
GWP	No.	1300	1300	1300	1300
Emissions	kt-CO_2 eq.	NE	NE	682.877	3382.11218

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 (“Information on Flexibility”) of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

For the uncertainties of the HFC emission factors, -5% to +5% was applied. For the uncertainties of the activity data, the 10% value of the Tier 2 method in the 2006 IPCC Guidelines was applied.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

4.8. Other product manufacture and use (CRT 2.G)

Category description and background

The manufacturing and use of electrical equipment and several other products results in the emission of sulphur hexafluoride (SF_6), perfluorocarbons (PFCs) and Nitrous oxide (N_2O). In the majority of these uses SF_6, PFC, and N_2O is intentionally added to the product to take advantage of specific physical characteristics of the chemical, such as SF_6 high dielectric strength, the stability of PFCs and the anaesthetic properties of N_2O.

4.8.1. Electrical equipment (11) (2.G.1)

Category description

Due to high electrical insulation and current interruption SF_6 is used as gas insulating agent in circuit breakers (GCB), gas insulated switchgear and in sub-stations (GIS). GCBs are categorised as closed pressure and sealed pressure electrical equipment's. SF_6 emissions from electrical equipment occurs at each phase of the equipment life cycle, manufacturing, installation, use, servicing, and disposal. SF_6 emissions from electrical equipment can be approximated using different methods, each differing in complexity and data availability. For estimating the emissions, Tier 1 Methodology explained below has been used for calculating greenhouse gas emissions during installation and use of Electrical Equipment's. SF_6 emissions from electrical equipment occurs at each phase of the equipment life cycle, manufacturing, installation, use, servicing, and disposal.

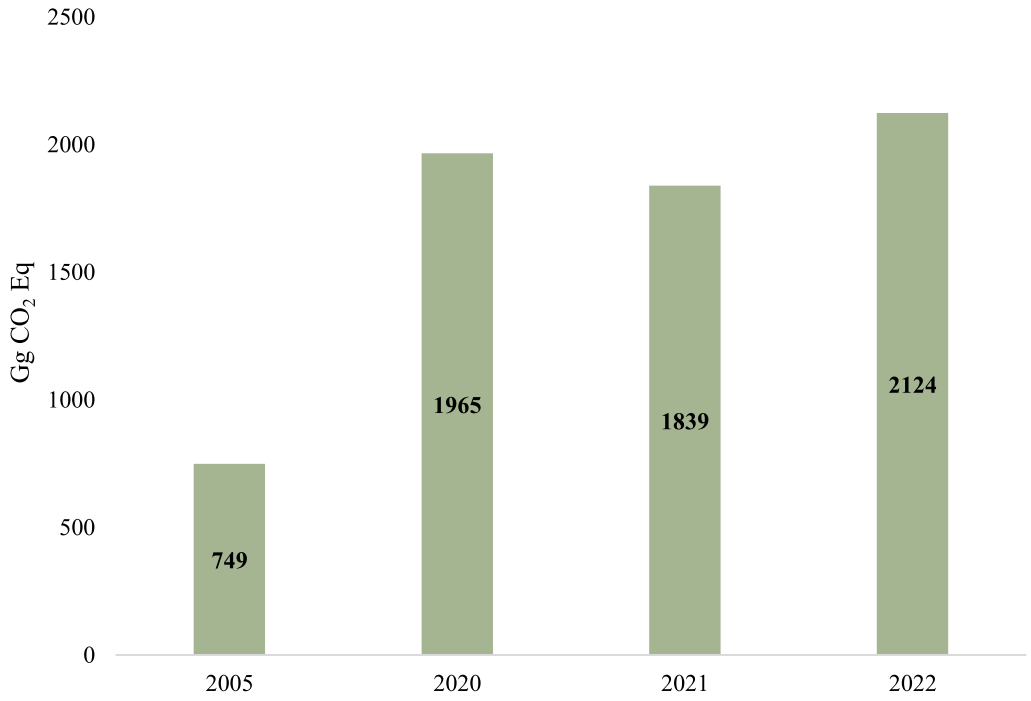


Figure 4.35 GHG emissions from Electrical equipment (2.G.1) in 2005, 2020-2022

Methodological issues

The IPCC Tier 1 methodology for estimating SF_6 emissions from electrical equipment. In this estimation, the installation emissions have been estimated along with in-use emissions. The installation emissions are calculated by multiplying the nameplate capacity of the equipment by a default emission factor as per IPCC 2006 guidelines, volume 3, chapter 8, Table 8.2. In use equipment estimations consider the bank of SF_6. The in-use emissions are estimated by cumulatively adding the nameplate capacity of the equipment in previous years and the current year. The users and the manufacturing industry has indicated that the lifetime of the electrical equipment containing SF_6 is more than 35 years when it is disposed. This aligns well with the IPCC 2006 guidelines. No recovery or residual emissions have been reported by them so far. Data for electrical equipment's has been collating by Central Electricity Authority of Ministry of Power, Government of India from DISCOMS across India. Not all have reported the data. Capacity building initiatives for the DISCOMS have to be taken up to enable gathering of this data on a continuous basis. The activity data includes total number of sealed pressure and closed pressure GCB's and GIS's purchased yearly for different voltages and their respective nameplate capacities. For emission estimates, the available data was bifurcated in 3 categories: (i) GCB-closed pressure, (ii) GCB-SP and (iii) GIS.

European default emission factors as per IPCC 2006 guidelines, volume 3, chapter 8, Table 8.2 and 8.3 is used for installation and use emission factors for GCB-CP and GCB-SP respectively. For GIS, the average value of the two available emission factors (table 8.2 and 8.3) has been used for estimating emissions during installation. Data on frequency of refilling of SF_6 gas and the amount of SF_6 gas refilled being available for GIS, is used to derive country-specific emission factor for in-use electrical equipment. A weighted average emission factor was derived from this data as country specific EF for in-use equipment for GIS. The SF_6 emission from electrical equipment's has increased from year 2005 to 2022 from 24.40 Gg CO_2 Equivalent to 194.15 Gg CO_2 Equivalent. This includes emissions during installation and use.

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

The tier 1 approach provided in the IPCC 2006 guidelines for this sector has been applied to estimate the related uncertainty. The emission factor uncertainty for installation and use is taken to be ranging between -30 to +30% in accordance with the 2006 IPCC guidelines. For the uncertainty of the activity data, the 10% value of the Tier 2 method for metal industry in the 2006 IPCC guidelines was applied. This methodology is consistent with Japan. As a result for the emissions, the uncertainty for installation and use was determined d to be 31.62%.

QA/QC and verification

In QC procedure the data and parameters used for the emission inventory preparation are checked for its integrity, correctness, relevance and completeness. Activity data was checked with inventory compliers to compare the data by different producers and distributors. The outliers, if any were also investigated. As outlined in the IPCC Good Practice Guidance, ensuring quality assurance involves carefully reviewing the inventory to assess its accuracy and identifying areas where improvements can be made to enhance its overall quality., The emission calculations are reviewed by the internal team who are not directly involved in the inventory preparation.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

4.8.2. SF_6 and PFCs from other product use (2.G.2)

4.8.2.1. Military applications (2.G.2.a)

NE notation key is used as activity data is unavailable due to technical and financial capacity contraints.

4.8.2.2. Accelerators (2.G.2.b)

NE notation key is used as activity data is unavailable due to technical and financial capacity contraints.

4.8.2.3. Soundproof windows (2.G.2.c)

NE notation key is used as activity data is unavailable due to technical and financial capacity contraints.

4.8.2.4. Adiabatic properties: shoes and tyres (2.G.2.d)

NE notation key is used as activity data is unavailable due to technical and financial capacity contraints.

4.8.2.5. Other (2.G.2.e)

4.8.2.5.1. Waterproofing electronic circuits (2.G.2.e.i.)

NE notation key is used as activity data is unavailable due to technical and financial capacity contraints.

4.8.2.5.2. Other (please specify) (2. G.2.e.ii.)

NE notation key is used as activity data is unavailable due to technical and financial capacity contraints.

4.8.3. N_2O from product uses (2.G.3)

4.8.3.1. Medical applications (2.G.3.a.)

NE notation key is used as activity data is unavailable

There is no single, authoritative public source that publishes a national "total quantity of N_2O supplied for medical use in India. Hence the notation NE is being used. This will be further explored in subsequent BTRs.

4.8.3.2. Other (2.G.3.b.)

4.8.3.2.1 Propellant for pressure and aerosol products (2.G.3.b.i)

There is no single, authoritative public figure that states "total quantity of N_2O supplied for propellants / aerosol products in India. Hence the notation NE is being used. This will be further explored in subsequent BTRs.

4.8.3.2.2 Other (please specify) (2.G.3.b.ii)

4.9. Other (CRT 2.H)

4.9.1. Pulp and paper (2.H.1)

IE notation key is used as this is accounted under 2.A.2. lime industry.

4.9.2. Food and beverages industry (2.H.2)

NE notation key is used as activity data is unavailable.

There is no dedicated source of data on CO_2 emissions from use of carbonates from Food and beverage Industries. Hence not estimated (NE) notation key is used for this category. This will be evaluated in subsequent BTRs.

CHAPTER-5

AGRICULTURE

AGRICULTURE

5.1. Overview of the sector (e.g. quantitative overview and description, including trends and methodological tiers by category) and background information

India's agriculture sector, accounts for emissions of three greenhouse gases: carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). These emissions are reported across six main categories:

(i) Enteric Fermentation (3A),

(ii) Manure Management (3B),

(iii) Rice Cultivation (3C),

(iv) Agricultural Soils (3D),

(v) Field burning of agricultural residues (3F) and

(vi) Urea Application (3H)

Methane (CH_4) emissions from enteric fermentation are reported for cattle, buffalo, sheep, goats, horses, mules and asses, mithun and yak, and swine under category 3.A. Under category 3.B, both CH_4 and nitrous oxide (N_2O) emissions from manure management are reported for the same livestock categories, along with poultry (hens, ducks, and broilers). CH_4 emissions from rice cultivation are reported for category 3.C 'Rice cultivation'. Category 3.D 'Agricultural Soils' covers direct and indirect N_2O emissions from agricultural soils. Emissions from prescribed burning of savannahs (3.E) are reported as "Not Occurring" (NO), as there are no sources of such emissions in India. CH_4 and N_2O emissions from the field burning of crop residues are reported under category 3.F. In category 3.G, CO_2 emissions from the application of limestone to soils are reported as "Not Estimated" (NE), as disaggregated data on lime application could not be collected in India due to constraints related to limited resources and technical capacity. CO_2 emissions resulting from urea application to soils are reported under category 3.H 'Urea application'. All emission data are presented on a calendar year (CY) basis.

Emission estimates for all categories are prepared in accordance with the 2006 IPCC Guidelines, applying both Tier 1 and Tier 2 methodologies. Both country-specific and default emission factors are used, depending on data availability and applicability. A detailed summary of the methods and emission factors applied is presented in Table 1.1.

For each category and its respective sub-categories, the following elements are described in this section: an overview of the activity, methodological approaches and data sources, identification of key categories, assessment of uncertainties and time-series consistency, flexibilities availed, quality assurance and quality control procedures, any recalculations undertaken, and planned improvements for future inventory cycles.

Summary of Emission trends

In 2022, India's agriculture sector emitted approximately 509,439 $GgCO_2e$, contributing 15% to the country's total greenhouse gas (GHG) emissions, excluding LULUCF. This represents a 15% increase from 2005 levels, which stood at 443,443 $GgCO_2e$. The emission in the year 2021 increased by 0.87% from the year 2020 and by 1.36% in 2022 from the year 2021.

Methane (CH_4) and nitrous oxide (N_2O) were the dominant GHGs emitted from this sector in 2022, accounting for 411,677.74 $GgCO_2e$ and 90,014.79 $Gg\text{-}CO_2e$, respectively. Together, they contributed significantly, with CH_4 comprising nearly 77% and N_2O about 71% of total CH_4 and N_2O emissions. In contrast, carbon dioxide (CO_2) emissions from the sector were minimal at 7,746.2 Gg, amounting to only 0.3% of India's total reported CO_2 emissions. The share of different gases in total sectoral emissions is given in figure 5.1.

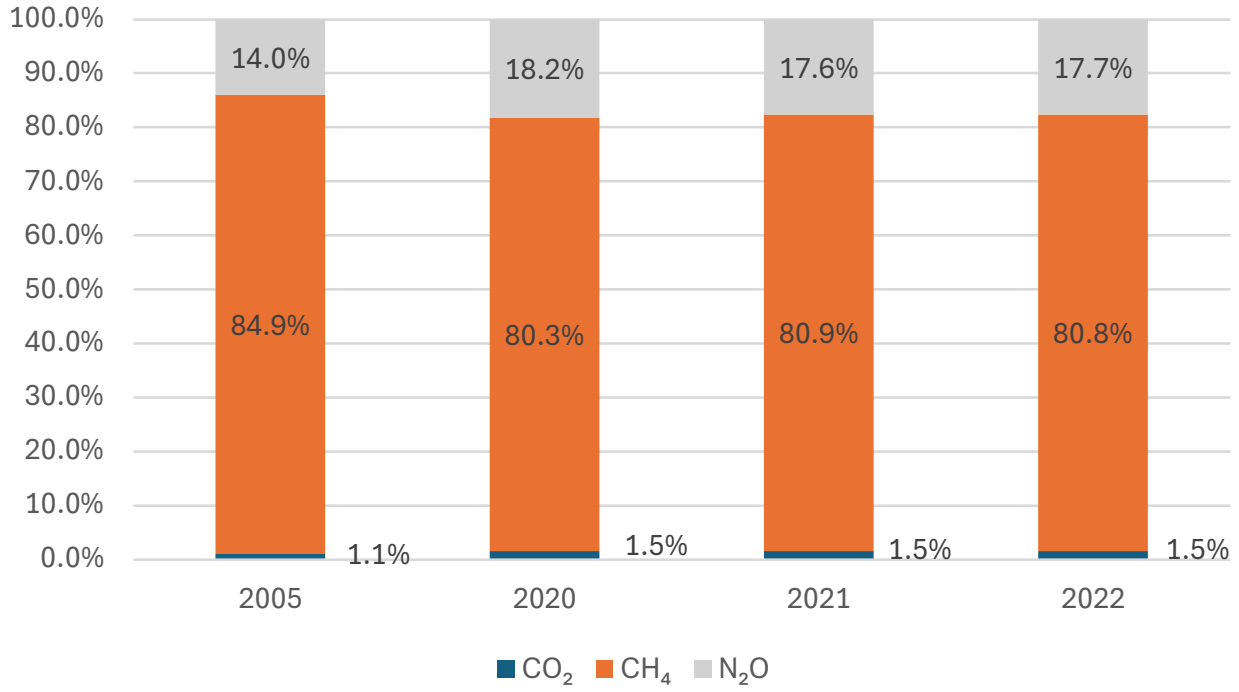


Figure 5.1 Share (%) from the agriculture sector by gas

Table 5.1 highlights that Category 3A 'Enteric Fermentation' is the largest source of CH_4 emissions within the agriculture sector, contributing 62.4% in 2005 and gradually declining to 58.9% in 2022. This is followed by Category 3C 'Rice Cultivation', which contributed between 19.9% and 19.2% of CH_4 emissions across the same years. For N_2O emissions, the primary source is Category 3D 'Agricultural Soils', accounting for 11.9% of total agricultural emissions in 2005 and increasing to around 15.7% by 2022. In the case of carbon dioxide (CO_2), Category 3H 'Urea Application' is the most significant contributor, with a relatively smaller but consistent share ranging from 1.1% in 2005 to 1.5% in 2020–2022.

Table 5.1 Percent share of GHG emissions from different sub-categories (gas-wise) from agriculture sector (2005,2020,2021 and 2022)

	2005 (% Share)			2020 (% Share)			2021 (% Share)			2022 (% Share)		
Category	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
3A	0.0	62.4	0.0	0.0	59.6	0.0	0.0	59.4	0.0	0.0	58.9	0.0
3B	0.0	1.1	1.7	0.0	1.0	1.6	0.0	1.0	1.6	0.0	1.0	1.6
3C	0.0	19.9	0.0	0.0	18.1	0.0	0.0	19.0	0.0	0.0	19.2	0.0
3D	0.0	0.0	11.9	0.0	0.0	16.2	0.0	0.0	15.6	0.0	0.0	15.7
3F	0.0	1.5	0.4	0.0	1.6	0.4	0.0	1.5	0.4	0.0	1.6	0.4
3H	1.1	0.0	0.0	1.5	0.0	0.0	1.5	0.0	0.0	1.5	0.0	0.0

Table 5.2 Total direct GHG emissions from different sub-categories from agriculture sector (2005, 2020, 2021 and 2022) in Gg CO_2e

Year	3A	3B	3C	3D	3F	3H
2005	276657.6	12582.5	88404.9	52974.8	8037.4	4785.7
2020	296843.0	13025.4	90300.3	80728.5	9748	7610.6
2021	298435.8	13057.9	95252.9	78584.2	9664.9	7582.9
2022	300170.2	13099.3	97920.0	80052.4	10450.6	7746.2

Enteric fermentation remained the dominant source of greenhouse gas emissions in the agriculture sector, contributing approximately 62.4% in 2005, 59.6% in 2020, 59.4% in 2021 gradually declining to 58.9% in 2022. Rice paddy cultivation was the second largest contributor, accounting for around 19.9% of emissions in 2005, 18.1% in 2020, 19% in 2021 and 19.2% during 2022 (Figure 5.2). Emissions from agricultural soils followed as the next significant source. Other sub-categories, including manure management, crop residue burning, and urea application to soils, contributed relatively smaller shares to the sector's overall emissions. The CO_2-e emissions from agriculture, by sub-sector, in the year 2005, 2020–2022 are shown in table 5.2.

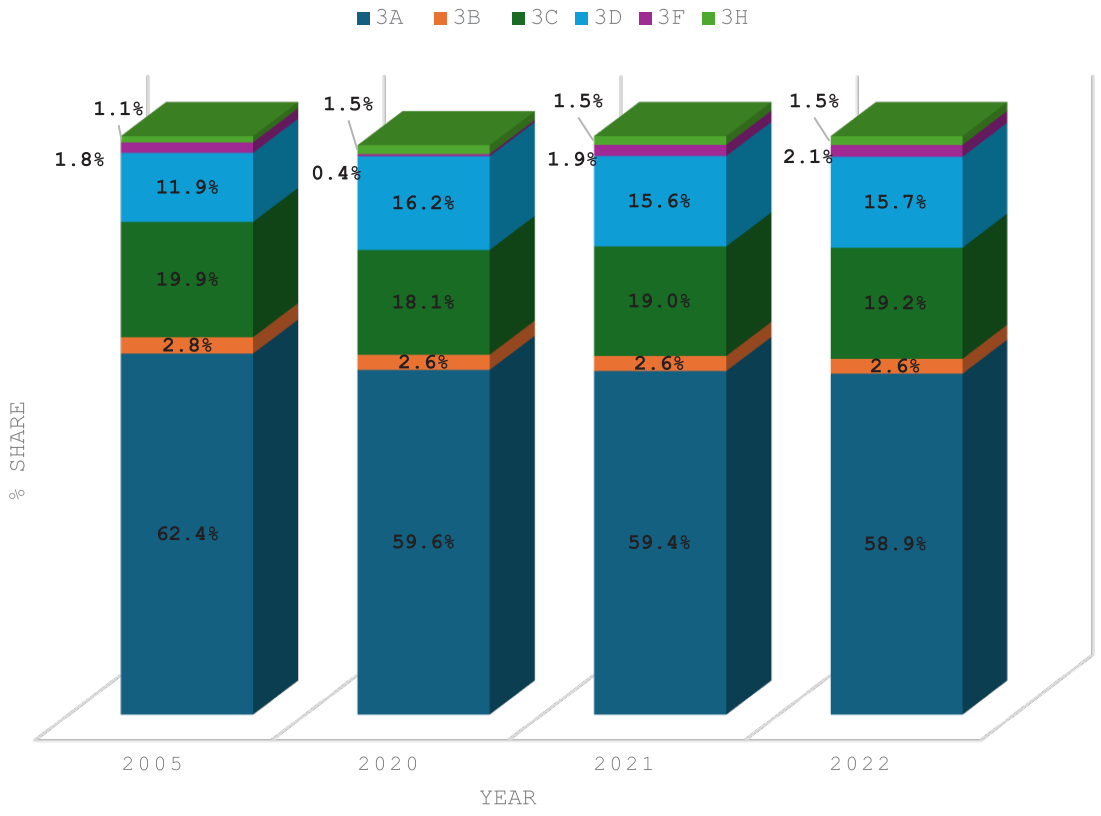


Figure 5.2 Share of direct GHG emissions from different sub-categories of agriculture sector (2005,2020,2021 and 2022)

Table 5.3 Key categories identified under agriculture sector

IPCC Category	Source category	GHG	Key Category
3.A Enteric Fermentation	3.A.1 Cattle	CH_4	Yes
	3.A.2 Sheep	CH_4	No
	3.A.3 Swine	CH_4	No
	3.A.4 Other Livestock	CH_4	Yes
3.B Manure Management	3.B.1 Cattle	CH_4, N_2O	No
	3.B.2 Sheep	CH_4, N_2O	No
	3.B.3 Swine	CH_4, N_2O	No
	3.B.4 Other Livestock	CH_4, N_2O	No
3.C. Rice cultivation	3.C.1 Irrigated	CH_4	Yes
	3.C.2 Rain-fed	CH_4	No
	3.C.3 Deep Water	CH_4	No
	3.C.4 Other	CH_4	No
3.D. Agricultural Soils	3.D.1 Direct N_2O emissions	N_2O	Yes
	3.D.2 Indirect N_2O emissions	N_2O	No
3.F Field Buning of Agricultural residue	3.F.1 Cereals	CH_4, N_2O	No
	3.F.4 Sugarcane	CH_4, N_2O	No
	3.F.5 Other	CH_4, N_2O	No
3.H Urea Application		CO_2	No

Methodological Tiers

Emissions from Category 3A 'Enteric Fermentation', 3B 'Manure Management', and 3F 'Field Burning of Agricultural Residue' were estimated using a combination of Tier 1 and Tier 2 approaches, applying both default and country-specific EFs. For Category 3C 'Rice Cultivation' and 3D 'Agricultural Soils', which are key categories, Tier 2 methodology was employed, utilizing country-specific EFs to enhance accuracy. While emissions from Category 3H 'Urea Application' were estimated using the Tier 1 approach with emission factors developed for National conditions based of Kim et.al. 2016 and 2017 as provided in IPCC EFDB. A summary description of the methods used in the estimation of emissions by category is provided in Table 5.4, whereas a more detailed description is available in subchapters of this Report.

Table 5.4 Summary of methods and emission factors used to estimate the agriculture sector emissions

Greenhouse Gas Categories	CO_2		CH_4		N_2O	
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
3.A. Enteric fermentation			T1/T2	D, CS		
3.B. Manure management			T1/T2	D, CS	T1/T2	D
3.C. Rice cultivation			T2	CS		
3.D. Agricultural soils					T2	CS
3.F. Field burning of agricultural residues			T1/T2	D, CS	T1/T2	D, CS
3.H. Urea application to soils	T2	D				

T1- Tier 1, T2- Tier 2, D- Default, CS- Country specific

Uncertainties and Time-Series Consistency

Results of uncertainty analysis of GHG emissions from Sector 3 'Agriculture' are described within this chapter and details are provided in table 1.4.

Quality Assurance and Quality Control

As part of the Tier 1 and Tier 2 methodological approach, standard verification and quality control checklists were completed for Agriculture sector. The activity data (AD) and methodologies used for estimating GHG emissionsin this sector were thoroughly documented and archived in both physical and digital formats. To identify potential errors in data entry and the emission estimation process, verification and quality control procedures were implemented. In line with the recommendations of the 2006 IPCC Guidelines, the estimates were based on activity data and nationally relevant emission factors and parameters sourced from official reference materials and published peer reviewed literature.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Assessment of Completeness

The current national inventory of India covers GHG emissions from 7 source categories: 'Enteric Fermentation (3A)', 'Manure Management (3B)', 'Rice Cultivation (3C)', 'Agricultural Soils (3D)', 'Field burning of agricultural residues (3F)' and 'Urea Application (3H)' (Table 5.5).

Table 5.5 Assessment of Completeness of GHG emissions from sector 3 Agriculture

IPCC Category	Source Category	CO_2	CH_4	N_2O
3A	Enteric Fermentation		X	
3B	Manure Management		X	X
3C	Rice Cultivation		X	
3D	Agricultural Soils		NO	X
3E	Prescribed Burning of Savannas		NO	NO
3F	Field burning of agricultural residues		X	X
3G	Liming	NE		
3H	Urea Application	X		
3I	Other Carbon-Containing Fertilizers	NO		
3J	Other	NO	NO	NO
X- source categories included in the inventory, NA- Not Application, NE- Not estimated, NO- Not Occurring				

Since, there are no savannas in India, no GHG emissions have been recorded from category 3E 'Prescribed Burning of Savannas' and Not Occurring (NO) notation key is used. In category 3.G, CO_2 emissions from the application of limestone to soils are reported as "Not Estimated" (NE), as disaggregated data on lime application could not be collected due to constraints related to limited resources and technical capacity. In category 3I, no other carbon containing fertilisers are used in India, no GHG emissionshave been recorded from this category.

Planned Improvements

Planned improvements at source category level under Agriculture sector are mentioned in the respective subchapters of this Report.

5.2. Enteric fermentation (CRT 3.A)

Category description and background

Ruminants such as cattle, buffalo, sheep, goats, mithun & yak have multi-chamber stomachs (rumen, reticulum, omasum, abomasum) converting complex feedstocks and biomass into food products by ruminants viz., milk and meat. The anaerobic fermentation by bacteria in the rumen of these animals converts cellulose and other fibrous substances into simple fatty acids, CO_2 and CH_4. Horses, mules & ass and swine are not ruminants and have monogastric stomachs, but fermentations in their hind guts produce a small amount of CH_4, which is released into the atmosphere either via belching and exhalation by the animals or fart. Ruminants (cattle, buffalo, sheep, goats) are the primary contributors to CH_4 emissions under Category 3A, though non-ruminants (pigs, horses, asses, mules) also contribute. Quantity of CH_4 emissions vary based on species, age, weight of the animal, and quality and quantity of feed intake etc.

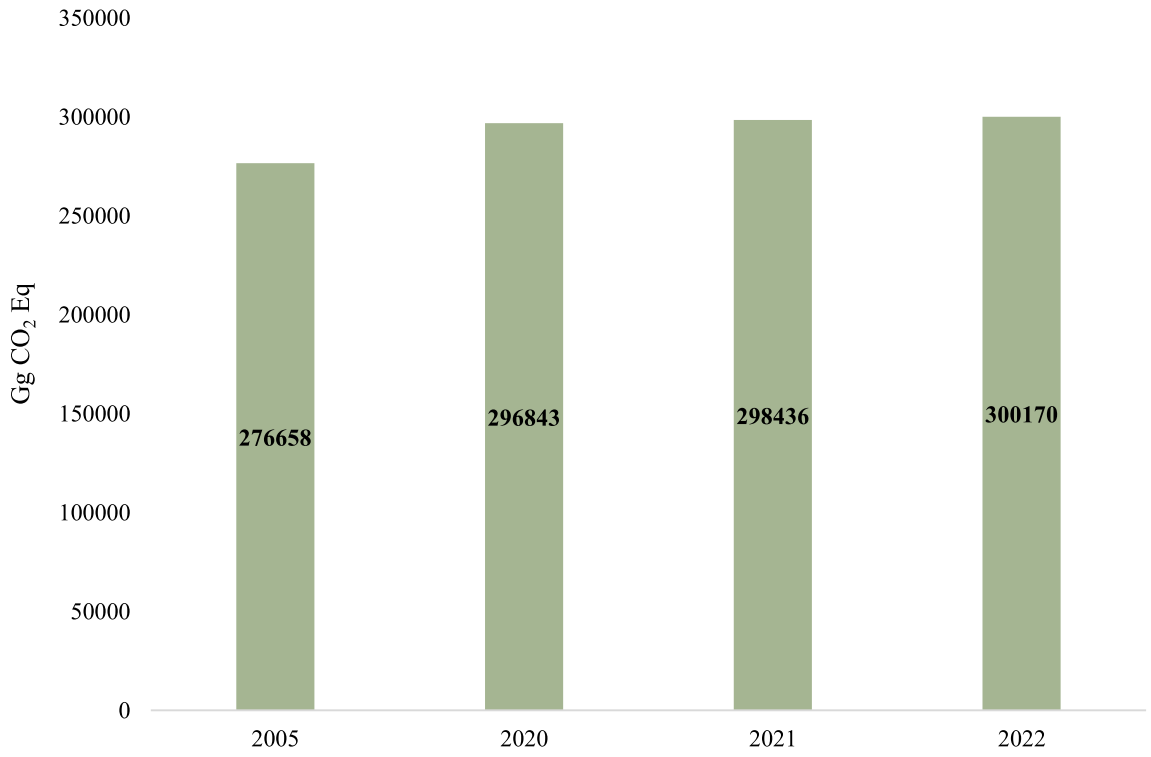


Figure 5.3 GHG emissions from Enteric fermentation (CRT 3.A) in 2005, 2020-2022

Methodological issues

Methane (CH_4) emissions from enteric fermentation in livestock are estimated following the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Vol. 4, Agriculture, Forestry and Other Land Use). The methodology applied varies by animal type, based on data availability and the significance of emissions. Tier 2 methods are used where detailed country-specific data are available. Here, the emission factors are calculated by multiplying the average gross energy intake of mature dairy cattle by the average CH_4 conversion factor (Ym). The average CH_4 conversion factor (Ym) is country specific which provides more accurate results. For Tier 1 methods default emission factors from IPCC 2006 guidelines are applied.

The emission was calculated by multiplying the cattle population by the emission factors.

E=(EF*A)

E: CH_4 emissions from enteric fermentation for cattle [kg-CH_4/yr]

EF: CH_4 emission factor of enteric fermentation of cattle [kg-CH_4 /head/yr.]

A: Population of cattle [head]

India uses livestock population data from the 20th Livestock Census (2019) conducted by the Department of Animal Husbandry and Dairying (DAD&F) (Ministry of Fisheries, Animal Husbandry & Dairying, 2019and 2017), Ministry of Agriculture and Farmers Welfare (MoAFW), Government of India. For the years 2020, 2021, and 2022, livestock populations are estimated using annualized growth rates derived from the 2012 and 2019 livestock censuses. Total livestock and poultry population in different years is shown in table 5.6.

Table 5.6 Livestock and poultry population (x 1000 heads) during the years (2005, 2020, 2021, and 2022)

Livestock Population	2005	2020	2021	2022
Cattle	189046	192752	192984	193215
Buffalo	100689	110014	110160	110331
Sheep	64825	75561	76885	78213
Goat	125197	150842	152815	154774
Swine	12771	8819	8623	8437
Others (Camels, Mules & Assess, Horse and Mithun & Yak)	2286	1179	1116	1042
Total	494814	539167	542583	546012
Poultry	246244	365986	373359	380733

In the Indian context, cattle are categorized as crossbred and indigenous, with population data available separately for males and females within each group. These are further divided into age groups based on maturity and production characteristics. Similar classification is applied to other livestock species to ensure accurate enumeration and effective implementation of livestock development programs.

For reporting emissions from enteric fermentation (3.A) and manure management (3.B) under the Common Reporting Format (CRT), Option B was selected, given India's availability of disaggregated livestock data. This detailed data was aggregated as per CRT requirements. The assumptions used to classify animals into various categories are outlined in Table 5.7. Growing crossbred and indigenous cattle and buffaloes were grouped under "growing cattle," while mature animals, whether lactating or dry, were included in the "mature" category. Similar classification principles were applied to other livestock types.

NA notation key is used for Dairy cattle and Non dairy cattle as India has detailed categorization of animals in the livestock census, so, cattle have been classified into mature, other mature and growing cattle. Again, NA is for sub categories Deer, Rabbit, Reindeer, Ostrich, fur-bearing animals also we don't have the classification in the census data. This is due to the insignificant or unavailability of the above mentioned animals in the country. In swine, horse, mules and camels- NA notation key used as IPCC default factor for GE intake and emission factor lacks of Indian specific data.

Table 5.7 Categorization and assumptions underlying calculation of CH_4 emissions associated with enteric fermentation in livestock.

IPCC Classification (Option B)	Livestock category in India		Additional information
Growing cattle	Crossbreed	Under 1 year male Under 1 year female 1 to 2.5 years female	Male and female group till 3 years of age
	Indigenous	Under 1 year male Under 1 year female 1 to 3 years female	
Mature Dairy cattle	Crossbreed	Over 2.5 yrs. lactating female Over 2.5 yrs. dry female	Lactating and dry animals only considered
	Indigenous	Over 3 yrs. lactating female Over 3 yrs. dry female	

IPCC Classification (Option B)	Livestock category in India		Additional information
Other mature cattle	Crossbreed	1 to 2.5 years male Breeding male Working male Breeding + working male Others male Heifer Female Other Female	Rest of the animals do not come under above two groups of indigenous and crossbred categorized on this group.
	Indigenous	1 to 3 years male Breeding male Working male Breeding + working male Other male Heifer Female Other female	
Growing Buffalo		Under 1 year male Under 1 year female 1 to 3 years female	Male and female up to 3 years age
Mature dairy Buffalo		Lactating female Dry female	Lactating and dry animal only considered
Other Mature buffalo		1 to 3 years male Breeding male Working male Breeding + working male Others male Heifer female Others female	Rest of the animals not comes under above two groups of indigenous and crossbred categorized on this group.
Sheep	Growing sheep Mature sheep	Up to 1 year 1 year and above	Growing or mature animals
Goat	Kids	Under 1 year male & female	Growing and as per their utility for breeding purposes
	Bucks	Over 1 year male	
	Mature Does	Lactating female Others female	
Horse		Under 3 years 3 years and above	Growing or mature animals
Donkeys and mules		Under 3 years 3 years and above	Growing or mature animals
Camels		Under 4 years 4 years and above	Growing or mature animals
Pigs		Under 6 months 6 months and above	Growing or mature animals
Others	Yak	Under 3 years 3 years and above	Growing or mature animals
	Mithun	Under 4 years 4 years and above	Growing or mature animals
Poultry	Broilers, layers, ducks, turkeys	Commercial and backyard	-

Description of methodological approach, activity data and emission factors used for each sub-category is provided in table 5.8.

Table 5.8 Details of enteric fermentation categories

IPCC Category	Source Category	Methodological approach	Activity data	Emission Factor
3.A.1.a.i	Mature dairy cattle	Tier 2	Population data from the 2019 Livestock Census; future years projected using growth rates from 2012–2019.	Estimated by multiplying average gross energy intake by country-specific Ym values.
3.A.1.a.ii	Other mature cattle	Tier 2	Based on livestock census and categorized by age and sex	Estimated by multiplying average gross energy intake by country-specific Ym values.
3.A.1.a.iii	Growing cattle	Tier 2	Population data from the 2019 Livestock Census; future years projected using growth rates from 2012–2019.	Estimated by multiplying average gross energy intake by country-specific Ym values.
3.A.2	Sheep	Tier 2	Derived from livestock census	Estimated by multiplying average gross energy intake by country-specific Ym values.
3.A.3	Swine	Tier 1	Derived from livestock census	Default IPCC 2006 Guidelines EF
3.A.4.a	Buffalo	Tier 2	Derived from livestock census and categorized into mature, growing and other mature buffalo	Estimated by multiplying average gross energy intake by country-specific Ym values.
3.A.4.b	Camel	Tier 1	Derived from livestock census	Default IPCC 2006 Guidelines EF
3.A.4.d	Goats	Tier 2	Derived from livestock census with separate accounting for kids, bucks, and mature does	Estimated by multiplying average gross energy intake by country-specific Ym values.
3.A.4.e	Horses	Tier 1	Derived from livestock census	Default IPCC 2006 Guidelines EF
3.A.4.f	Mules and Asses	Tier 1	Derived from livestock census	Default IPCC 2006 Guidelines EF
3.A.4.g	Poultry	Enteric methane emissions from poultry have not been estimated for India, as the 2006 IPCC Guidelines do not provide emission factors for poultry, and country-specific data on this aspect is also unavailable.		
3.A.4.h.v	Other (Mithun, Yak)	Tier 2	Derived from livestock census	Estimated using body weight comparable to mature cattle. by multiplying average gross energy intake by country-specific Ym values.

CH_4 emissions from the above-mentioned categories are provided in the table 5.9.

Table 5.9 Total CH_4 emissions from different sub-categories of 3A 'Enteric Fermentation

Category	Total CH_4 emissions (Gg)			
	2005	2020	2021	2022
Mature dairy cattle (3.A.1.a.i)	2195.74	2773.64	2808.64	2843.61
Other mature cattle (3.A.1.a.ii)	2484.24	2555.77	2612.43	2669.10
Growing cattle (3.A.1.a.iii)	806.68	588.44	550.29	512.13
Sheep (3.A.2)	270.29	310.17	315.48	320.80
Swine (3.A.3)	12.77	8.82	8.62	8.44

Category	Total CH_4 emissions (Gg)			
	2005	2020	2021	2022
Buffalo (3.A.4.a)	3506.11	3671.75	3663.12	3659.75
Camel (3.A.4.b)	27.19	7.31	5.80	4.42
Goats (3.A.4.d)	547.81	662.83	671.35	679.81
Horses (3.A.4.e)	11.74	5.51	5.42	5
Mules and Asses (3.A.4.f)	6.99	2.56	2.21	1.89
Other (Mithun, Yak) (3.A.4.h.v)	11.07	14.74	15.06	15.41

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

The uncertainties in estimating methane emissions from enteric fermentation arise from both the livestock population data and the emission factors applied. As both Tier 1 and 2 methodological approaches have been used, the uncertainties depend on the how accurately the characteristics of basic categories of livestock have been applied and the extent to which the calculation methods and coefficients used on the different equations used to calculate the emission factors. Details on the uncertainty pertaining to the activity data and emission factor is provided in Table 1.4.

QA/QC and verification

As part of the Tier 1 and Tier 2 methodological approach, standard verification and quality control checklists were completed for 3A 'Enteric Fermentation'. The AD and methodologies used for estimating GHG emissionsfor 3A were thoroughly documented and archived in both physical and digital formats. To identify potential errors in data entry and the emission estimation process, verification and quality control procedures were implemented. In line with the recommendations of the 2006 IPCC Guidelines, the estimates were based on AD and nationally relevant EFs and parameters sourced from official reference materials such as National Livestock Census etc.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

5.3. Manure management (CRT 3.B)

Category description and background

Methane (CH_4) emissions from manure management arise primarily from the anaerobic decomposition of organic matter present in livestock manure. This process is driven by methanogenic bacteria under anaerobic conditions, with the quantity of methane produced being influenced by several factors, including livestock type, manure management systems, and prevailing environmental conditions such as temperature and humidity.

Under Indian context, ruminant animals such as cattle and buffalo contribute significantly to methane emissions from manure management. Manure of ruminants is managed different ways: (i) solid storage (ii) pasture, range and paddock (iv) cake, (v) others including construction, flooring and composting. Dung cakes are used for household fuel, construction material (e.g., flooring, construction of wall/additive for brick making), and (vi) anaerobic digestion for biogas production.

Methane emissions are more pronounced when manure is stored or treated in liquid systems (e.g., anaerobic lagoons or pits), where decomposition occurs under anaerobic conditions. In contrast, when manure is stored as solid piles or deposited directly on land (e.g., during grazing), it tends to decompose under aerobic conditions, leading to relatively lower methane emissions. For estimating CH_4 emissions under this category, livestock populations were disaggregated into subgroups reflecting differences in manure production and management practices across animal types. Emission estimates were derived using a combination of country-specific emission factors and default IPCC 2006 emission factors. The methodological approach follows the IPCC 2006 Guidelines, applying Tier 2 methods where country-specific data are available and Tier 1 methods otherwise.

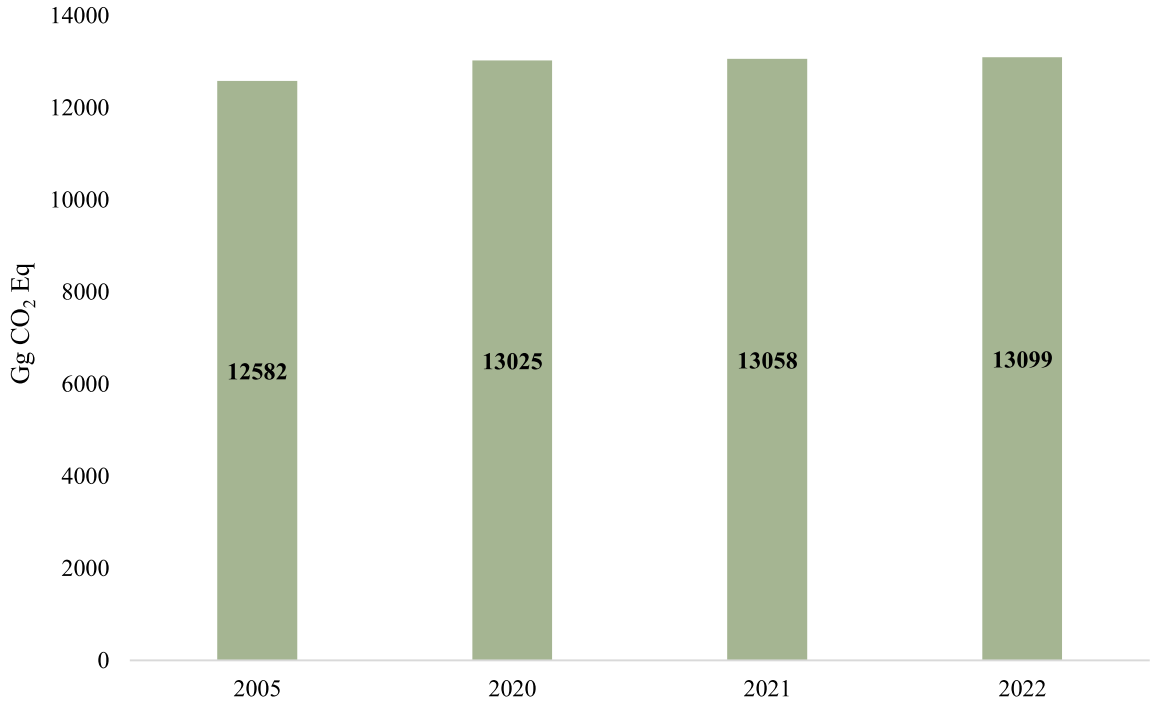


Figure 5.4 GHG emissions from Manure management (3.B.) in 2005, 2020-2022

Methodological issues

Methane emissions from manure management are estimated using the Tier 2 approach as per the 2006 IPCC Guidelines *(Volume 4, Chapter 10)*, incorporating both country-specific data and default emission factors. Country-specific information includes the distribution of animals across climatic zones (temperate and warm), manure management systems, and average volatile solid (VS) excretion rates (Table 5.4). IPCC default values are used for the methane conversion factor (MCF) and methane production potential (Bo).

The general formula used to estimate emissions is:

$EF = VS \times 365 \times Bo \times 0.67 \times MCF$

Where:

EF = Emission factor (kg CH_4/head/year)

VS = Average daily volatile solids excretion (kg DM/head/day)

Bo = Methane production potential (m^3 CH_4/kg VS)

MCF = Average methane conversion factor (%)

0.67 = Conversion factor from m^3 CH_4 to kg CH_4

Total methane emissions are then derived by multiplying the emission factor (EF) with the annual livestock population for each category.

Table 5.10 Daily volatile solid excreted (VS) calculated for 2005,2020,2021 and 2022, kg dry matter/day

IPCC Category	Source Category	2005	2020	2021	2022
3.B.1.a.i	Mature dairy cattle	2.38	2.38	2.38	2.38
3.B.1.a.ii	Other mature cattle	1.79	1.79	1.79	1.79
3.B.1.a.iii	Growing cattle	1.02	1.02	1.02	1.02
3.B.2.a.1	Growing Sheep	0.25	0.25	0.25	0.25
3.B.2.a.2	Mature Sheep	0.34	0.34	0.34	0.34
3.B.3	Swine	0.58	0.58	0.58	0.58
3.B.4.a.1	Mature Buffalo	3.46	3.46	3.46	3.46
3.B.4.a.2	Growing Buffalo	1.25	1.25	1.26	1.25
3.B.4.a.3	Other mature Buffalo	2.61	2.36	2.61	2.61
3.B.4.b	Camel	NA	NA	NA	NA
3.B.4.d.1	Kids	0.22	0.22	0.22	0.22
3.B.4.d.2	Bucks	0.21	0.21	0.21	0.21
3.B.4.d.3	Mature Does	0.28	0.28	0.28	0.28
3.B.4.e	Horses	NA	NA	NA	NA
3.B.4.f	Mules and Asses	NA	NA	NA	NA
3.B.4.g	Poultry	NA	NA	NA	NA
3.B.4.h.v	Other (Mithun, Yak)	1.79	1.79	1.79	1.79

Description of methodological approach, activity data and emission factors used for each sub-category is provided in table 5.11.

Table 5.11 Details of the manure management category

IPCC Category	Source Category	Methodological approach	Activity data	Emission Factor
3.B.1.a.i	Mature dairy cattle	Tier 2	Population data from the 2019 Livestock Census; future years projected using growth rates from 2012–2019.	Country-specific data include VS excretion, manure distribution among four application types, and zone classification (temperate/ warm). Bo and MCF values were taken from IPCC 2006 (Tables 10.14 and 10.15)
3.B.1.a.ii	Other mature cattle	Tier 2	Based on livestock census and categorized by age and sex	Country-specific data include VS excretion, manure distribution among four application types, and zone classification (temperate/ warm). Bo and MCF values were taken from IPCC 2006 (Tables 10.14 and 10.15).
3.B.1.a.iii	Growing cattle	Tier 2	Population data from the 2019 Livestock Census; future years projected using growth rates from 2012–2019.	Country-specific data include VS excretion, manure distribution among four application types, and zone classification (temperate/ warm). Bo and MCF values were taken from IPCC 2006 (Tables 10.14 and 10.15)
3.B.2	Sheep	Tier 2	Derived from livestock census	Country-specific data include VS excretion, manure distribution among four application types, and zone classification (temperate/ warm). Bo and MCF values were taken from IPCC 2006 (Tables 10.14 and 10.15).

IPCC Category	Source Category	Methodological approach	Activity data	Emission Factor
3.B.3	Swine	Tier 2	Derived from livestock census	Country-specific data include VS excretion, manure distribution among four application types, and zone classification (temperate/ warm). Bo and MCF values were taken from IPCC 2006 (Tables 10.14 and 10.15)
3.B.4.a	Buffalo	Tier 2	Derived from livestock census and categorized by age and sex	Country-specific data include VS excretion, manure distribution among four application types, and zone classification (temperate/ warm). Bo and MCF values were taken from IPCC 2006 (Tables 10.14 and 10.15).
3.B.4.b	Camel	Tier 1	Derived from livestock census	Emission estimation was done using country-specific distribution and manure practices. Emission factor was derived from the average of IPCC default values for temperate and warm zones (Table 10.14 and 10.16).
3.B.4.d	Goats	Tier 2	Derived from livestock census with separate accounting for kids, bucks, and mature does	Country-specific data include VS excretion, manure distribution among four application types, and zone classification (temperate/ warm). Bo and MCF values were taken from IPCC 2006 (Tables 10.14 and 10.15).
3.B.4.e	Horses	Tier 1	Derived from livestock census	Methane emissions were calculated using country-specific livestock and manure data with IPCC default EF averages from temperate and warm zones
3.B.4.f	Mules and Asses	Tier 1	Derived from livestock census	Methane emissions were calculated using country-specific livestock and manure data with IPCC default EF averages from temperate and warm zones
3.B.4.g	Poultry	Tier 1	Derived from livestock census	Methane emissions from poultry manure were estimated using IPCC default EF values specific to developing countries (Table 10.15), with animal distribution across climatic zones considered.
3.B.4.h.v	Other (Mithun, Yak)	Tier 2	Derived from livestock census	Country-specific data include VS excretion, manure distribution among four application types, and zone classification (temperate/ warm). Bo and MCF values were taken from IPCC 2006 (Tables 10.14 and 10.15).

CH_4 emissions from the above-mentioned categories are provided in the table 5.12. NA notation key used for cool region as no Indian states the cool category. NA notation key is for sub categories Deer, Rabbit, Reindeer, Ostrich, fur-bearing animals. This is due to the insignificant or unavailability of the above mentioned animals in the country. NA used for horse, mules, poultry and camel Bo and VS as we are lacking in these Indian specific data

For nitrous oxide from manure management from Indian livestock , anaerobic lagoon, liquid system, daily spread , pit storage, dry lot and deep bedding is not practiced or even its practiced, no data is available, hence NA notation

key used. Manure of a particular species is used for specific purpose i.e., either PRP or solid storage or others, hence, NA used to mention that particular field in the CRT. Notation key IE used in nitrous oxide emission from camel, horse, mules, donkey and others (yak and mithun) as the manure from these animals are used either in PRP (agriculture / crop production) or burned for fuel (energy sector)

Table 5.12 Total CH_4 emissions from different sub-categories of 3B 'Manure Management'

Category	Total CH_4 emissions (Gg)			
	2005	2020	2021	2022
Mature dairy cattle (3.A.1.a.i)	39.56	49.97	50.60	51.23
Other mature cattle (3.A.1.a.ii)	38.62	39.74	40.62	41.50
Growing cattle (3.A.1.a.iii)	14.93	10.89	10.18	9.48
Sheep (3.A.2)	2.31	2.65	2.69	2.74
Swine (3.A.3)	4.83	3.33	3.26	3.19
Buffalo (3.A.4.a)	70.28	72.83	72.59	72.48
Camel (3.A.4.b)	0.27	0.07	0.06	0.04
Goats (3.A.4.d)	3.64	4.40	4.46	4.51
Horses (3.A.4.e)	0.26	0.12	0.12	0.11
Mules and Asses (3.A.4.f)	0.15	0.05	0.05	0.04
Poultry (3.B.4.g)	0.005	0.007	0.008	0.008
Other (Mithun, Yak) (3.A.4.h.v)	0.17	0.23	0.23	0.24

Nitrous oxide (N_2O) emissions from livestock manure result from microbial nitrification and denitrification processes acting on nitrogen compounds within the manure. The magnitude of these emissions is primarily determined by the total nitrogen excreted, which varies by animal species and diet composition, and is further influenced by the specific manure management system employed and prevailing environmental conditions.

Direct nitrous oxide emission from manure management was estimated using tier 1 approach and equation 10.31 of IPCC 2006 Guidelines (Chapter 10, Page number 10.58). Country specific values for the N excretion (Table 5.13) and application for different management practices while emission factors for direct nitrous oxide emission from different animal waste management systems were taken from IPCC 2006 guidelines. Nitrogen excretion for different categories of livestock was derived from following equation:

Nex(T,A) (kg d-1) = Ni(T,A)*(1-Nr(T,A))

Where;

Nex(T,A)= daily N excretion rates(kg N per animal per day),

Ni(T,A)=The daily N intake (kg d-1) per head of a category of T livestock species,

Nr(T,A)= Fraction for daily N intake that is retained by A category of T livestock species.

Table 5.13 Nitrogen excretion rate (Kg N/head/yr) across different animal species in India

Species	Nitrogen excretion rate (Kg N/head/yr)			
	2005	2020	2021	2022
Mature dairy cattle (3.B.1.a.i)	52.52	52.52	52.52	52.52
Other mature cattle (3.B.1.a.ii)	32.96	32.96	32.96	32.96
Growing cattle (3.B.1.a.iii)	18.98	18.98	18.98	18.98
Growing sheep (3.B.2.a.1)	7.11	7.11	7.11	7.11
Mature sheep (3.B.2.a.2)	13.08	13.08	13.08	13.08
Swine (3.B.3)	33.44	33.44	33.44	33.44
Mature dairy buffalo (3.B.4.a.1)	47.98	47.98	47.98	47.98
Growing buffalo (3.B.4.a.2)	12.68	12.68	12.68	12.68
Other mature buffalo (3.B.4.a.3)	41.17	41.17	41.17	41.17

Species	Nitrogen excretion rate (Kg N/head/yr)			
	2005	2020	2021	2022
Camels 3.B.4.b)	43.23	43.23	43.23	43.23
Kids (3.B.4.d.1)	18.43	18.43	18.43	18.43
Bucks (3.B.4.d.2)	19.51	19.51	19.51	19.51
Mature does (3.B.4.d.3)	25.75	25.75	25.75	25.75
Horses (3.B.4.e)	39.96	39.96	39.96	39.96
Mules and asses (3.B.4.f.1)	25.68	25.68	25.68	25.68
Poultry (3.B.4.g)	0.80811	0.80811	0.80811	0.80811
Others (Yak and mithun) (3.B.4.h.vi)	32.96	32.96	32.96	32.96

Intakes of N by cattle, buffalo, sheep, goat and swine species were calculated by from crude protein requirements for maintenance, growth, milk production and pregnancy *(Khan et al.,1988; Paul et al., 2002; Paul et al., 2003; Paul et al., 2007)*, respectively. N retention in milk was derived from milk production kg d-1 by cattle, buffaloes, and goats and the protein content in milk. Matured animals are assumed to be in zero N balance. The default values of N excretion by other livestock species were taken from IPCC 2006 guidelines *Table 10.19 Chapter 10 Page no 10.59*.

Nitrogen excretion (expressed in kg N per head per year) is a key determinant of nitrous oxide (N_2O) emissions from manure management, as it influences the pool of nitrogen available for microbial transformation processes such as nitrification and denitrification particularly under storage conditions conducive to such activity.

Over the reporting period, direct N_2O emissions from growing cattle declined from 2.481 kt in 2005 to 1.575 kt in 2022, likely due to reductions in population or changes in manure handling practices. In contrast, mature dairy cattle exhibited a notable increase in emissions, rising from 7.797 kt in 2005 to 10.097 kt in 2022, attributable to higher nitrogen excretion rates and possibly intensification of production systems. Other cattle categories, including mature indigenous breeds and buffaloes, also showed increasing trends in emissions. Specifically, mature dairy buffalo emissions increased from 5.694 kt in 2005 to 6.134 kt in 2022, while emissions from other mature buffaloes declined from 1.553 kt to 0.623 kt over the same period.

Small ruminants (sheep and goats), along with other species such as camels, horses, donkeys, and mules, contributed negligibly to direct N_2O emissions—likely due to lower nitrogen output and/or manure management systems that result in less N_2O generation. Swine emissions showed a slight decline, from 3.355 kt in 2005 to 2.217 kt in 2022, possibly due to changes in herd size or improved manure handling systems. Minor contributors like yaks and mithun had minimal impact on total emissions. Overall, direct N_2O emissions from manure management increased marginally, from 28.988 kt in 2005 to 29.824 kt in 2022.

The table 5.14 provides direct N_2O emissions from various livestock species during manure management for the years 2005, 2020, 2021, and 2022.

Table 5.14 Total nitrous oxide emission from manure management during 2005, 2020, 2021 and 2022

Species /Year	Direct N_2O emission (kt)			
	2005	2020	2021	2022
Growing cattle	2.481	1.810	1.693	1.575
Mature Dairy cattle	7.797	9.849	9.973	10.097
Other mature cattle	6.352	6.535	6.680	6.825
Growing Buffalo	1.204	1.630	1.660	1.679
Mature dairy Buffalo	5.694	6.130	6.132	6.134
Other Mature buffalo	1.553	0.752	0.671	0.623
Sheep	0.115	0.130	0.133	0.134
Goat Kids	0.132	0.171	0.176	0.180
Bucks	0.052	0.045	0.044	0.043
Mature Does	0.253	0.311	0.314	0.317
Horse	0	0	0	0

Species /Year	Direct N_2O emission (kt)			
	2005	2020	2021	2022
Donkeys and mules	0	0	0	0
Camels	0	0	0	0
Swine	3.355	2.317	2.266	2.217
Others (Yak and mithun)	0	0	0	0
Total livestock N_2O emission	28.988	29.680	29.742	29.824
Total Poultry N_2O emission	0.00000031	0.00000046	0.00000047	0.00000048

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

An uncertainty assessment was conducted by each manure management practice. The uncertainties for emission factors were calculated by finding the 95% confidence interval. The uncertainly range for the default factors for Tier 1 is estimated to be ±30% (IPCC 2006 Guidelines table 10.14 and 10.16). Improvements achieved by Tier 2 methodologies reduced uncertainty ranges in the emission factors to ±20%. .

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

5.4. Rice cultivation (CRT 3.C)

Category description and background

Methane emissions from rice cultivation constitute the second largest source category under India's agricultural emissions. Paddy fields, owing to their prolonged flooded and anaerobic conditions, create an ideal environment for methanogenesis, a microbial process driven by methanogenic archaea that decompose organic matter under oxygen-limited conditions.

In India, rice is cultivated during both Kharif (wet season, June-November) and Rabi seasons (dry season, Oct-Nov to Feb-March). While Kharif rice includes both irrigated and rainfed systems, Rabi rice cultivation is predominantly irrigation-dependent, except in regions receiving winter precipitation. The rice–rice cropping system, where rice is grown in both seasons, is practiced in certain regions. Notably, Kharif season accounts for approximately 65% of the country's total rice production.

Methane emissions vary depending on the water regime and type of rice ecosystem i.e. irrigated, rainfed, deepwater, and upland. In irrigated systems, continuous flooding or multiple aeration practices dominate,

influenced by the availability of irrigation and the soil's water-holding capacity. Rainfed systems, on the other hand, are more susceptible to drought due to unpredictable rainfall patterns.

The magnitude of CH_4 emissions is directly linked to the extent of rice area under different irrigation regimes, soil conditions, cropping duration, and management practices such as water control. While the addition of organic amendments (e.g., manure or crop residues) can significantly increase CH_4 emissions, such practices are not common in India. These residues are often diverted for alternate uses like fuel, fodder, or burned in the field. Due to the absence of national-level statistics and the limited adoption of organic amendments, they have not been accounted for in the current GHG inventory.

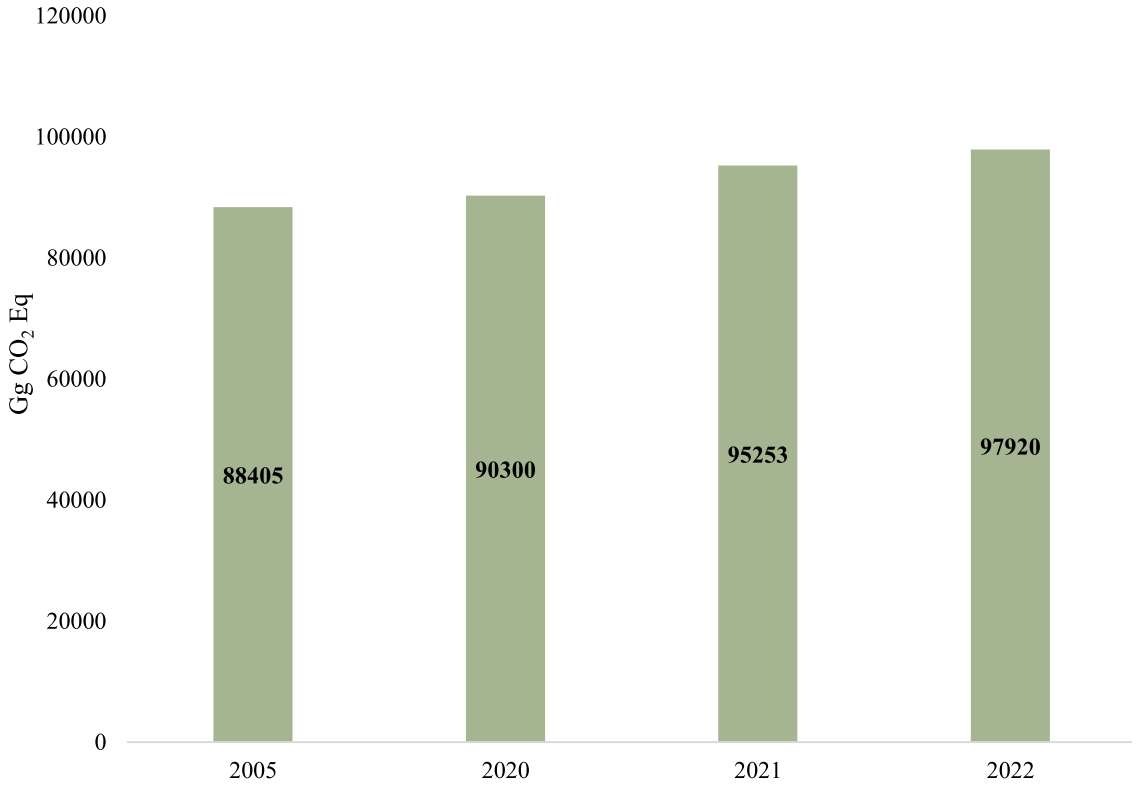


Figure 5.5 GHG emissions from Rice cultivation (3.C.) in 2005, 2020-2022

Description of rice under different regimes in India

5.4.1. Irrigated (3.C.1)

In India, paddy cultivation is not uniformly irrigated across all regions. The percentage of irrigated rice area in each state was obtained from Agricultural Statistics (MoAFW, 2022–23). The water regime in rice fields varies based on regional water availability and soil characteristics. Typically, transplanted puddled rice is grown under irrigated conditions, either through continuous flooding or intermittent irrigation (multiple aeration). While coarse-textured soils in the northwestern Indo-Gangetic Plains favor multiple aeration regimes, the finer clay soils of Eastern and Southern India often support continuous flooding; overall, irrigated rice area expanded from 56.5% in 2005 to 72.9% in 2022. Additionally, some upland rice areas that were previously rainfed now receive intermittent irrigation.

5.4.1.1. Continuously flooded (3.C.1.a)

In 2022, continuously flooded rice cultivation covered 11.34 million hectares in India, accounting for 23.9% of the total rice-growing area. In comparison, the continuously flooded area in 2005 was 9.51 million hectares *(SAC, 2009)*.

5.4.1.2. Intermittently flooded (3.C.1.a)

The intermittently flooded rice cultivation area in India is estimated at 23.25 million hectares. Midseason drainage is generally not practiced; instead, intermittent flooding occurs naturally due to the percolating nature of sandy soils, especially in the northwestern and central regions. Irrigation availability depends on both electricity supply and rainfall, which recharge groundwater and canal systems. The distribution of this water regime was determined using expert judgment, considering regional soil characteristics and local farming practices. Of the intermittently flooded area, 20.41% is under single aeration and 79.59% under multiple aeration.

5.4.2. Rainfed (3.C.2)

Rainfed rice cultivation in India relies primarily on summer and winter monsoon rainfall. In 2022, the total rainfed rice area was 9.8 million hectares, accounting for 20.7% of the country's total rice cultivated area. This area was further categorized into flood-prone (FP) and drought-prone (DP) zones. The classification for each rice-growing state was based on expert judgment, considering regional climate characteristics. These climate conditions were determined using agro-climatic zoning and regional precipitation patterns.

The flood prone area and drought prone area in the year 2022 was 36.23 % and 63.77% of the total rainfed area respectively.

5.4.3. Deepwater (3.C.3)

There is around 1.3-1.4 Mha of rice area under Deep water rice *(World Rice Statistics (IRRI, 2008))*. The deep-water rice area is around 3% of the total rice cultivated area in the country. The deep-water rice ecosystem may not be under deep water for the whole rice growing period, as it is dependent on rainfall and the water depth during the rice growing period lies in the category of >50 cm) *(NRRI, 2020)*. Very few studies have been reported methane emissions from deep water-rice cultivation. In order to provide representative emission factor, we considered observations from a report submitted by ICAR- National Rice research Institute, Cuttack, Odisha *(ICAR-NICRA, 2024)* for the emission factor of deep-water rice cultivation, with a scaling factor of 0.8.

Accordingly, methane emissions under Category 3C 'Rice Cultivation' in India are estimated based on rice grown under continuous flooding (encompassing both low- and non-low-emission varieties), intermittent flooding, and rainfed systems, in alignment with IPCC 2006 Guidelines and available national data.

The highest methane emissions were from continuous flooded rice field followed by multiple aeration water regime in the year 2022 (Table 5.15). The continuously flooded water regime contributed 49% of the total methane emissions in 2022 (Figure 5.6).

Table 5.15: Methane emission and CO_2 equivalents under different water regimes in rice ecosystems

Year	Area Mha	MA 000kg	SA 000kg	CF 000kg	DW 000kg	RF FP 000kg	RF DP 000kg	Total 000kg	GgCO_2 eq.
2005	43.2	257	348	1443	159	330	621	3157	88404.9
2020	45.2	428	364	1531	167	345	390	3225	90300.3
2021	46.2	437	371	1674	170	352	398	3402	95253.0
2022	47.4	449	382	1721	175	362	409	3497	97920.0

*MA- Multiple Aeration; SA: Single Aeration; CF: Continuously Flooded; DW: Deep water; RF FP: Rainfed Flood prone; RF DP: Rainfed Drought Prone

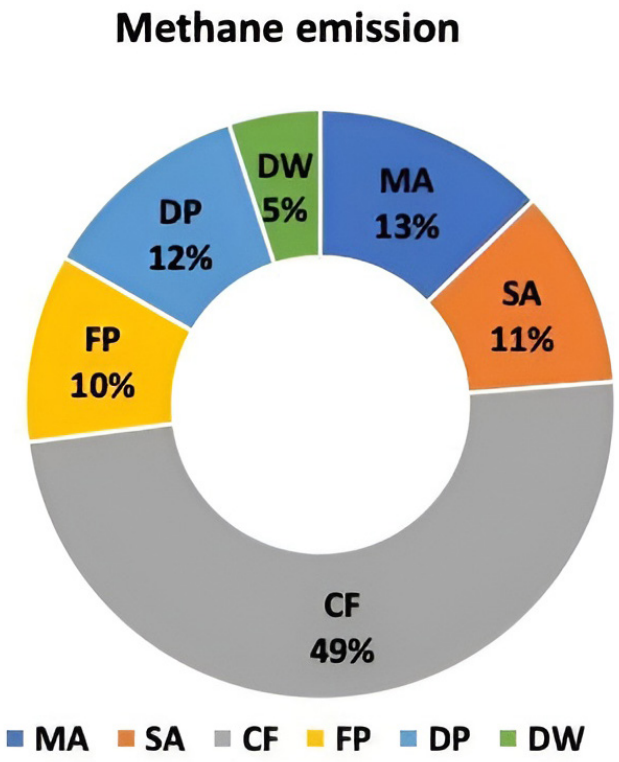


Figure 5.6 Methane emission under different water regimes in 2022

Methodological issues, activity data and emission factors

For methane emission estimation of category 3C 'Rice cultivation' in India, Tier 2 methodological approach is used. The equation 5.1 chapter 5, vol 4, of 2006 IPCC guidelines for national GHG inventories was used for estimating methane emission from rice cultivation using the following formula.

$$CH_4 \text{ Rice} = \sum_{i,j,k} (EF_{i,j,k} \cdot A_{i,j,k} \cdot 10{-}6 \cdot t)$$

Where:

CH_4 Rice = annual methane emissions from rice cultivation, Gg CH_4 yr-1

EFijk = a daily emission factor for i, j, and k conditions, kg CH_4 ha-1 day-1

t = cultivation period of rice, day

A_{ijk} = annual harvested area of rice for i, j, and k conditions, ha yr-1

i, j, and k = represent different rice ecosystems and water regimes types

The change in area under different rice ecosystems and water regimes from 2005 to 2022 is shown in figure 5.7. The rice area under different rice water regimes for the year 2022 is provided in figure 5.8.

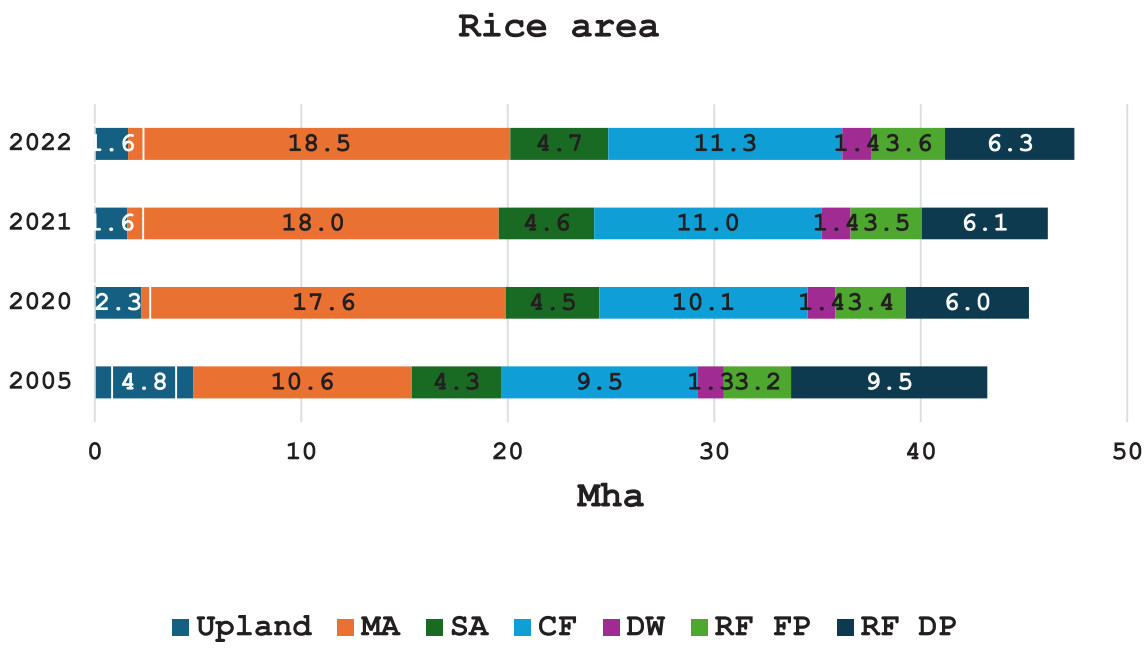


Figure 5.7 The change in rice area under different water regimes over the time series

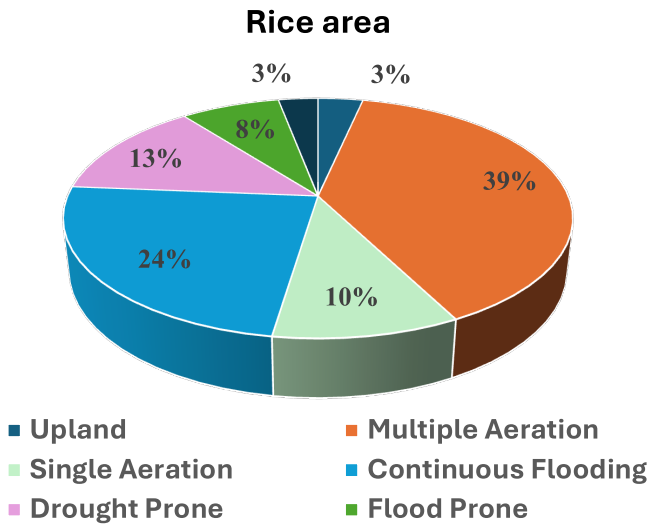


Figure 5.8 The distribution of rice area under different water regimes for 2022

The scaling factors for methane emission under the different water regimes is shown in Table 5.16.

Table 5.16 Scaling factors of methane emission coefficients for different rice ecosystems

Ecosystem	Water regime	Scaling factor
Irrigated	CF*	1
	SA	0.53
	MA	0.16
Rainfed	DP	0.43
	FP	0.67
Deep water	DW	0.81
Upland		0

*CF- Continuously flooded, SA- Single aeration, MA- Multiple aeration, DP – Drought prone, FP- flood prone, DW- Deep water

Methodological issues

Activity data

In India, rice is cultivated across four major water systems: irrigated, rainfed, deepwater, and upland. In irrigated systems, continuous flooding and multiple aeration practices are commonly observed, influenced by the availability of irrigation and the soil's water retention capacity. Rainfed systems, however, are more vulnerable to drought due to the unpredictability of rainfall. The use of organic amendments such as manure and crop residues in rice cultivation is uncommon, as these materials are typically used for other purposes like fuel or are burned on-farm. Due to the lack of statistical data and limited adoption, organic amendments have not been included in the current rice cultivation emissions inventory.

Based on the calculation method in the 2006 IPCC Guidelines, the emissions were estimated using country specific emission factors taken from peer reviewed published literature for different water regimes *(Gupta 2008, Adhya 2000, Pathak 2003, Bhatia 2005, Bhatia 2012, Jain et al 2016, Bhatia 2023, Cowan 2021, Bhattacharya 2013, Das 2014, Gogoi 2005, Deka 2024, MOEFCC project report)*. The measurements for the emission factors were conducted using the closed chamber technique from rice fields followed by Gas chromatographic analysis of methane in the collected samples.

The rice area under different water regimes was apportioned based on reports and peer reviewed publication *(NRRI, 2020; 2006; Hukes and Hukes 1997)*. The irrigated rice area in different rice growing states were divided into three water regimes of multiple aeration (MA), single aeration (SA) and continuous flooded (CF) using expert judgement based on the soil type, farmer cultivation practice of the region and peer reviewed literature. The maximum irrigated area was under multiple irrigation water regimes. This has resulted in a decrease in rainfed upland rice area in the country and increase in the irrigated rice area under multiple aeration, followed by rice area under continuous flooding (Figure 5.8).

NO notation key is used for water depth>100 cm, as cultivated area under this water regime is not significant in India.

Emission factor

The emission factor under different water regimes in the different rice ecosystems was obtained from methane emission studies published across the country under the different rice ecosystems and water regimes. There are many rice varieties cultivated in the country. The average rice crop duration in different rice growing regions varies from 120-130 days. The organic carbon content of the rice soils is much below 1%, averaging to 0.4-0.5% for the whole country. The rice soils in the north western part of the country have more sand content and have poor water holding capacity with organic carbon below 0.5%, whereas in the eastern and southern regions the clay content of soil is higher and the organic carbon content may vary from 0.5 to 0.8%.

The methane emission factors under continuous flooding were based on different peer reviewed literature *(Mitra et al., 1991, Gupta et al., 2008, Adhya et al., 2000, Bhatia et al., 2004; Bhatia et al., 2013; Jain et al 2014, Jain et al 2016, Cowan et al., 2021, Pathak 2003, Das et al., 2014, Deka et al., 2024)*. The methane emission factors for intermittent flooding (multiple aeration) were based on *(Bhatia et al., 2005, Jain et al., 2016, Bhatia et al., 2023, Adhya et al., 2000; Cowan et al., 2021)*. The methane emission factors under single aeration were based on *(Gupta et al., 2009; Government of India (GoI), 2024 report)*. The emission factors under rainfed water regime were compiled from *(Adhya et al., 2000; Bhattacharya et al., 2013; GoI 2024 report)*.

The daily emission factor of methane under CF was estimated to be 1.2 kg CH_4/ha/day. The scaling factors for the emission coefficients of methane emission under the different rice ecosystems are listed in Table 5.4.2 and the daily emission factor was adjusted accordingly for the different rice water regimes during the cultivation period as per the following equation

$EFi = EFc \bullet SFw$

Where

EFi = adjusted daily emission factor for rice harvested area

EFc = baseline emission factor for continuously flooded fields without organic amendments

SFw = scaling factor to account for the differences in water regime during the cultivation period. As organic amendment application to rice fields is not occurring in the country, the scaling factor for type and amount of

organic amendment applied was not considered for adjusting the daily emission factor. Due to non-availability of activity data of rice area harvested according to different cultivars and soil types, their scaling factors were also not considered for adjusting the daily methane emission factor.

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

As the national statistics does not give rice cultivated area under different water regimes, the uncertainty is based on expert judgement and was taken as 5%. The uncertainty in emission factors ranged from 23% for MA regime and 33% for CF water regime. Under rainfed water ecosystem, the uncertainty in EF was 17% for drought prone and 44% for flood prone water regime. Emissions are estimated by using consistent estimation methods and data sources.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

5.5. Agricultural soils (CRT 3.D)

Category description and background

Direct and indirect emissions of nitrous oxide from soils arise from microbial and chemical transformations that produce and consume nitrous oxide in the soil. The transformations involve inorganic nitrogen compounds in the soil, namely ammonium, nitrite and nitrate. This section provides the estimation methods for N_2O direct emissions from soils by applied inorganic N fertilizers, organic fertilizers, grazing livestock manure, crop residue, mineralization by soil carbon loss, and for indirect N_2O emissions by the processes of atmospheric deposition of volatilized NH_3 and NOx and leaching and run-off of mineral nitrogen from soils. The N_2O emissions were calculated by Tier 2 method, using country-specific emission factors in accordance with decision tree of the 2006 IPCC Guidelines (Vol. 4, p.11.9, Fig.11.2).

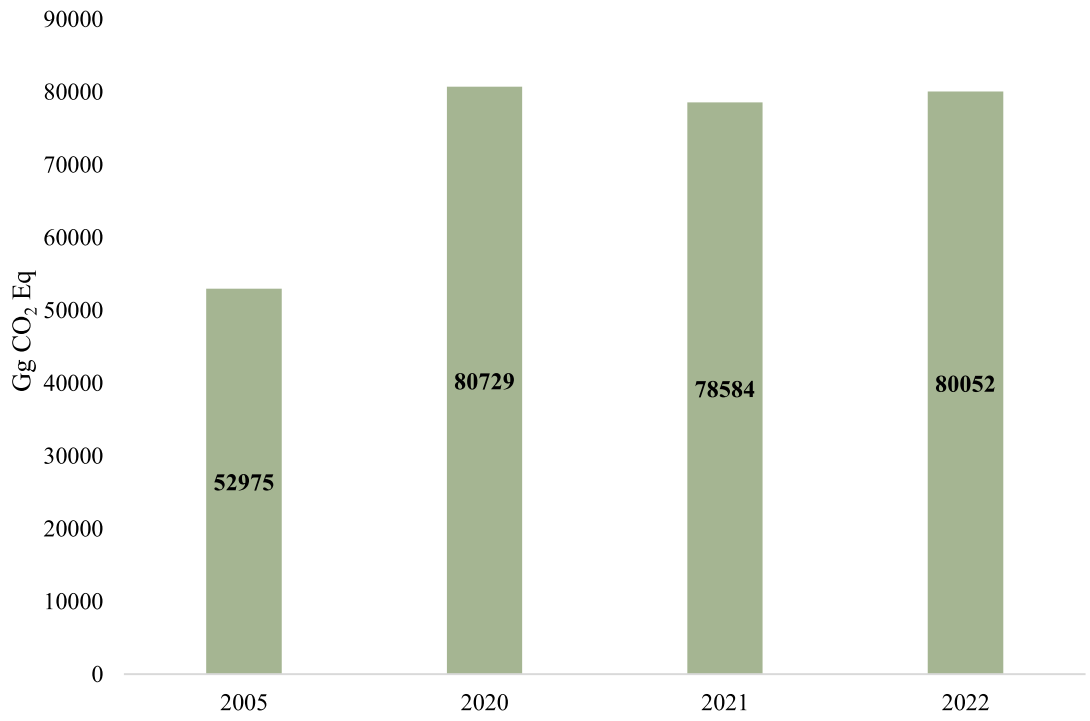


Figure 5.9 GHG emissions from Agricultural soils (3.D.) in 2005, 2020-2022

5.5.1. Direct N_2O emissions from managed soils (3.D.1)

Category description and background

Direct N_2O emission was estimated using net N additions to soils (synthetic or organic fertilizers, deposited manure, crop residues) and mineralization of N in soil due to cultivation/land-use change on mineral soils. The indirect N_2O emissions was estimated from volatilization of NH_3 and NOx from managed soils and the subsequent re-deposition of these gases and their products (NH_4 and NO3) to soils and after leaching and runoff of N, mainly as NO3 from managed soils.

Nitrogen compounds added to the soil through the following processes were considered for inventory estimation:

a. the application of inorganic nitrogen fertilisers
b. the application of animal wastes to pastures
c. the application of crop residues
d. mineralisation due to loss of soil carbon
e. mineralisation due to cultivation of organic soils
f. atmospheric nitrogen deposition
g. leaching of N from soils and surface runoff.

The Direct N_2O emissions for the year 2022 were 64617 Gg CO_2 eq. The total N_2O emissions (direct and indirect) for 2022 were 80.1 Gg CO_2 eq.

Methodological issues

A tier 2 method is used to estimate emissions from inorganic fertilisers. Activity data is sourced from Fertilizer association of India (FAI), which gives state wise N consumption data. All the inorganic N fertilizer produced in the country and imported from outside is considered for agricultural soil emission.

The total inorganic N fertilizer consumed in 2022 was 20.014 Mt, which has increased from 12.47 Mt in 2005. The amount of Synthetic N from 2005, 2020, 2021 and 2022 is shown in Table 5.5.1. The N_2O emission from inorganic N fertilizer application to agricultural soils in the year 2022 was 45840 kt CO_2 eq., contributing 71% to the total direct emissions.

The EFs of N_2O emission from synthetic/chemical N fertilizer applications are based on analyses of Indian measurement studies (Pathak et al., 2002, Malla et al. (2005), Jain et al., (2016), Fagodia et al., (2019), Bhattacharyya et al., 2013, 2018, Cowan et al., 2021, Bhatia et al 2005, 2012, 2023; Das et al., 2014, Mohanty et al., 2017; Das et al., 2024. Many emission factors were taken from reports of programs such as the ICAR-National innovations for climate resilient agriculture (NICRA) and projects of MOEFCC, GoI. These research was done to quantify emissions of N_2O from the application of fertilisers to different crops and cropping systems and climatic regions of India. The EFs for all crops and systems fall much lower than the default range provided in IPCC (2006) for N inputs to crops cultivated under aerobic soil conditions, which cover most agricultural soils in India. The studies compiled are mostly based on urea fertiliser, which represents ~ 82-83% of the nitrogen in inorganic nitrogen fertilisers to the total amount of synthetic fertilizer consumed annually. Data on synthetic fertilizer N consumption for the year 2022 was obtained from FAI data books (FAI 21-22 and 22-23).

Crop wise synthetic N fertiliser application for different regions (states) is not available. Variation in EFs with region and crops is to be expected. However, most crops are grown under irrigation in the country having 52% irrigated area. Most N fertilizer application occurs in irrigated agriculture. Under rainfed agriculture rice is the major crop in the country.

The EFs used in the inventory for inorganic N fertiliser for different crops were normalised for the area under each crop and the EF for synthetic fertilizer was derived. With the use of Neem coated urea (NCU) across the country since 2016 for crop cultivation, the EF from the use of synthetic N fertiliser has reduced by approximately 5% as neem is a natural nitrification inhibitor and results in reduction of N_2O emission (Paul et al., 2024; Bhatia et al., 2023, Cowan et al., 2021). As inorganic fertiliser N application to flooded rice crop is not available in any national statistics, the same EF was used for estimation of N_2O from all cropped soils.

The amount of manure N available for application to agricultural soils was obtained after adjusting the total amount of managed animal manure used for feed, burned for fuel or used for construction and other use. The nitrous oxide was primarily emitted from soil through the mineralisation of animal manure derived principally from cattle and buffaloes. Poultry and swine manure application as organic fertiliser to cropped soils is not prevalent in the country. The country specific EF of 0.005 Gg N_2O-N/Gg N from animal wastes was used (Bhatia et al., 2003, Bhatia et al., 2005, Pathak et al., 2002, Das and Cowan et al., 2021). The amount of nitrogen applied to soils is the nitrogen excreted, adjusted for the nitrogen that has already been lost as N_2O, NH_3 and NOx during storage in the different manure management system (MMS). The animal population was taken from the livestock census 2020 and the population for 2022 was arrived at based on the applicable growth rate for each livestock category. The animal waste was allocated to the different manure management systems as given in section 5.3 (CRT 3B(b)). No national statistics or report gives the amount of animal manure applied to agricultural soils. Out of the total N allocated to the MMS of solid storage, 75% of the N was considered applied to agricultural soils for all livestock, except swine and poultry. Swine manure is not applied to agricultural soils in India.

Application of sewage sludge to agricultural soils is not a prevalent practice in India. No data is available for the amount of sewage sludge applied to arable soils. Thus, this category is considered not occurring (NO) in the country.

The compost N (rural and urban), kg N yr-1 and Green manure nitrogen, kg N yr-1 applied to soils annually was considered under other organic fertilizers. These were obtained from Fertilizer statistics. Addition of N through green manure crops (NGM) such as sesbania (Sesbania aculeata) and sun hemp (Crotalaria juncea) was calculated taking into account total harvested area under these crops in different states of India and considering that these crops fix on an average 30 kg N ha-1 (Motsara et al., 1995). An EF of 0.005 Gg N_2O-N/Gg N was used for other organic waste based on peer reviewed literature (Bhatia et al., 2005, Das et al., 2014).

Nitrous oxide is emitted from soil through the mineralisation of N in urine and faeces deposited directly onto pastures. The amount of animal dung allocated to the PRP MMS was considered as an input to agricultural soils and thus used for the direct and indirect N_2O calculation. 90% of the sheep and goat dung was allocated to the PRP MMS. The animals considered were cattle, buffalo, sheep, goat, camel, horses and mules. The EFs for N_2O from PRP N deposited was based on an unpublished study carried out in the farmers field by ICAR-Indian Agricultural Research Institute, New Delhi. Due to the tropical ecology, the N is lost as ammonia, thus EF of 0.5 per cent (0.005 Gg N_2O-N/Gg N), is used to estimate N_2O emissions from urine and faecal N deposition to soil. This value is within the uncertainty range of the default EF given in IPCC (2006) guidelines.

The method used to estimate emissions from crop residues returned to the soil is based on the IPCC tier 2 method. The amount of straw of both non-N fixing and N fixing crops was considered for incorporation to the soil as residue. Activity data of grain yield was sourced from Agricultural statistics (21-22 and 22-23) published by Department of Agriculture and farmers welfare, GoI. The straw yield was calculated using the following equation from the harvest Index (Bandyopadhyay et al., 2001). Straw Yield= (Grain Yield/Harvest Index)-Grain Yield. It is assumed that only 5% of straw produced is incorporated to the soil for all crops based on expert judgement as no national statistics is available. In India, crop residues are used for fuel, feed and other domestic purposes. In some states the crop residues are burnt. Thus, very little of crop residues are incorporated in the field. The nitrogen content of residue of different crops was taken from (Subrian et al., 2000). Eleven major non-N fixing crops and four major N- fixing crops -tur, gram, groundnut soybean, and other rabi and kharif pulses, were taken for the calculation, whose residue may be incorporated as residue. The N_2O EFs from crop residue were lower than the synthetic N fertilizer and were taken from annual report of ICAR- Conservation Agricultural Platform project and Pathak et al., 2006. The Table 5.5.4 gives the production of crops (grain yield, Mt) considered for N_2O emissions.

The term FOS refers to the total annual area (ha) of drained/managed organic soils. FOS is the area of organic soils harvested (area of organic soils cultivated annually). Organic soils are those, which contain more than 12-18% of organic carbon depending upon the clay content (Brady, 1984). Indian soils are deficient of organic carbon, which is generally less than 1%. Only some cultivated soils of Kerala and northeast hill regions contain higher organic carbon (about 2-3%). Therefore, in the present estimation area under organic soil cultivation is reported as NO (not occurring) in the country.

No N fertiliser is applied in Indian forests, and grasslands as they are all unmanaged. All the country's fertilizer and animal manure are accounted as applied to cropped soils.

NO notation key is used for sub categories 3.D.1.b.ii, 3.D.1.e and 3.D.1.f as these activities doesn't occur in India.

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

The uncertainty for activity data of synthetic fertiliser, which is the largest contributor to N_2O emission is taken as 1% as the data was obtained from statistical data published annually by Fertiliser Association of India. The uncertainty for other activity data may be 5% based on expert judgement. The uncertainty in EF for the Direct N_2O was 23%. Uncertainties in emission factors arise due to differing conditions of climate, soil properties and water, and fertilizer and crop management. Various physical, chemical and biological properties of soil influence formation of N_2O in soil and their diffusion from soil to air. The percentage of uncertainties associated with the activity data is based on expert judgment. The emission factor uncertainties are calculated based on published studies as per the IPCC 2006 uncertainty calculation methodology.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

5.5.2. Indirect N_2O emissions from managed soils (3.D.2)

Category description

Nitrogen compounds such as ammonia, that volatilize and are released into the atmosphere from synthetic fertilizers and, organic fertilizers applied to agricultural soils and the grazing livestock manure applied to soil are deposited on soil as the results of various actions, including turbulent diffusion, molecular diffusion, effect of electrostatic forces, chemical reactions, plant respiration, and being washed out of the air by rain. In this section, the amount of N_2O generated by microbial activity on the deposited nitrogen compounds has been calculated. N_2O is also generated by the microbial action on nitrogen that leaches or runs off as nitrate from synthetic fertilizers, organic fertilizers, etc. N_2O emissions have been calculated in accordance with decision tree of the IPCC 2006 guidelines (Vol. 4, Page 11.23, Fig 11.3).

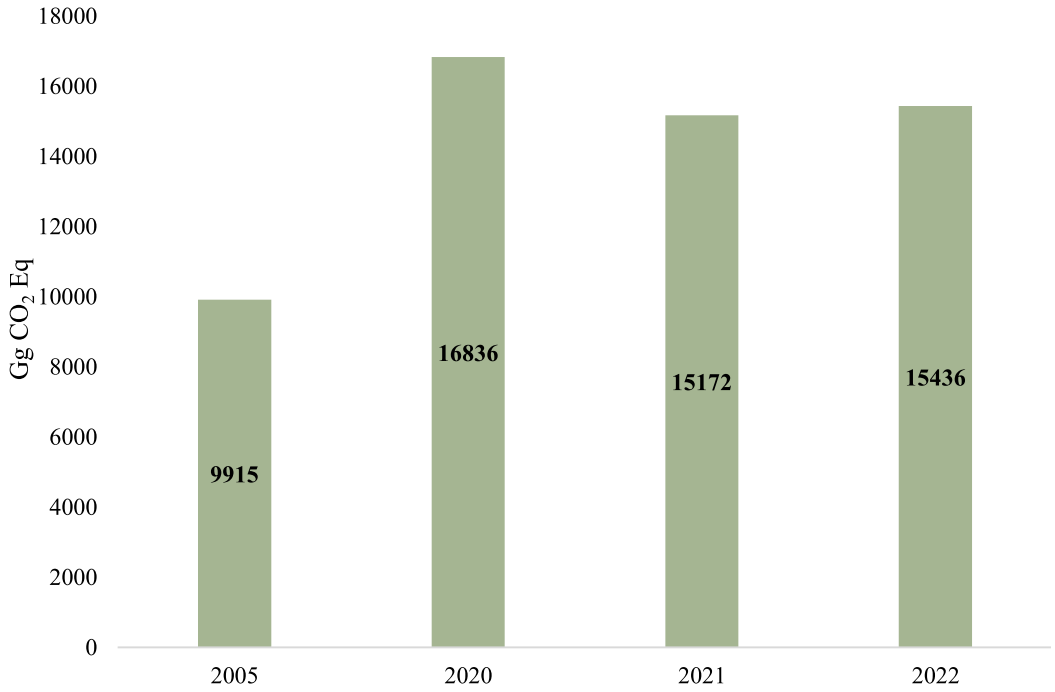


Figure 5.10 GHG emissions from Indirect N_2O emissions from managed soils (3.D.2) in 2005, 2020-2022

Methodological issues

A Tier 2 method using country specific volatilization fractions was used to estimate indirect N_2O emissions by atmospheric deposition from inorganic fertilisers, manure, crop residue and dung & urine deposition on PRP as per equation 11.9, chapter 11, Vol4. 2006 IPCC guidelines. The emission factors for ammonia volatilisation is taken as 20% based on indigenous studies (Cowan et al.,2021; Paul et al., 2024; Chatterjee et al.,2024; SANH 2024; BASF). As disaggregated data for N applied to soil under different conditions was not available, thus uniform EF across the different conditions was used. India has about 166 Mha cropland area. For N volatilised from inorganic or organic fertilisers, PRP and crop residue, the EFs applied for atmospheric deposition was 0.5 per cent (0.005 Gg N_2O-N/Gg N) and fall within the uncertainty range of IPCC and are similar to the direct N_2O EFs (averaged for the direct N sources). These EFs best represents the production system immediately surrounding the cropland used to estimate atmospheric deposition emissions.

Country specific A Tier 2 method using country specific leaching fractions was used to estimate indirect N_2O emissions by leaching and run off from inorganic fertilisers, manure, crop residue and dung & urine deposition on PRP. The emission factors for mineral N leaching were based on indigenous studies (Kumar et al.,2024; Chatterjee et al.,2024; SANH 2024) and a fraction of 10% N was taken to be leached. As disaggregated data for N applied to soil under different conditions was not available, thus uniform EF across the different conditions was used. The EF for N_2O emission from N leaching was taken to be 0.005 kg N_2O–N/kg N , similar to indirect N_2O EFs for N deposition and is well within the uncertainty range of the IPCC (2006) EFs.

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

The uncertainty for activity data of synthetic fertiliser, which is the largest contributor to N_2O emission is taken as 1% as the data was obtained from statistical data published annually by Fertiliser Association of India. The uncertainty for other activity data may be 5% based on expert judgement. The uncertainty in EF for the Direct N_2O was 23%. Uncertainties in emission factors arise due to differing conditions of climate, soil properties and water, and fertilizer and crop management. Various physical, chemical and biological properties of soil influence formation of N_2O in soil and their diffusion from soil to air. The percentage of uncertainties associated with the activity data is based on expert judgment. The emission factor uncertainties are calculated based on published studies as per the IPCC 2006 uncertainty calculation methodology.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

5.6. Prescribed burning of savannahs (CRT 3.E)

This source is given in the 2006 IPCC Guidelines as "being for the purpose of managing pastureland in sub-tropical zones". There is no equivalent activity in India, and this source has been reported as "NO".

5.7. Field burning of agricultural residues (CRT 3.F)

Category description

Burning of crop residues in field releases CO_2, CH_4 and N_2O and other air pollutants into the atmosphere. As per the IPCC Guidelines (IPCC 2006), the CO_2 emissions from burning of agricultural crop residues are not included in the inventory total since it is assumed that an equivalent amount of CO_2 is being removed by the growing crop. However, emissions of CH_4 and N_2O from this source are calculated and reported in this category. The Non-CO_2 GHG emissions from field burning of crop residues were calculated by combination of Tier1/Tier2 method, using country-specific and default factors in accordance with decision tree of the 2006 IPCC Guidelines (Vol. 4, p.11.9, Fig. 2.44).

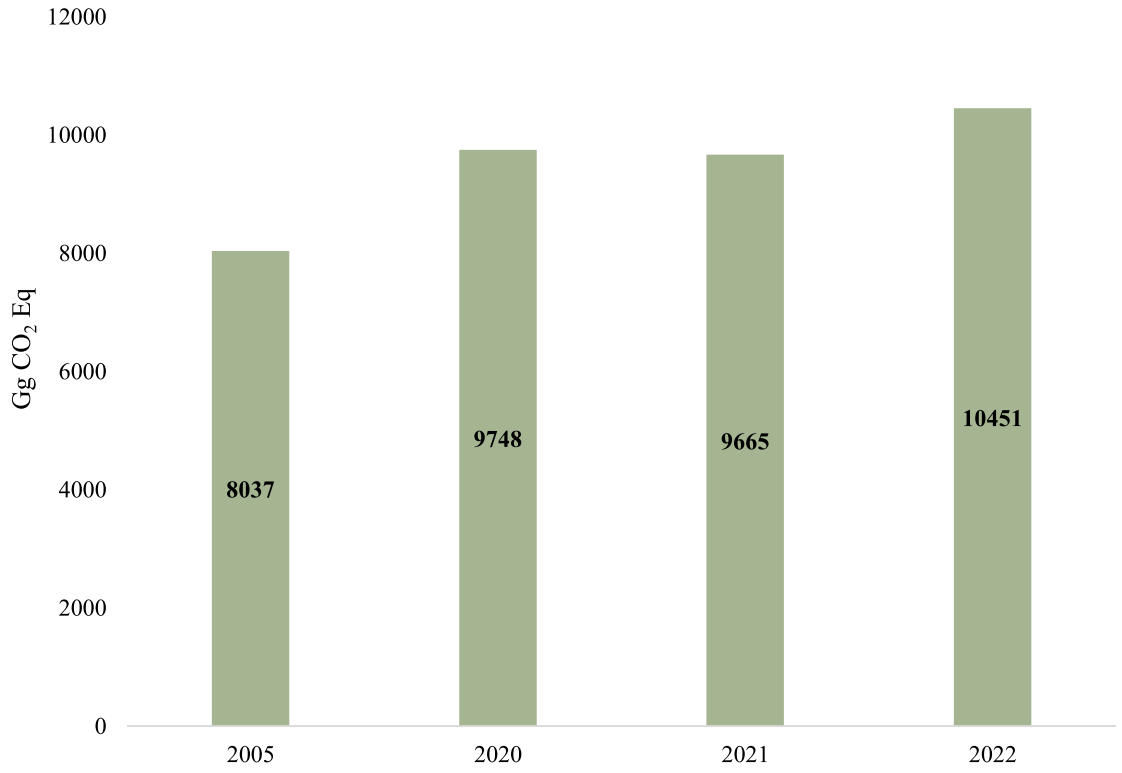


Figure 5.11 GHG emissions from field burning of agricultural residues (3.F.) in 2005, 2020-2022

Burning of crop residues in field releases CO_2, CH_4 and N_2O and other air pollutants into the atmosphere. As per the IPCC Guidelines (IPCC 2006), the CO_2 emissions from burning of agricultural crop residues are not included in the inventory total since it is assumed that an equivalent amount of CO_2 is being removed by the growing crop. However, emissions of CH_4 and N_2O from this source are calculated and reported in this category. The non-CO_2 GHG emissions from field burning of crop residues were calculated by combination of Tier1/Tier2 method, using country-specific and default factors in accordance with decision tree of the 2006 IPCC Guidelines (Vol. 4, p.11.9, Fig. 2.44).

The emissions of CH_4 and N_2O due to field burning of agricultural residues ranged from 230.49 Gg to 299.7 Gg/yr and 5.98 Gg to 7.77 Gg/yr, respectively. The total GWP due to crop residue burning varied from 8037 Gg CO_2e in 2005 to 10451 Gg CO_2e in 2022 (table 5.17).

Table 5.17 Trends in emission of non-CO_2 GHG from on farm burning of crop residues

Crop	CH_4 emission (Gg)				N_2O emission (Gg)				CO_2eq emission (Gg)			
	2005	2020	2021	2022	2005	2020	2021	2022	2005	2020	2021	2022
Rice	108.80	118.97	120.32	130.38	2.82	3.08	3.12	3.38	3793.8	4148.7	4195.6	4546.3
Wheat	49.55	75.20	64.24	70.18	1.28	1.95	1.67	1.82	1727.9	2622.3	2240.1	2447.3
Maize	4.64	4.64	10.60	11.75	0.12	0.12	0.27	0.30	161.6	161.6	369.5	409.7
Cotton	15.79	31.30	28.64	28.92	0.41	0.81	0.74	0.75	550.6	1091.4	998.6	1008.3
Sugarcane	44.43	39.19	42.72	47.25	1.15	1.02	1.11	1.23	1549.3	1366.4	1489.6	1647.7
Rapeseed & Mustard	2.39	5.10	5.90	6.61	0.06	0.13	0.15	0.17	83.3	177.9	205.7	230.5
Millets	4.90	5.15	4.75	4.61	0.13	0.13	0.12	0.12	170.9	179.6	165.8	160.6
Total	230.49	279.55	277.17	299.70	5.98	7.25	7.19	7.77	8037.43	9747.86	9664.92	10450.60

Methodological issues

For category 3.F 'Field burning of agricultural residues', according to IPCC 2006 guidelines, in tier 1 methodology, non-CO_2 emissions are best estimated using the actual fuel consumption provided in 2006 GL and appropriate emission factors. Whereas, Tier 2 method employs the same general approach as Tier 1 but make use of more refined country-derived emission factors and/or more refined estimates of biomass densities and combustion factors than those provided in the default tables.

The amount of biomass that can be burnt is given by the area burnt and the density of biomass present on that area. The combustion factor is a measure of the proportion of the biomass that is actually combusted, which varies as a function of the amount of biomass fuel load), the moisture content of the biomass and the type of fire (i.e., intensity and rate of spread which is markedly affected by climatic variability and regional differences). Finally, the emission factor gives the amount of a particular greenhouse gas emitted per unit of dry matter combusted, which can vary as a function of the carbon/ nitrogen content of the biomass and the completeness of combustion.

The IPCC 2006 guidelines recommend the use of area burnt to estimate the biomass burnt on farm. However, if crop specific area burnt is not available, the crop biomass production data can be used for estimating the crop biomass burnt on farm. During the current inventory process, crop biomass production data was used to estimate the amount of crop biomass burned on farms. This approach was necessary due to the lack of detailed information on the exact area burnt for each crop whose biomass is burned in the field. For calculating GHG emissions from these crops, the default emission factors for methane (CH_4) and nitrous oxide (N_2O) as recommended by IPCC 2006 guidelines were applied. This ensures that, despite gaps in on-ground burn data, emissions from crop residue burning are estimated consistently across various crop types. The emissions are then aggregated to arrive at national emission of non-CO_2 GHG emission from crop residue burning.

The total crop residue generated was estimated as 503134 Gg in 2005, 712832 Gg in 2020, 732186 Gg in 2021 and 754729 g in 2022 on dry weight basis (table 3, see CRT Table 3.F). Out of the total crop biomass generated 85368 Gg in 2005 (16.97%), 103535 Gg in 2020 (14.52%), 102654 Gg in 2021 (14.02%) and 110999 Gg in 2022 (14.71%) was burned on farm. Rice, wheat and sugarcane biomass contributed 82-88% of the total biomass burnt in different years (Figure 5.12, Table 5.18).

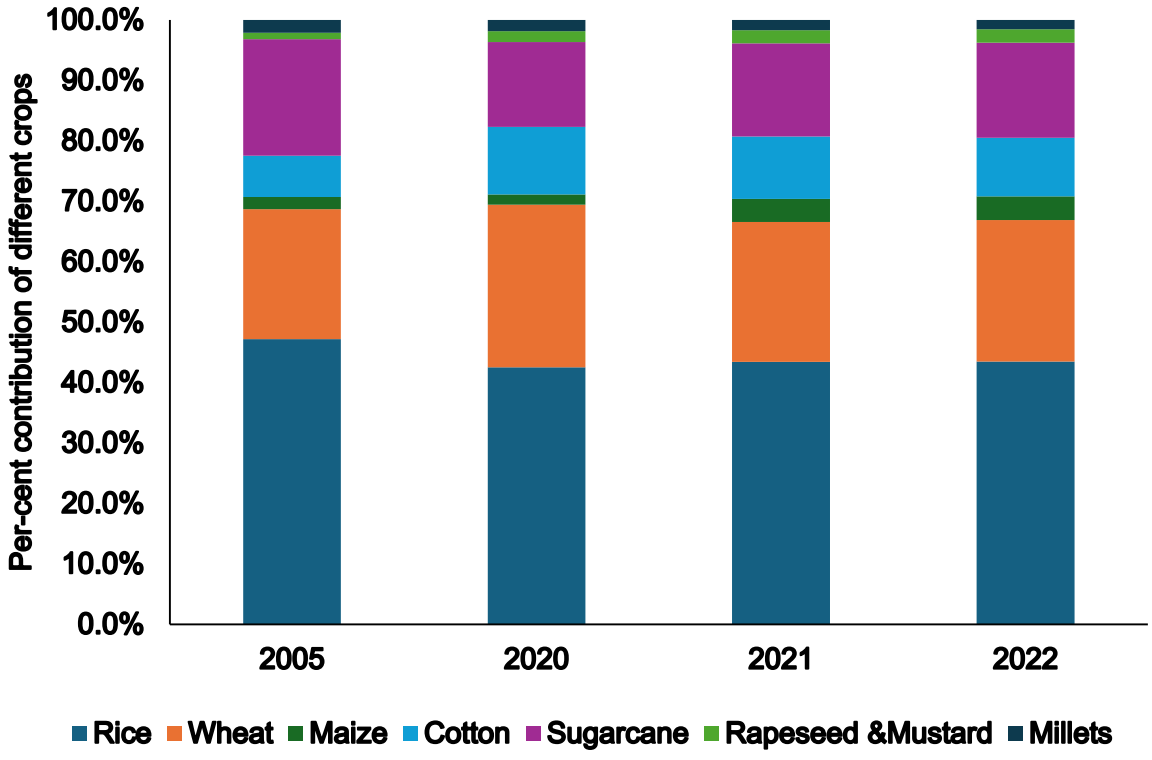


Figure 5.12 Contribution of different crops to total crop biomass burned over the years

Table 5.18 Crop-wise annual dry residue generation and biomass burned in 2005, 2020, 2021 and 2022

Crop	Dry residue generated (Gg)				Biomass burnt (Gg)			
	2005	2020	2021	2022	2005	2020	2021	2022
Rice	181240	263757	263718	275875	40295	44064	44563	48288
Wheat	101934	154700	152557	144685	18352	27852	23793	25994
Maize	19075	19075	43607	48356	1717	1717	3925	4352
Cotton	73102	144901	132578	133875	5848	11592	10606	10710
Sugarcane	94035	82932	90411	100003	16456	14513	15822	17500
Rapeseed & Mustard	11059	23618	27309	30607	885	1889	2185	2449
Millets	22689	23849	22007	21328	1815	1908	1761	1706
Total	503134	712832	732186	754729	85368	103535	102654	110999

Crop residues are burnt on farm in many Indian states particularly in Punjab, Haryana and western Uttar Pradesh. The emission of CH_4 and N_2O was estimated from the residue burning in India disegregated at state level except in case of the states of Punjab and Haryana for rice residue burning which was further desegregated at district level. Generally, residues from eight crops (rice, wheat, cotton, maize, millet, sugarcane, rapeseed and mustard) are burned in field. However, surveys are also being conducted with farmers and experts from crop specific institutions to identify the crops, for which unutilized biomass is burned on farm and will be reported in the future national communications. In the current inventory non-CO_2 emissions from crop residue burning were calculated using the equation given below.

$FBCR = \sum_{crops} (A \times B \times C \times D \times E \times F)$

Where, FBCR= Emissions from residue Burning, A = Crop production, B = Residue to crop ratio, C = Dry matter fraction, D = Fraction burnt, E = Fraction actually oxidized, F = Emission factor.

To estimate the crop wise biomass burned the data desegregated at state level was used. The crop area (table 5.19) and production figures for 2005,2020,2021 and 2022 *(Ministry of Agriculture, 2019-2023, FAI 2019-2023)* were used as the basic activity data.

Table 5.19 Harvested area of major crops (Mt) (MoA 22-23)

Crop	Area harvested (000 ha)			
	2005	2020	2021	2022
Rice	43251	46299	46109	47314
Wheat	26420	32687	30681	25748
Maize	7387	9902	9892	9912
Cotton	8696	13347	12676	12147
Sugarcane	3981	4767	5067	3998
Rapeseed & Mustard	7032	6598	7561	8113
Millets	20572	13776	12736	11977
Total	119345	129394	126743	121232

Ratio of residue to economic yield was taken from *Bandyopadhayay et al. (2001) Jain et al 2018, annual reports (IARI), National Biomass Atlas of India (MNRE), RREL biomass report 2019-22.* Fractions of residues burned in field were taken from *Gadde et al. (2009) and Jain et al 2018* for rice and expert judgement for other crops based on the interaction with farmers and crop specific experts. Satellite remote sensing was also employed to determine the rice burnt area in this study using the satellite images received at IARI satellite ground station. The images from different satellites were utilized for real-time detection of active fire events in the states of Punjab and Haryana. The fraction of rice straw burnt was estimated based on daily real time satellite-based measurements of rice area burned for two months aligned with the harvesting of the crop in the two states disaggregated at district level for the years 2020, 2021 and 2022. The normalised rice burnt area estimated based on area weighted average for the states of Haryana and Punjab were then used to estimate the fraction of rice biomass burned in the two states. The study was also conducted to estimate the fraction of sugarcane trash burned on farm in the state of

Uttar Pradesh *(Khatri 2024, unpublished)*. The combustion factor of different crop residues was obtained from *IPCC 2006 guidelines and Khatri (2024, unpublished)* (table 5.20).

The notation key NA is used for area burned and biomass available in the burned area. The emission from crop biomass burning is calculated based on crop production data.The data for area burned and biomass available in the burned area is not available. Moreover, NO notation key is used for activity data 'total biomass' and the emission from this category is not estimated as the biomass of pulses, tuber crop and barley is not burned in the country.

Table 5.20 Coefficients used for inventory of Non-CO_2 GHG emissions from on farm burning of crop residues

Crop	Residue to Crop Ratio	Dry Matter Fraction	Fraction burnt			
			2005	2020	2021	2022
Rice*	1.6	0.86	0.247 (0.05-0.562)	0.186 (0.05-0.562)	0.188 (0.05-0.544)	0.194 (0.05-0.624)
Wheat*	1.5	0.88	0.205 (0.1-0.25)	0.205 (0.1-0.25)	0.177 (0.1-0.25)	0.204 (0.1-0.25)
Maize	1.5	0.88	0.1	0.1	0.1	0.1
Cotton	3	0.8	0.1	0.1	0.1	0.1
Sugarcane	0.24	0.88	0.25	0.25	0.25	0.25
Rapeseed & Mustard	3	0.8	0.1	0.1	0.1	0.1
Millets	1.5	0.88	0.1	0.1	0.1	0.1

*Weighted average across states
Source: IPCC 2006 Guidelines, IARI 2019-2020; Gadde et al 2009, Jain et al 2014 ,2018, 2021, Rice area burnt reports to MoA, Khatri (2024)

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

Uncertainties associated with activity data of crop production and crop harvested area are estimated to be 5%. Uncertainties associated with the default emission factor are estimated as 15%.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

5.8. Liming (CRT 3.G)

Application of lime (e.g. calcic limestone ($CaCO_3$) or dolomite ($CaMg(CO_3)_2$)) to the acidic soil results in CO_2 emissions, as the carbonate reacts with acids in the soil to produce bicarbonate (HCO_3-) and eventually leading to the production of CO_2 and water. The CO_2 is emitted to the atmosphere. The emission from this category is reported as not estimated (NE) as disaggregated data on lime application could not be collected due to constraints related to limited resources and technical capacity. In India ~96% Of the lime produced in the country is used in cement production. Rest 4% is used in other sectors which includes around 12-13 application. No segregated data is available for lime application to agricultural soils. India is reported to have 49 m ha of acidic land (ICAR-NBSSLUP reports). The area under acid soils is used for growing the crops suitable for acidic conditions e.g Rice, Mustard, Potato based on the discussion with different agricultural institutes in different locations. To verify the information, data was collected for crop area and production of rice, mustard and potato in the states with area under acid soils. For further validation, the crop masks of rice, mustard and potato were overlayed on the acid soil map of India. It was observed that rice is the main crop grown in acid soils followed by mustard and potato.

5.9. Urea application (CRT 3.H)

Category description

Application of urea to soils for fertilisation of crops leads to a loss of the CO_2 that was fixed during the manufacturing process. Urea ($CO(NH_2)_2$) is converted into ammonium (NH_4+), hydroxyl ion (OH-), and bicarbonate (HCO_3-), in the presence of water and urease enzymes. The bicarbonate (HCO_3-) formed during this process releases as CO_2 to the atmosphere. This category deals with estimation and reporting for this CO_2 emissions. CO_2 emissions from this category in the year 2022 was 7746 $GgCO_2$. The emission from this category has increased by 61.9 % from the year 2005 due to increase in consumption urea fertiliser.

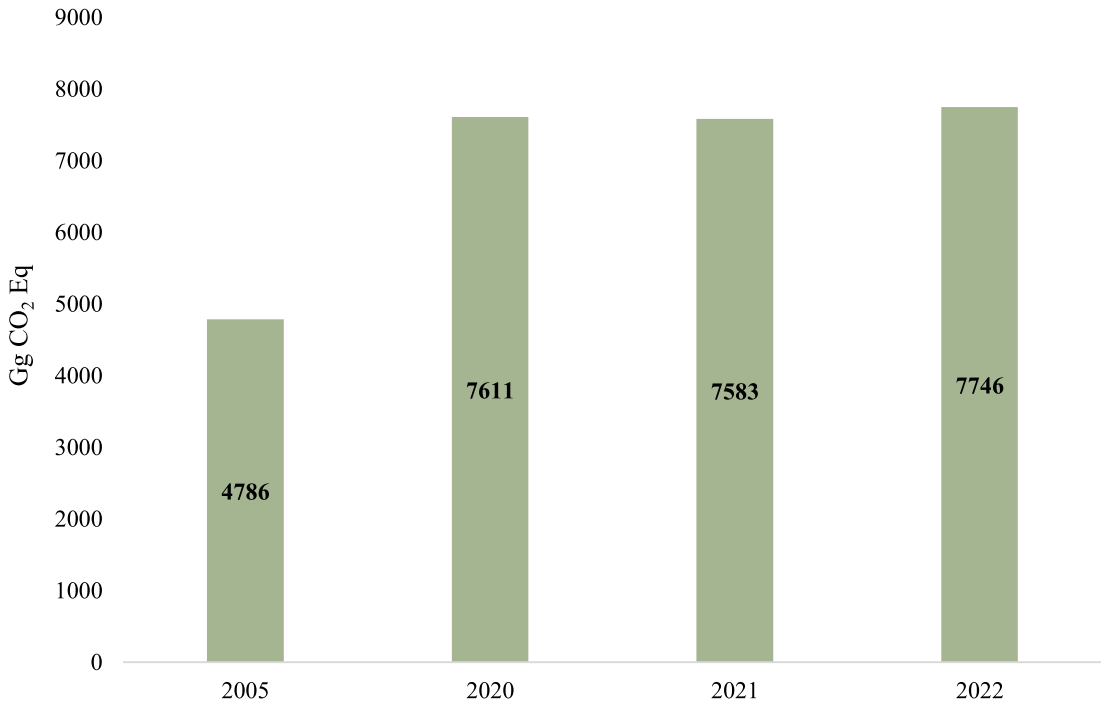


Figure 5.13 GHG emissions from Urea application (3.H.) in 2005, 2020-2022

Methodological issues

The Tier 1 method is used in accordance with the decision tree described in the 2006 IPCC Guidelines. The amount of urea applied, total consumption of urea fertilizer in India for the year 2005, 2020, 2021 and 2022 is taken from the fertiliser statistics published by Fertiliser Association of India. The EF is the emission factor for

CO_2-C emitted from the additions of urea to the soil. The default emission factor 0.20 [kt-C/kt] given in 2006 IPCC Guidelines (p.11.34) is very high with an uncertainty of 50%. Therefore, based on review of literature and analysis of EFs published by EFDB, an EF of 0.06% (instead of default EF based on the studies conducted by Kim et al. 2016 & 2017 for rice and other upland crops). We have considered the EFs given for rice and upland crops grown from June to Oct as the average temperature of the India were found to be similar . The area weighted average EF for CO_2 was used to calculate the emission of CO_2 from urea application to soil. The EF was selected based on the assumption that all C in urea is released to the atmosphere as CO_2 seems unlikely based on current knowledge of carbonate dissolution and transport through soil and also possibility of bicarbonate leaching into waters, thereby not contributing to CO_2 emissions. In India all the urea used for agricultural purpose is neem oil coated urea. Neem oil has the nitrification inhibitory properties. The neem oil coated urea has been reported to reduce the emission of CO_2 from soil compared to urea (Fagodia et al 2018). Nitrification inhibitors are reported in literature to reduce CO_2 emissions. Detailed studies on fate of urea carbon are required to estimate the robust India specific EF.

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 (“Information on Flexibility”) of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

The uncertainty for activity data of urea fertiliser is taken as 1% as the data was obtained from fertiliser association of India statistics. The uncertainty in EF for the CO_2-C was 3.5% estimated based IPCC 2006 guidelines for uncertainty calculation methodology.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India’s first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

CHAPTER-6

LAND USE, LAND-USE CHANGE AND FORESTRY (LULUCF)

LAND USE, LAND-USE CHANGE AND FORESTRY (LULUCF)

6.1 Introduction

Land Use sector plays a critical role in Indian economy, rural employment, biodiversity conservation, food production, and climate change mitigation. In India, about 60% of the population depends directly on agriculture and forestry. India has a target of creating a carbon sink of 2.5 – 3 billion tonnes of CO_2 by 2030 by enhancing forest and tree cover as one of the strategies in the NDC. GHG inventory conducted so far in India since 1994 is generally shown to be a net sink of CO_2 for LULUCF sector. In this chapter, GHG emissionsand removal estimates for LULUCF sector are presented along with methodologies, uncertainty estimates and planned improvements. India has a world class remote sensing and forest inventory system to enable GHG inventory estimates for the land use sectors. Section 6.1 to 6.3 deals with largely methods, sources and estimates of Activity Data (e.g., area under different land categories). Methods for estimating the Emission Factors for different carbon pools and Non-CO_2 GHGs are given in the respective land categories from Section 6.4 to 6.8 and Section 6.10 deals with CO_2 stock change estimates for the Harvested Wood Products pool.

6.1.1. Overview of GHG emissions for LULUCF Sector

India has been estimating the GHG inventory for LULUCF sector starting from 1994 for the Initial National Communication reporting. Since then, India has made multiple estimates, the latest being Third National Communication and BUR-4. India has submitted its Biennial Update Report – 4 in 2024, where the emission and removal for LULUCF sector is estimated for the inventory year 2020. India is reporting GHG inventory for its First Biennial Transparency Report (BTR-1) for the four inventory years namely 2005, 2020, 2021 and 2022. The CO_2 removals for the LULUCF sector is marginally increasing over the recent periods. The trends in GHG emissionsfor LULUCF sector for the four inventory years is presented in Figure 6.1. It can be observed from Figure 6.1 that LULUCF sector has been a net sink since 2005 and it has increased from 206,020 $GgCO_2eq$ during 2005 to 571,823 $GgCO_2eq$ during 2022 under the estimate made for BTR.

6.1.2. Land Categories Considered and GHGs Estimated

IPCC has stratified the land into 6 main categories namely; Forestland, Cropland, Grassland, Wetland, Settlements and Other Land. Harvested Wood Products (HWP) pool is an additional reporting category. The list of IPCC emissions / removals categories considered, GHGs estimated for its BTR-1 reporting are provided in Table 6.1. India is still unable to report inventory for Wetlands due to lack of Activity Data and Emission Factors. The GHGs estimated for the Forestland includes CO_2, CH_4 and N_2O, Grassland includes CO_2 and N_2O, for Croplands, and Settlements only CO_2 is estimated.

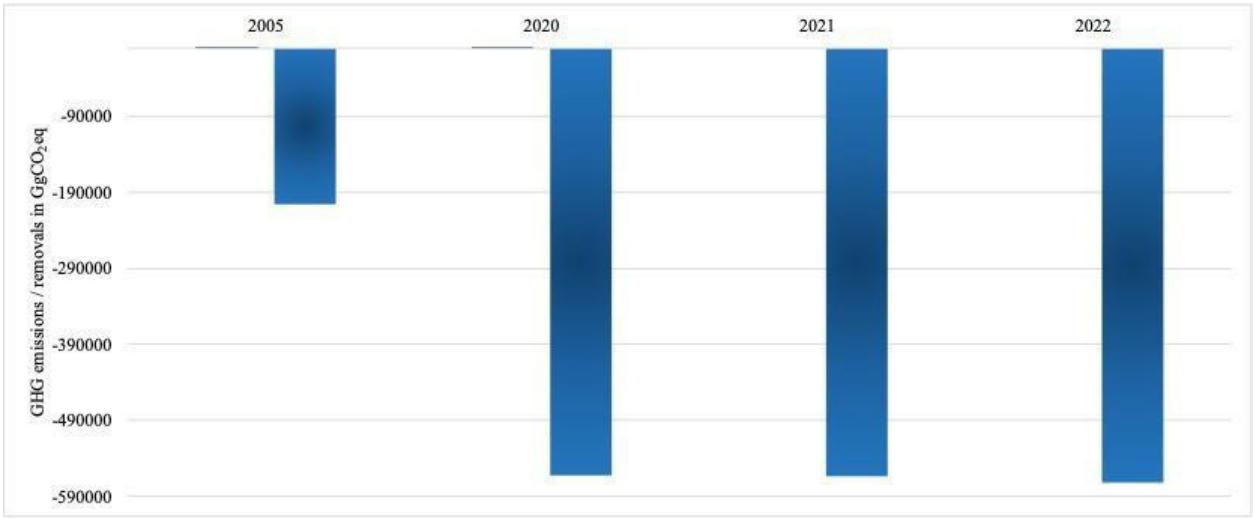


Figure 6.1 Trends in total GHG emissions from LULUCF sector

Table 6.1 IPCC emissions / removals categories considered and GHGs estimated

IPCC Reporting Categories	GHGs estimated
Forestland (FL)	CO_2, CH_4, N_2O
Cropland (CL)	CO_2
Grassland (GL)	CO_2, N_2O
Settlements (SL)	CO_2
Other Land (OL)	NA
Harvested Wood Products (HWP)	CO_2

6.1.3. Choice of Methods: Tiers and Methods used for different Land Categories and GHGs

The tiers and methods used for GHG estimation for different land categories is presented in Table 6.2. India has adopted IPCC 2006 GHG Inventory Guidelines. India has largely adopted Tier-2 methods for GHG Inventory for different land categories and GHGs.

Table 6.2 Tiers and methods adopted for BTR GHG inventory for LULUCF

Type of emission factor and methodological tier adopted for GHG estimation						
Gas	CO_2		CH_4		N_2O	
Sector / Category	Method Used	Emission Factor	Method Used	Emission Factor	Method Used	Emission Factor
Land Use, Land Use Change and Forestry (LULUCF)						
A. Forestland	T2	CS	T2	D, CS	T2	D, CS
B. Cropland	T2	CS	NO		NO	
C. Grassland	T2	CS	NO		T2	D, CS
D. Settlements	T2	CS	NO		NO	
E. Wetlands	NE	NE	NE		NE	
F. Harvested Wood Products	T2	D	NO		NO	
G. Other Land	NA	NA	NA	NA	NA	NA

Footnote: T2: Tier 2 from IPCC guidelines, CS: Country Specific, D: IPCC Default value

6.2. Land use Definition and Land Representation Approaches

In this section, definitions of different land categories adopted by India are presented, along with land representation approach adopted.

6.2.1. Definition of IPCC emissions / removals Categories

The definitions of land categories adopted for the inventory are given below. These definitions are used by national agencies such as National Remote Sensing Centre (NRSC) and Forest Survey of India (FSI) for monitoring and estimating area under different land categories. The definitions used by NRSC and FSI are used in the GHG inventory process, since they are based on advanced remote sensing methods. However, there are other methods and estimates of area under different land categories that are available in India.

- Forestland includes plantations, fruit orchards and agroforestry systems which meet the forest definition criteria.
- Cropland includes not only the Net Cropped / Net Sown area, but also the Current Fallow land, which is not cropped during the year of reporting.
- Grassland includes largely all lands which are not Forestlands and Croplands. Such lands are largely used for livestock grazing in India.
- Flooded Land (Wetland) includes the areas with surface water, either impounded in the form of reservoirs, lakes, ponds, aquaculture lands etc., or flowing in the form of rivers, canals, streams etc. However, currently, India is unable to separate constructed wetlands or submerged area and natural water bodies.
- Settlements include buildings, paved surfaces, commercial and industrial sites, and urban green areas.
- Other Lands includes Rann, natural water bodies, snow cover and rocky outcrops.
- Harvested Wood Products includes i) Solid wood which has Sawn Wood and Wood Panels and ii) Paper and paperboard.

Definitions of the IPCC emissions / removals categories considered for GHG inventory

Land Category	Definition	Reference
Forestland / Forest Cover	Forestland / Forest cover refers to tree patches that have canopy density of more than 10% and area of one hectare or more in size, irrespective of land use, legal status and ownership. It may include orchards, bamboo, and palms, etc. and is assessed through remote sensing.	India State of Forest Report, FSI, 2021
Cropland	Croplands may be defined as those lands which are cultivated to produce food crops and related activities. This includes Annual and Perennial Cropland including Orchards and Agroforestry systems, which do not qualify as forests.	Annual Land Use Land Cover Atlas, NRSC, 2024
Grassland	These are the areas of natural grass along with other vegetation, predominantly grass-like plants (Monocots) and non-grass-like herbs (except Lantana species which are to be classified as scrub). It includes natural/semi-natural grass/ grazing lands of Alpine/Sub-Alpine or temperate or sub- tropical or tropical zones, desertic areas and manmade grasslands.	
Flooded Land / Wetlands	Flooded Land (Wetland) includes the areas with surface water, either impounded in the form of reservoirs, lakes, ponds, aquaculture lands etc., or flowing in the form of rivers, canals, streams etc.	
Settlements / Built up Land	Built-up land refers to an area with buildings (roofed structures), paved surfaces (roads, parking lots), commercial and industrial sites (ports, landfills, quarries, runways), and urban green areas (parks, gardens).	
Other land	Other land includes Rann (salt marsh area), natural water bodies, snow cover and rocky outcrops.	

Land Category	Definition	Reference
Harvested Wood Products	Harvested Wood Products pool refers carbon stored in wood-based products. This reporting category includes i) Solid wood which has Sawn Wood and Wood Panels and ii) Paper and paperboard.	IPCC, 2006; Kant and Nautiyal (2021)

6.2.1.1. Map of Land Use Categories and Soil Types

Land Use Map: In this section, different maps with respect to land use pattern and soil type are presented. Figure 6.2 provides the Forest cover Map of India from ISFR, 2023. Figure 6.3 presents the Land Use Land Cover maps for the year 2022, based on remote sensing techniques including; Built-up Land, Cropland, Current Fallow Land, Plantation / Orchard, Woodland, Littoral/Swamp/Mangroves, Grassland, Shifting Cultivation, Wastelands, Rann, Water Bodies and Snow covered/Glacial areas. These categories are slightly different from the IPCC's six land categories. Forestland dominates the Western Ghats, Northeastern States and parts of Himalayan region. Cropland exists in all the climatic regions of India. Kharif season from June to September dominates the land use followed by the Rabi season (October to January).

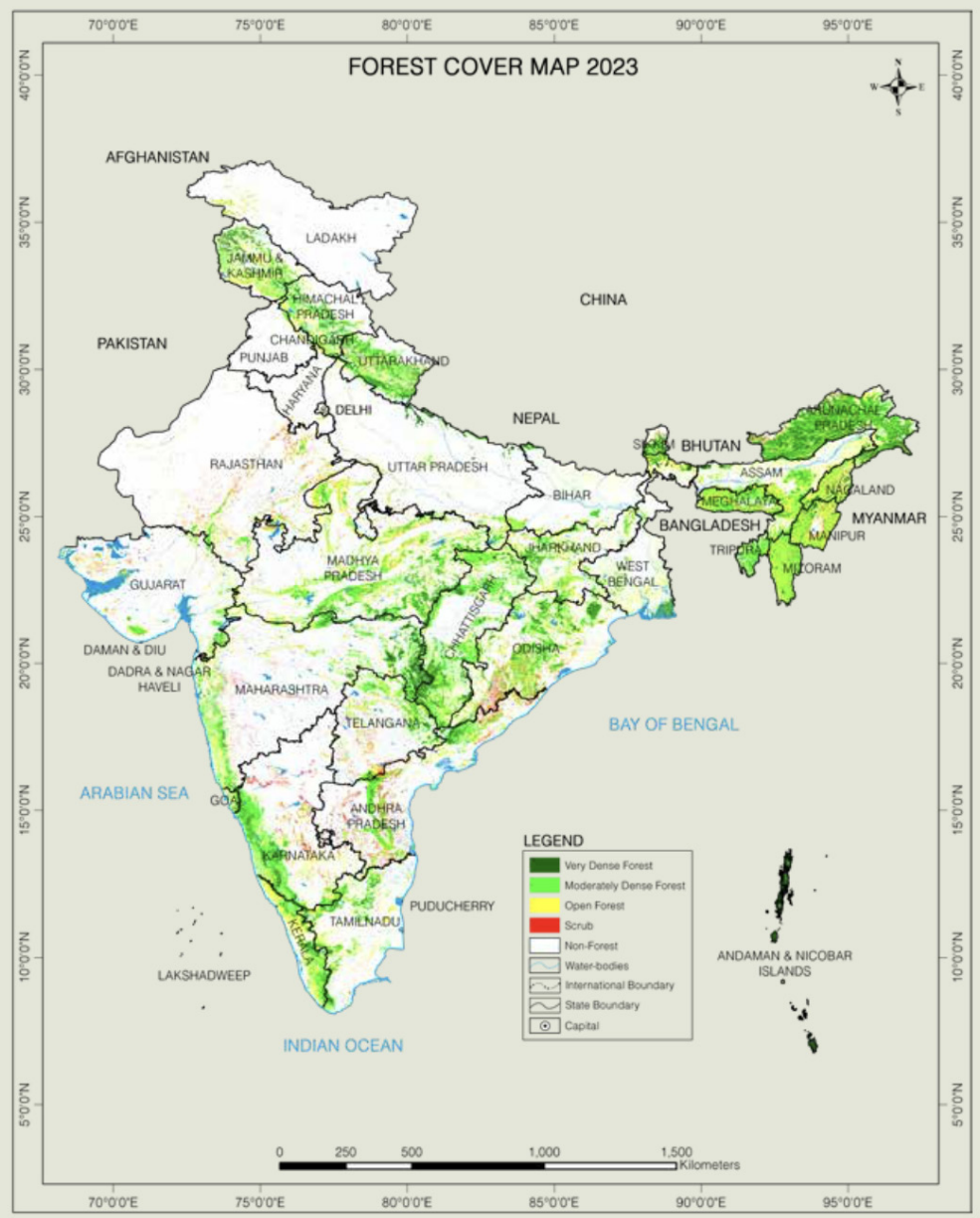


Figure 6.2 Forest Cover Map of India

Source: ISFR, FSI, 2023

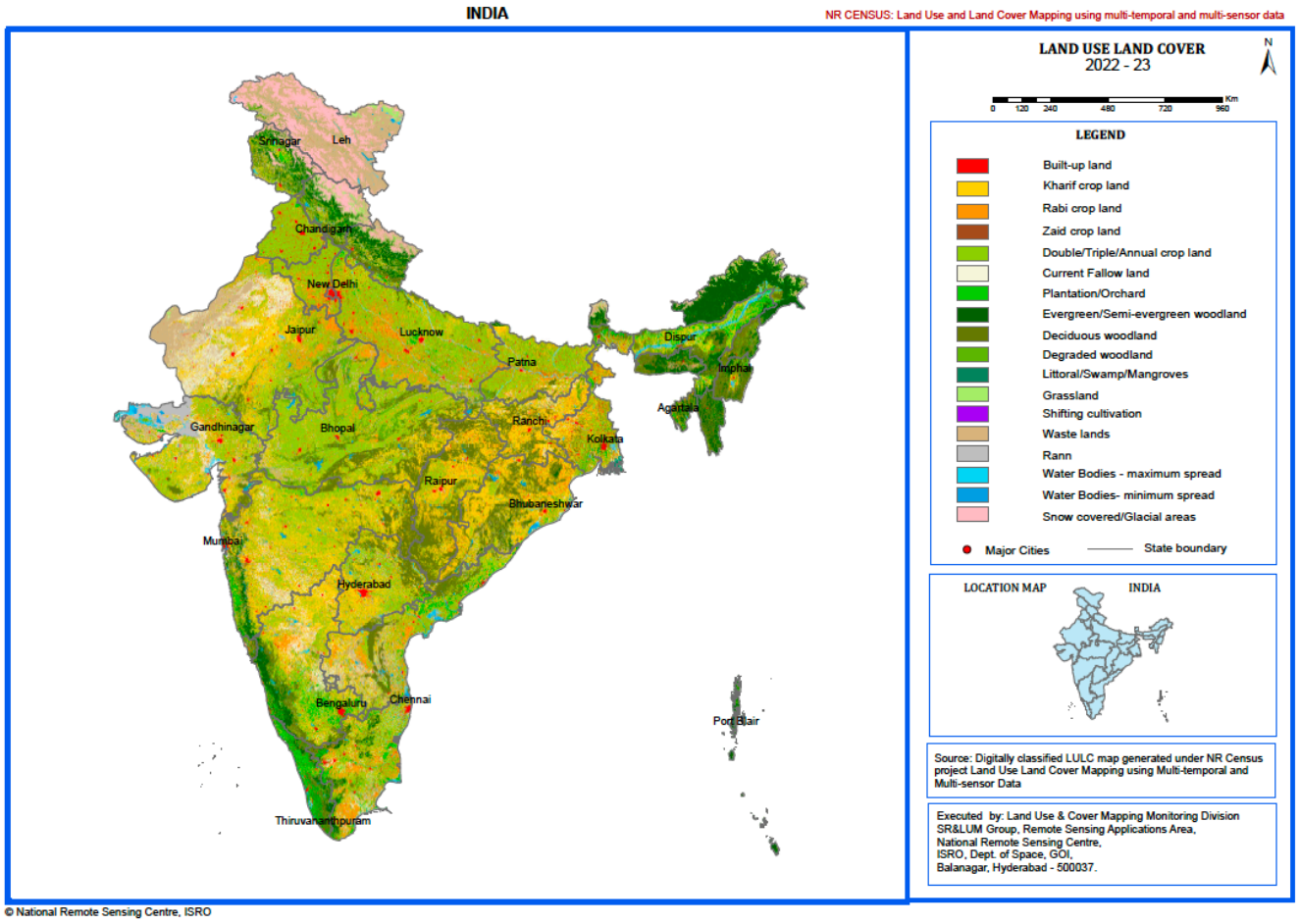


Figure 6.3 Land Use Land Cover Map

Source: NRSC, 2024

Soil Map: The dominant soil type map of India provided by NBSS&LUP (National Bureau of Soil Survey and Land Use Planning) is given in Figure 6.4. The dominant soil types in India are Inceptisols, Entisols, Alfisols, Vertisols, Aridisols, Ultisols, and Mollisols.

Mineral Soils Vs Organic Soils

Organic soils are soils that contain a minimum of 12% Soil Organic Carbon (SOC) by weight in the mineral soil fraction. The organic soils have either *folistic* or *histic* surface horizons and are classified as *Histosols* in USDA Soil Taxonomy. The *folistic* surface soil horizon must have saturation for less than 30 days (cumulative) in normal years and consist of organic material that is 20 cm or more thick and either contains 75% or more (by volume) sphagnum material or has a bulk density (BD) <0.1 g cm-3 (Or) is a plough layer (Ap horizon) when mixed to a depth of 25 cm, has an SOC content of >8% by weight. The *histic* surface horizon is saturated for 30 days or more during normal years and is 20 to 60 cm thick with 75% sphagnum fibers and BD <0.1 g cm-3 or a plough layer (Ap horizon) with SOC content of >8% by weight in 25 cm. The soils in India do not meet these criteria to be defined as organic soils or classified as Histosols and are not reported to occur. Hence for the purpose of this report, soils in Forestlands, Croplands, Grasslands, Settlements and Other Lands are assumed to be Mineral Soils.

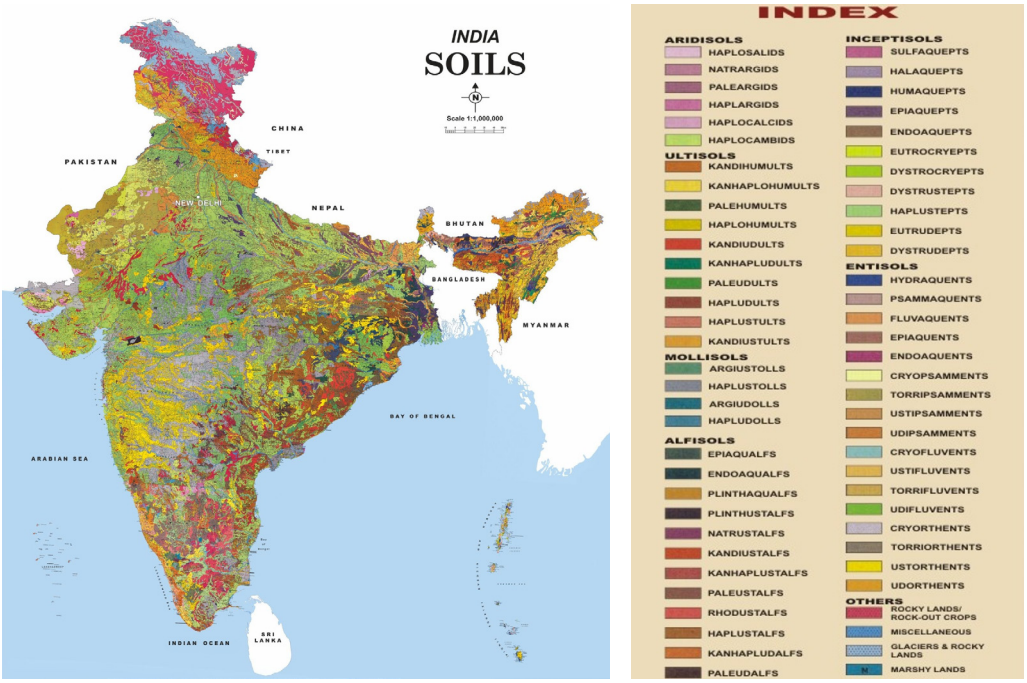


Figure 6.4 Soil map of India

Source: NBSS&LUP Staff (2015) ICAR-NBSS&LUP Serving Science & Society

CO_2 emissions from Rewetted Mineral Soils

Rewetting of dry soils induce a burst in microbial activity, which leads to CO_2 emission and this phenomenon is known as Birch Effect. India is dominated by arid and semi-arid tropical (SAT) climate and the soils are dry during the summer months (April-May) and gets rewetted during the monsoon season. However, significant CO_2 emission from dry soils upon rewetting requires a large and rapid change in soil water potential which does not occur in the SAT soils of India due to partial wetting of soils caused by intermittent spells of rainfall during the monsoon season. The soil moisture regime generally does not change annually in India. Therefore, it is assumed that there is no significant CO_2 emission from the rewetted mineral soils. Further, mineral soils under the croplands are net sink of CO_2 and therefore, rewetting is not assumed to alter the carbon budget of the LULUCF sector.

6.2.2. Land Use Pattern in India

India has been monitoring and estimating Land Use and Land Cover data using remote sensing technology coupled with ground-based observations. Land use for five land categories is given in Table 6.3 for the reporting years 2005, 2020, 2021 and 2022. Land area is reported for the five IPCC land categories. In India, area under different land use categories is monitored periodically by the National Remote Sensing Centre (NRSC) and the area under forests is monitored biennially by the Forest Survey of India (FSI). Cropland which is a dominant land use category includes Kharif (June – September), Rabi (October – January) and Zaid or summer season cropped area (March – May) along with fallow land and area under shifting crop cultivation (which do not qualify as forests).

- **Forestland:** Forestland accounts for 21.7% of the total geographic area during 2022. The area under Forestland was 69.16 Mha in 2005 and it has increased to 71.61 Mha during 2022, an increase by 2.45 Mha.
- **Cropland:** Cropland area dominates by accounting for 52% of total geographic area during 2022. The area under Cropland fluctuates from year to year depending on the monsoon rainfall. Cropland area also includes fallow land which is not cropped during the year for several reasons including rainfall pattern, market conditions, etc. Area under Cropland during 2022 is estimated to be 172.50 Mha.

- **Grassland:** Grassland accounts for 18.03 Mha during 2022 and it includes a variety of land categories which do not qualify as Forests and Cropland. Area under Grassland is largely used for livestock grazing and is in a degraded state.
- **Settlements:** Settlements include rural and urban settlements and infrastructure. The area under Settlements is continuously increasing due to population growth in urban and rural areas. The area under Settlements is estimated to be 10.65 Mha during 2022.
- **Other Land:** Other Land category is not considered for GHG inventory, and it covers an area of 55.94 Mha during 2022. Area under Other Land category is declining mainly due to land use conversion, largely, into Settlements and infrastructure.

India has a large population of about 1.4 billion and livestock population of 536.76 million and 640 thousand villages. There is human habitation inside the Forestland also. The Forestland is also partly used by the local communities for;

- Grazing
- Firewood collection
- Non-Timber Forest Products collection.

Managed Land: Forestland is managed by the State Forest Departments. Reserve forests are managed by Forest Departments based on Working Plans. Some forests are also managed by communities through community forestry practices. Thus, all Forestland in India is considered as "Managed Forestland", since there is anthropogenic intervention or pressure. Similarly, Grasslands are also managed in India, since they are used by humans for livestock grazing, fuelwood collection, etc.

Table 6.3 Land use and land cover trends in India for the period 2005 to 2022 (in Mha)

Year	Forestland	Cropland	Grassland	Settlements	Other Land	Total area
2005	69.16	160.65	20.35	8.61	69.96	328.73
2020	71.45	168.93	22.26	10.03	56.06	328.73
2021	71.53	168.89	20.74	10.07	57.50	328.73
2022	71.61	172.50	18.03	10.65	55.94	328.73

Source: FSI and NRSC

6.2.2.1. Land Use Pattern according to Agricultural Department Estimates

In India, area under different land categories is also estimated by Ministry of Agriculture and State Revenue Departments. The land use pattern for the years 2005, 2020, 2021 and 2022 is given in Table 6.4, according to Ministry of Agriculture and Farmers Welfare. The land categories used by the department of Agriculture are different from IPCC land categories as reported by NRSC. It can be observed that area under crops or net sown area is estimated to be 141 Mha accounting for about 43% of the total geographic area during 2022, excluding the fallow land. Further area under fallow land is estimated to be 24.17 Mha. The total Cropland area including net cropped area, area under miscellaneous tree crops and the fallow land is estimated to be 168.18 Mha during 2022, compared to area under Cropland estimated at 172.50 Mha by NRSC (Table 6.3). The difference in area of 4.32 Mha under Cropland is due to the difference in the definitions and the methods of monitoring.

Table 6.4 Land use pattern in India according to Ministry of Agriculture and Farmers Welfare, Govt. of India

Land use categories	Year (Mha)			
	2005-06	2019-20	2020-21	2021-22
Forests	71.43	71.75	71.98	71.00
Not Available for Cultivation (Area under non-agriculture use + Barren and unculturable land)	42.32	44.32	44.40	44.09
Other Uncultivated land excluding fallow land (Culturable Wasteland)	23.67	22.43	22.13	22.20

Land use categories	Year (Mha)			
	2005-06	2019-20	2020-21	2021-22
Land under Miscellaneous Tree Crops & Groves not included in Net Area Sown	3.39	3.13	3.01	3.01
Fallow lands	24.91	25.01	23.80	24.17
Net sown area	141.16	139.90	141.54	141.00

Source: Agricultural Statistics at a Glance, 2022, Ministry of Agriculture and Farmers Welfare, GoI

** Area data for the year 2021 and 2022 are from the website Land Use Statistics at a Glance from Economics, Statistics and Evaluation Division, Ministry of Agriculture and Farmers Welfare, GoI, 2023 (https://desagri.gov.in/document-report-category/land-use-statistics-at-a-glance/).*

6.3. Country Specific Approaches for Land Use and Land Cover Estimation

6.3.1. Land Classification

India is monitoring area under different land categories based on remote sensing approach. India has monitored spatial extent of area under different land categories produced by National Remote Sensing Centre (NRSC). NRSC produces annual area under different land categories and maps of different land use categories and publishes in its *Annual Land Use Land Cover Atlas of India*. An example of the land use map generated by NRSC is given in Figure 6.2.2 These maps are produced at a scale of 1:250,000. Further, detailed maps of spatial distribution of different land categories is given by Bhuvan website at a scale of 1:50,000 conducted during 2015-16 *(https://bhuvan-app1.nrsc.gov.in/thematic/thematic/index.php)*. The land categories reported under Bhuvan by NRSC include;

- **Built Up land** includes Urban, Rural and Mining.
- **Agriculture land** includes Cropland, Plantation, Fallow Land, Current Shifting Cultivation.
- **Forestland** includes Evergreen / Deciduous / Forest Plantation / Scrub Forest / Swamp / Mangroves.
- **Grass/Grazing land**.
- **Barren/Unculturable/Wasteland** includes Salt Affected Land, Gullied/Ravinous Land, Scrub land, Sandy Area, Barren rocky, Rann.
- **Wetland/Waterbodies** includes Inland Wetland, Coastal Wetland, River/Stream/Canals, Water Bodies.
- **Snow Cover**.

The detailed estimates of area and spatial distribution at state and district level are also provided under the Bhuvan program. Even though geospatial distribution of area under different land categories is available for the recent years, India is adopting IPCC Approach – 2, where physical estimates of area under different land categories and land transitions are given. In India, even though land use transitions data is available for recent years, there are data limitations with respect to estimation of land use transitions for 20-year period, hence for BTR-1, Approach-1 was used. India has plans to adopt Approach – 3, providing spatial transitions of land categories in the coming years.

6.3.2. Methods for Monitoring Area under Different Land Use Categories

The methods adopted by NRSC for monitoring area under different land categories are described in this section. The preparation of land use and land cover map involves utilization of multi-temporal and multi-sensor satellite data. Prior to classification, requisite pre-processing is conducted. The classification system comprises of five primary types and 18 sub-divisions. Figure 6.5 illustrates the datasets utilized and the methodology implemented.

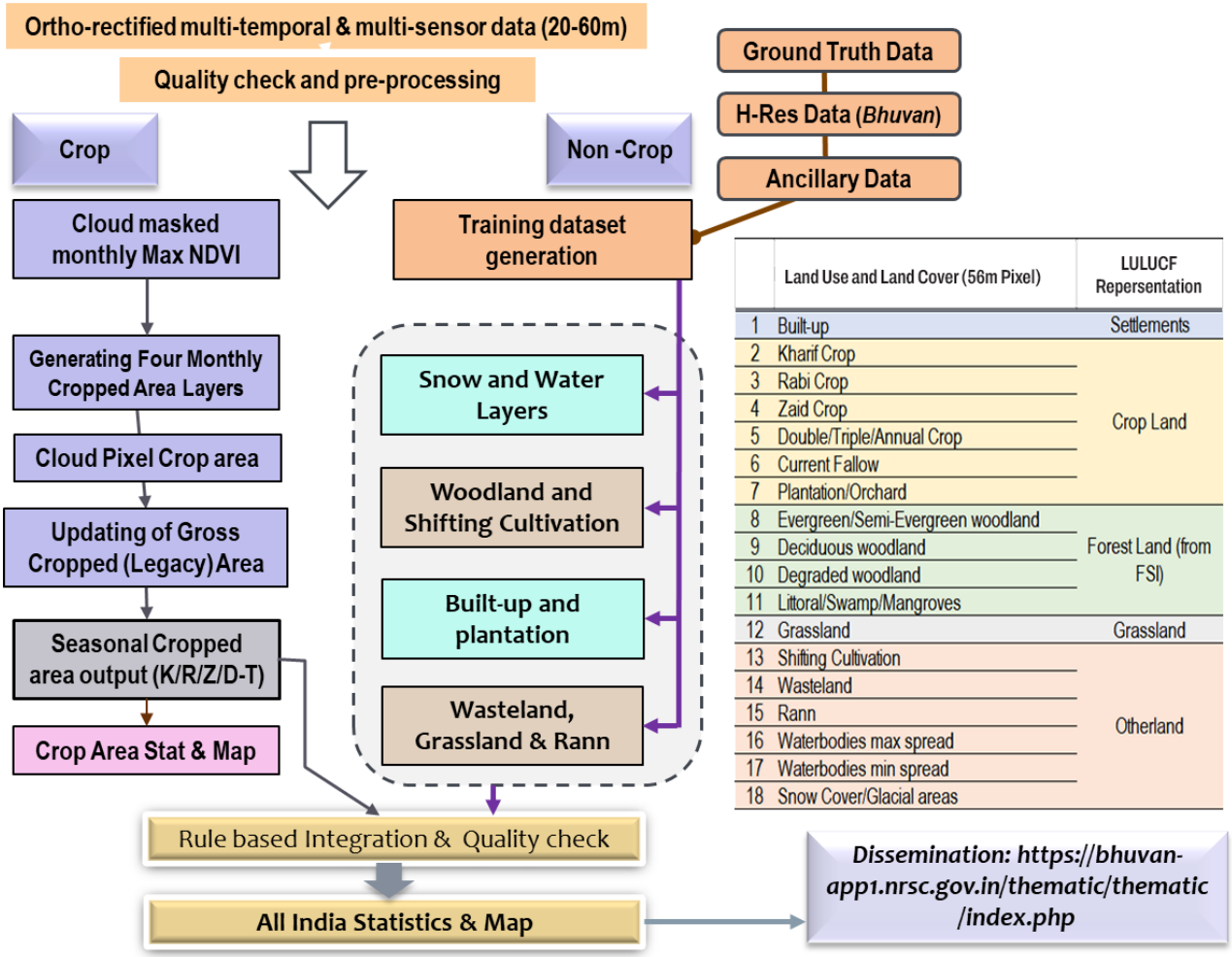


Figure 6.5 Overall approach to delineate land cover classes for the LULUCF sector

Source: NRSC

Annual Land Use and Land Cover Geospatial Database is prepared using a 56 meter spatial resolution data from AWIFS, supported by open source datasets, wherever required. Programme aims to classify entire India for 18 various land cover classes. The programme is carried on a yearly basis since 2004-2005. This programme analyses remotely sensed data to assess Crop Sown Areas in Seasons of Kharif (Monsoon), Rabi (winter) and Zaid (summer) using respective monthly Normalized Difference Vegetation Index (NDVI) composites. It makes use of Otsu Thresholding technique to extract cropped area in Gross Cropped Area envelope for entire country using a tile based method. Essential four interim monthly sown area products viz., August, September, December, and February are also provided to address seasonal patterns.

Classes other than cropped area are derived from multiple sources such as legacy datasets, open source Sentinel images for specific season, as well as visual verification of the information overlaps. Classes such as Built-up, Snow area and Waterbody are extracted using digital classification such as Machine learning methods, while wasteland delineation relies on interactive validation of other expanding landcover elements. Integration of various classes extracted in this way is carried out using a customised tool to consider the primacy of particular class in a defined hierarchy. Outputs are verified for internal coherence of class harmony and with respect to previous year output before preparation of statistics. Outputs are disseminated and visualised (maps/statistics at national and state level) through Bhuvan.

These multiyear datasets are used for providing land representation for the LULUCF Sector. Essentially, these land cover mapping and change assessment analyses between two reporting years are represented based on the proportionality principle. The probability of change of a particular land cover entity to another (e.g., Other Land to Settlement) is applied to compute the land cover change, based on the major land cover transitions between two year period (previous year to current year). Probability is derived from the Transition Matrix between two year spatial datasets at appropriate resolution.

Forest Area proportions are adopted after harmonisation with corresponding State of the Forest Report national level statistics. The generalisation of LULC classes adopted from 18 fold classification to 5 fold classes is shown in Figure 6.5.

Land Classification System: The land use and land cover classification has been done by employing an 18-fold classification system developed for the project by utilizing multi-temporal and multi-sensor satellite data. The details of the classification system are available in LULC Atlas, 2024. The land categories under this classification system are as follows;

- Built-up Land, Cropland, Current Fallow Land, Plantation / Orchard, Woodland, Littoral/Swamp/ Mangroves, Grassland, Shifting Cultivation, Wastelands, Rann, Water Bodies and Snow covered / Glacial areas.

6.3.3. Land Use Database and Sources of Data for Different IPCC Land Categories

The main source of data for area under Forestland is from State of Forest Reports, biennially produced by Forest Survey of India. This is a very detailed biennially produced report, which provides very detailed methodology for monitoring forest area and carbon stock changes. It provides area under different tree crown classes at the state and district level, along with the maps. The latest ISFR 2023 report is published by FSI in the year 2024 (which carries the statistics for the year 2021). Hence, we have extrapolated the values for Forestland and TOF categories for 2022 based on ISFR 2021 (referring to 2019 data) and ISFR 2023 (referring to 2021 data). The main source of data for other land categories; Cropland, Grassland, Flooded Land, Settlements and Other Land category is from *Annual Land Use and Land Cover Atlas* produced by NRSC (2024) annually. The details of the sources of Emission Factors for different land categories and different GHGs are given in the respective land category Sections 6.4 to 6.8 and 6.10 for HWP.

6.3.4. Land Use Conversions among 6 IPCC Land Categories

Spatial estimates of area under different land categories are available under NRSC produced *Annual LULC Atlas 2024*. However, it is still not possible to trace the conversion of Forestland to other land categories or conversion from other land categories such as Cropland, Grassland to Forestland, due to absence of spatially explicit Activity Data for the past 20 years. Similarly, India is unable to estimate and report land conversions for Cropland, Grassland, Flooded Land and Settlements from one Land category to another Land category due to data limitations, especially for the past 20 years. Thus, India is unable to report GHG inventory for Forestland remaining Forestland and Land converted to Forestland or Cropland remaining Cropland and Land converted to Cropland, etc. Further, country specific Emission Factors for different carbon pools for the land remaining in the same category and land converted to another IPCC land category are also not available, limiting the ability to report GHG emissionsand removals separately for land conversions for the past 20 years.

6.3.5. Harvested Wood Products (HWP)

HWP pool is one of the reporting categories in the IPCC 2006 Guidelines. Harvested Wood Products were not considered in GHG emissions/removal estimates in the inventory submissions under the previous National Communications and up to BUR-3 due to lack of Activity Data. A recent report provides Activity Data for the major wood products (Kant and Nautiyal (2021)). Thus, GHG emissions/removals are estimated for HWP pool for the first BTR and reported here. The HWP categories included in the inventory process are as follows:

- Solid Wood
    - Sawn Wood: Wood produced from both domestic and imported roundwood, sawn lengthways, or by profile-chipping processes.
    - Wood Panel: An aggregate category comprising veneer sheets, plywood, particle board, and fiber board.
- Paper and paperboard:

- The paper and paperboard category is an aggregate that includes a variety of products such as graphic papers, sanitary and household papers, packaging materials, and other types of paper and paperboard.

For BTR, the Production Approach (Approach B) is adopted, which utilizes production data for wood products, in line with the IPCC's prescribed methodology for calculating emissions / removals. The contribution of HWP to emissions from sources and removals by sinks is assessed using the IPCC Inventory Software v2.93 supported by the Technical Support Unit (TSU) for IPCC Task Force on National Greenhouse Gas Inventories (TFI). The Production Approach, from IPCC 2006 Guidelines is adopted for estimating changes in carbon stocks specifically within a country's forest pool and the wood products pool derived from domestically harvested wood.

6.3.6. Uncertainty Estimation and Time-series Consistency

The uncertainty analysis conducted for the inventory serves the purpose of assessing the contribution of each input parameter to the overall uncertainty for each source or sink category, quantifying the uncertainty linked to the emission and removal estimates, and evaluating the uncertainty in the overall emissions and removals for both the latest reporting year and the base year, as well as in the emission trends over time.

Uncertainty for the LULUCF sector was calculated following Approach 1, also known as the Error Propagation Approach, as described in the IPCC 2006 Guidelines. The Tier 1 uncertainty analysis (i.e. Approach 1) methodology estimates uncertainties through a two-step process using the error propagation equation. In the first step, uncertainties in Emission Factors and Activity Data are combined for each source category and greenhouse gas. This provides a category-specific estimate of uncertainty, accounting for variations in both Activity Data and Emission Factor estimates. In the second step, these combined uncertainties are used to calculate the overall uncertainty in national emissions, as well as the uncertainty in the trend between the base year and the current year. This method offers a straightforward approach to quantify the uncertainties affecting the inventory, ensuring a consistent and transparent assessment of potential errors across sectors.

The combined uncertainty (Column G of IPCC Guideline) is calculated using the error propagation equation, incorporating both Emission Factor uncertainty (Column F of IPCC Guideline) and Activity Data uncertainty (Column E of IPCC Guideline). The formula used is:

$$G = \sqrt{E^2 + F^2}$$

The combined uncertainty as a percentage of the total emissions in year t (column H of IPCC Guideline) is calculated as:

$$H = \frac{(G * category\ specific\ emission\ in\ year\ t)^2}{(Total\ emissions\ in\ year\ t)^2}$$

The total emission uncertainty is computed using the equation:

$$Total\ emission\ uncertainty = \sqrt{\sum \quad H}$$

The Activity Data for this inventory are sourced from nationally recognized publications by the NRSC and FSI, while Emission Factors are obtained from the national institutions, including NRSC, FSI, and ICAR (NBSS&LUP). For the key land category of Forestland, FSI conducted an accuracy assessment to evaluate the quality of remote sensing data. This assessment involved preparing an error matrix, with a reported producer's accuracy of 92.99% (ISFR, 2021). The accuracy was further validated through Kappa analysis, yielding a score of 0.89% and 0.91% for density wise error matrix and simplified error matrix, respectively. Regarding inventory data, the Standard Error reported for growing stock in Forestland is 4.4%, while for Trees Outside Forests (TOF), it is 1.82% at the national level. Similarly, for the land categories of Cropland, Grassland, Settlements, and Other Land, where Activity Data were derived from NRSC, the accuracy was recorded at 90.07%. The LULUCF sector inventory adopts the Tier 1 Uncertainty Analysis method, and the results from the Error Propagation Approach are presented in the respective sections.

6.4. Forestland

Forestland in India covers 71.61 Mha, which accounts for about 21.7% of the total geographical area during 2022. The dominant areas under forests are located in the ecologically sensitive regions like the Northeastern states, the Western Ghats, and the Himalayan belt, which are crucial for maintaining biodiversity and carbon sink. Forestland has been a carbon sink since 2005. Forest fire related emissions of CH_4 and N_2O contribute marginally to the emissions from Forestland.

6.4.1. Forestland Category Description

Forest Survey of India (FSI), an organization under the Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India, has been monitoring forest resources of India through periodic assessments and presents these results in their biennial publications, "India State of Forest Report" (ISFR). FSI initiated the forest area assessment in 1987 and since then wall-to-wall Forest Cover Mapping (FCM) of India is being carried out using remote sensing based methodology.

Forest cover refers to any land area that is covered by forest resources in the country. All lands more than 1 hectare area, with a tree canopy density more than 10 percent including tree orchards, bamboo, palms etc., occurring within recorded forest and other government lands, private community or institutional lands are included in the assessment of forest cover. The forest cover reported by FSI does not differentiate between the origin of tree crops (whether natural or manmade) or tree species. LISS-III data with the resolution of 23.5 meters allows mapping at the highest scale of 1:50,000 at which Minimum Mapping Unit (MMU) becomes 1 hectare. During the interpretation of the satellite data, FSI classifies forest cover into three different classes: Very Dense Forests (VDF), Moderately Dense Forests (MDF) and Open Forests (OF). The distinction between the three classes is based on the canopy density, the details of which can be found in Table 6.5 and Figure 6.6 provides canopy density classes and scrub land. In addition to these three classes, scrub areas, which are not part of the forest cover, are also classified and mapped.

Table 6.5 Forest cover classification in terms of canopy density classes

Class	Description
Very Dense Forest	All lands with tree canopy density of 70 percent and above.
Moderately Dense Forest	All lands with tree canopy density of 40 percent and more but less than 70 percent.
Open Forest	All lands with tree canopy density of 10 percent and more but less than 40 percent.
Scrub	Forest lands with canopy density less than 10 percent.
Non-forest	Lands not included in any of the above classes. (includes water)
Source: ISFR, 2023	

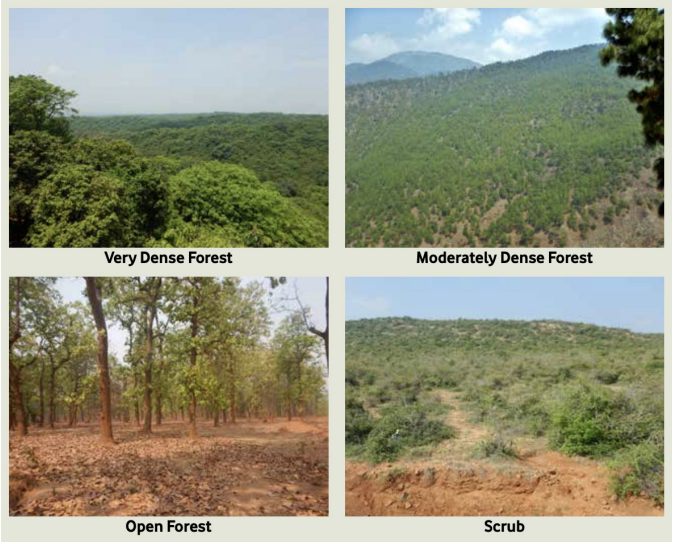


Figure 6.6 Pictorial depiction of different forest cover classes and scrub land

Source: ISFR, FSI 2023

6.4.2. Methodological Issue

6.4.2.1. Forest Cover Activity Data

India has adopted Tier 2 approach to estimate GHG emissionsand removals from Forestland. The Forest Survey of India (FSI) utilises remote sensing-based methodologies for its Forestland area estimation. Since the release of its first report in 1987, FSI has continuously adapted to technological and methodological advancements in forest cover mapping, driven by the availability of improved satellite data, larger mapping scales, and enhanced interpretation methods. The inaugural 1987 report utilized LANDSAT-MSS satellite data with a spatial resolution of 80 meters. Over time, the methodology evolved alongside advancements in satellite data resolution and mapping scales, with a significant shift to digital interpretation by 2001. In the most recent assessments, the IRS-Resourcesat LISS III sensor has been employed for remote sensing, offering a spatial resolution of 23.5 meters at a mapping scale of 1:50,000. The data generated from this monitoring process is used as Activity Data for GHG Inventory.

The forest cover assessment utilizes a hybrid approach for classifying satellite data, integrating digital image processing, visual image analysis, post-classification comparison, ground truthing, and validation by State Forest Departments. This process includes incorporating post-field corrections and generating outputs in the form of maps and area statistics. The hybrid classification method employed in forest cover mapping capitalizes on algorithms to cluster pixels with close associations and then assigns them to appropriate forest cover density classes. Over successive Forest Cover Mapping (FCM) cycles, continuous refinements have been made to capture the latest developments in image interpretation techniques.

Each assessment estimates changes in forest cover compared to the previous assessment, analysing not only transitions between forest and non-forest areas but also shifts within the forest, such as changes in canopy density classes. Increases in forest cover are primarily attributed to conservation efforts, afforestation initiatives, improved protection measures for forests and plantations, and the management of traditional forests. However, some negative changes in specific forest types are observed, often due to the harvesting of short-rotation plantations, shifting cultivation practices, biotic pressures related to climate change, and developmental activities. Additionally, certain changes arise from subjectivity in classification aspects, indicating the need for further analysis using high-resolution data and enhanced ground-truthing techniques. Ground truthing is a crucial component of remote sensing-based assessment and mapping of forest resources, linking image data to ground reality. During the most recent FCM cycle, analysts from FSI ground-truthed 4,780 points, the officials of State Forest Departments verified 3,714 points, as shown in Figure 6.7.

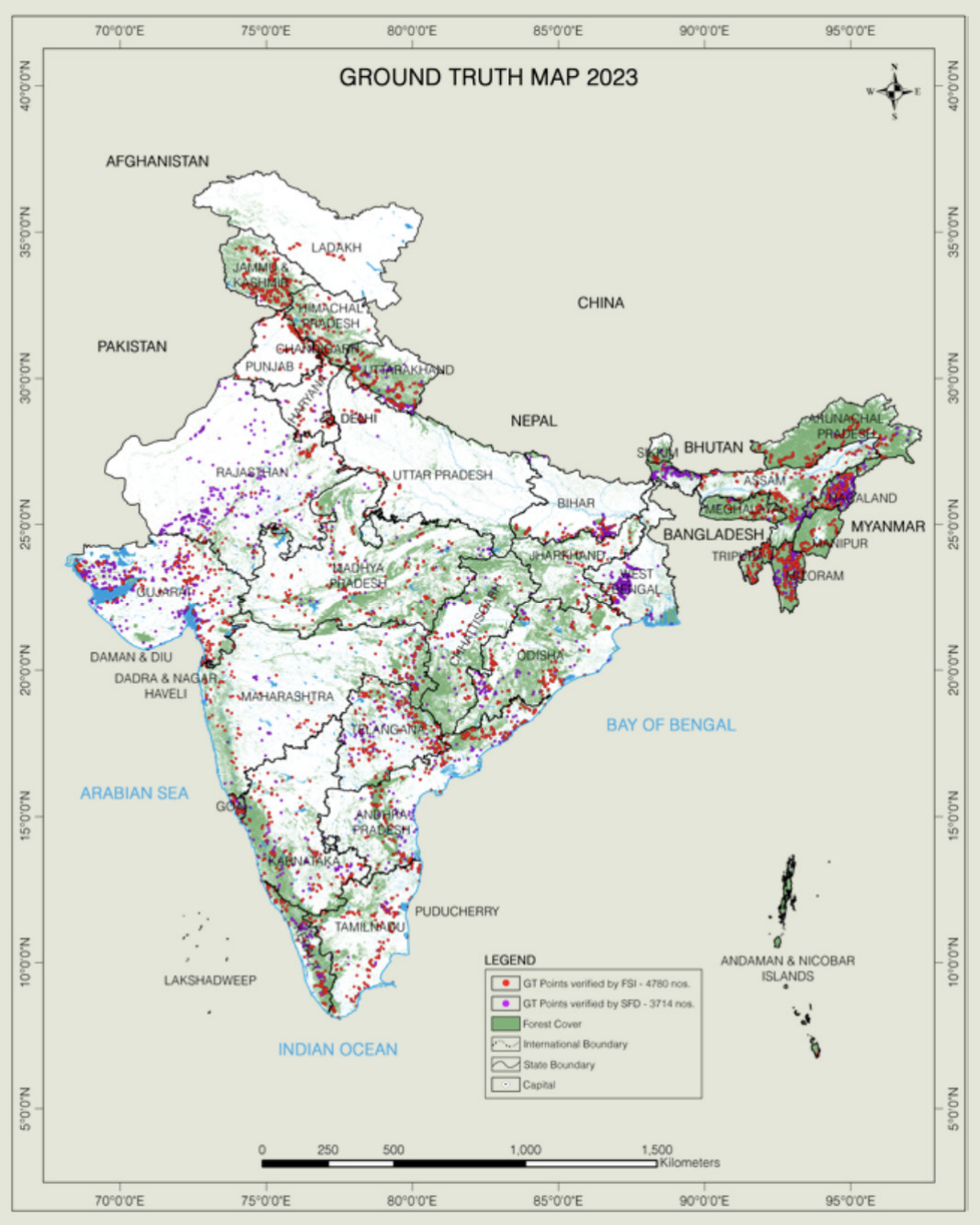


Figure 6.7 Ground truthing mapping for forest cover

Source: ISFR, FSI, 2023

6.4.2.2. Trees Outside Forest (TOF) Activity Data

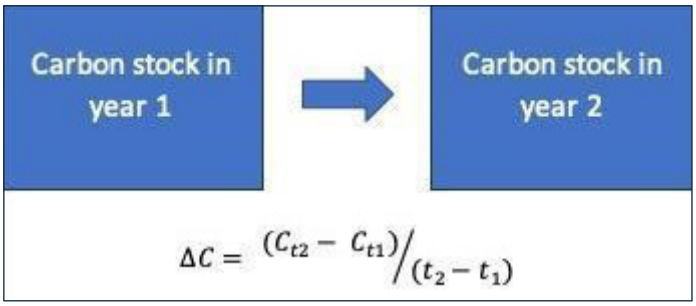
Apart from forest cover assessment, FSI also estimates area under Trees Outside Forest (TOF).

TOF refers to all trees growing outside recorded forest area (RFA), irrespective of patch size. Tree cover, which are scattered trees and isolated patches of trees, is a subset of TOF. Within the country, there are small patches of trees which are less than 1 hectare in extent in farms, village woodlots, homesteads and trees along linear features such as roads, canals, bunds, trees in urban areas, and also scattered trees, which do not get included in the forest cover assessment due to technological limitations of satellite data used for forest cover mapping. The extent of such small patches of trees outside forests is estimated as tree cover using a methodology based on stratified random sampling, and estimated partly by using high-resolution data and partly from field inventory data. Since 2016, with the implementation of the new National Forest Inventory (NFI) design, tree cover of the

country has been estimated state-wise using data collected during the inventory of TOF in urban and rural areas by adopting the grid-based inventory design (refer for details to ISFR 2023).

6.4.2.3. Methods for Estimating Carbon stock

The Forest Survey of India (FSI) estimates Carbon stock using a post-sampling stratification approach, where sample plot data from the National Forest Inventory is combined with forest cover and forest type layers. A forest type refers to a distinct unit of vegetation with broad physiognomic and structural characteristics that allow it to be differentiated from other vegetation units. The Forest Survey of India (FSI) initially mapped India's forest types in 2011, based on the Champion & Seth (1968) classification, at a 1:50,000 scale. Recently, FSI completed a second exercise aimed at refining this forest type map. Using these updated forest type maps, the distribution of forest cover across different forest types in the country has been determined. Forest cover data, classified into three density classes, has been overlaid on the forest type map, which includes 17 type groups such as trees outside forests and plantations, resulting in 51 distinct strata. GIS was used to generate area statistics for each stratum. This stratification process improves the accuracy of estimates by dividing a heterogeneous population into more homogeneous sub-populations based on specific stratification criteria. Since forest carbon storage in vegetation is highly influenced by both canopy density and forest type, these two layers are crucial for assessing forest carbon stock across the country. Change in forest carbon stock between two assessments is used to calculate the annual change in biomass carbon stock, using stock difference approach (GPG, 2003) as shown in Figure 6.8.



Where: ΔC = Annual carbon stock change in pool (tC/yr)

Ct1 = Carbon stock in pool at time t1 (tC)

Ct2 = Carbon stock in pool at time t2 (tC)

Figure 6.8 Carbon stock estimation approach

A flowchart describing the methodology used to estimate carbon stock is given in Figure 6.9. FSI has developed volume equations for various forest species and, through specialized studies, and has created biomass equations for key species across different forest types. By applying forest type-specific volume equations and Biomass Expansion Factors (BEF), biomass in different pools is determined. The specific gravity and carbon content in biomass for different forest types/species, as referenced in various literature, including the IPCC Guidelines (2006), are used in estimating forest carbon stocks. With data from over 23,500 sample plots collected over the years, FSI estimates Above Ground Biomass (AGB), Below Ground Biomass (BGB), Dead Organic Matter (DOM), Litter, and Soil carbon pools for all Forestland in each biennial report. AGB is calculated using FSI-developed volumetric equations, while BGB is estimated using default IPCC values for the root-to-shoot ratio, linking AGB to BGB for carbon estimates. DOM, Litter, and Soil organic matter are sampled from selected inventory plots, with carbon stock in these pools separately estimated in laboratories.

The methodologies implemented by FSI for the National Forest Inventory (NFI) have significantly enhanced the stratification of Forestland, allowing for a more detailed and accurate classification of areas under different forest categories based on density and forest type. However, a critical challenge persists in estimating carbon stock for "Forestland remaining Forestland" and "Land converted to Forestland" categories, primarily due to the lack of Activity Data on the origin of land converted to forests and relevant Emission Factors for different land categories that have been converted to Forestland.

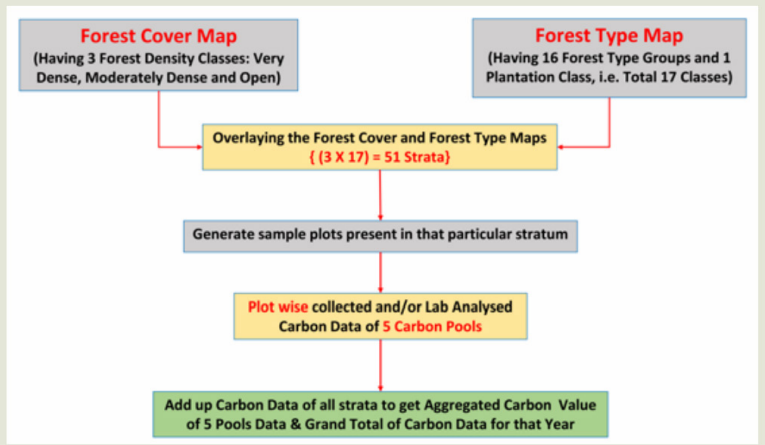


Figure 6.9 Schematic representation of method for estimating forest carbon stocks

Source: ISFR, FSI 2023

6.4.2.4. Forest Fire Emissions

FSI provides information on forest fires in India, including the extent of forest fire exposure and the area burnt by forest fires. Currently, Forest Survey of India (FSI) has been alerting State Forest Departments about forest fire incidences detected by MODIS (Moderate Resolution Imaging Spectro-radiometer) sensor on-board Aqua and Terra Satellite of NASA and based on SNPP-VIIRS sensor. The burnt area assessment has been carried out to assess the fire affected forest areas at country level using Sentinel 2 and Landsat 8/9 satellite data. Apart from high temporal and high spatial resolution satellite data, ancillary data has also been used to assess the accuracy of the satellite data. In the present assessment, the Near Real-Time Forest Fire Detections and Large Forest Fire Detections have been used for better identification and delineation of the burnt areas. While the geo-coordinates of the near real-time detections have helped in better identification of the locations of the burnt scars, the large forest fire polygons have helped in the identification of the extent of the scars. The forest area burnt is then converted to CH_4 and N_2O emissions by multiplying the combustion efficiency, the methane and nitrous oxide emission factors and the GWP of methane and nitrous oxide respectively. The combustion efficiency and Emission Factors are taken from IPCC default values and the GWP values are taken from IPCC AR5.

6.4.2.5. Trends in Area under Forestland from 2005 to 2022

The forest cover assessment by FSI utilizes a hybrid approach for classifying satellite data, integrating digital image processing, visual image analysis, post-classification comparison, ground truthing, and validation by State Forest Departments. The overall trend in forest cover since 2005 is shown in Figure 6.10.

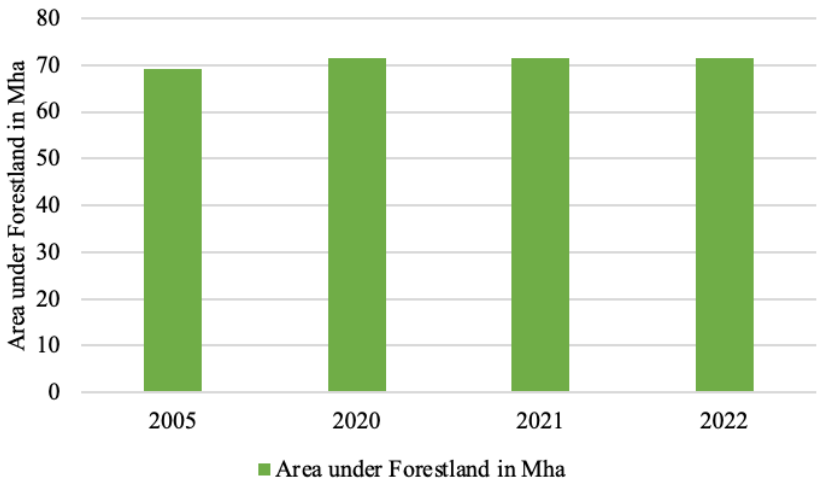


Figure 6.10 Trends in area under Forestland

Source: ISFR, 2023, FSI

Activity Data: In 2022, according to the FSI assessment, forest cover is estimated to be 71.61 Mha, which accounts for 21.7% of the total geographical area of India. There is an increase of 2.45 Mha between 2005 to 2022. Over the past decades, overall forest cover in India has been growing. Under the National Afforestation Programme, there has been large afforestation drives within the country, and aided by the efforts from the State Forest departments in increasing afforestation as well as conservation practices, there is an increasing trend in forest cover in India. In 2011 there was also a drive to increase Mangrove regeneration, a high carbon density forest type.

6.4.2.6. Carbon Stock Change in Forestland during 2022

Emission Factors: FSI measures carbon stock in different pools of the forest cover, namely, Above Ground Biomass (AGB), Below Ground Biomass (BGB), Litter, Dead Organic Matter (DOM) and Soil Organic Carbon (SOC). The method for estimating different carbon pools is described in Section 6.6.

The total carbon stock estimated for Forestland during the year 2022 is 7,326.775 MtC. There is an increase of 41.275 MtC from 2021 to 2022. The breakup of the total carbon stock into different carbon pools can be seen in Table 6.6. Soil organic carbon is the largest pool contributing to 54.7% of the total carbon stock, followed by AGB (32.7%) and BGB (10%). Maximum change observed from the previous assessments is in AGB which can be attributed to increase in forest cover, restoration and conservation activities leading to enhanced carbon capture ability of the forests.

Table 6.6 Carbon stocks (MtC) in different carbon pools during 2005, 2020, 2021 and 2022

Pools (Carbon stock in million tonnes)	C stock in 2005 (Based on ISFR 2011 and ISFR 2015)	C stock in 2020 (Interpolated Based on values from ISFR 2021 and ISFR 2023)	C stock in 2021 (ISFR 2023	C stock in 2022 (Projected Based on values from ISFR 2021 and ISFR 2023)
AGB	2190	2347.15	2374.40	2401.821
BGB	690	727.05	735.20	743.403
Dead wood	26	52.05	56.40	60.754
Litter	129	107.55	107.80	108.058
Soil	3891	4010.95	4011.70	4012.739
Total	6,926	7,244.75	7,285.50	7,326.775

Source: Forest Survey of India (ISFR 2011, ISFR 2015, ISFR 2021 and ISFR 2023)

6.4.2.7. CH_4 and N_2O Emissions from Forest Fires during 2022

Forest fires occur periodically in Indian forests. Forest fires may also provide benefits in terms of clearing forest floor and paving way for regeneration of grass, herbs and saplings. Controlled forest fires are often used as resource management tools for eliminating excessive fuel built up in forest areas. In India, more than 36% of forest cover is prone to frequent fires which includes mostly dry deciduous forests. Since 2004, FSI has been assisting state forest departments and other agencies in dealing with problems associated with forest fires using remote sensing and other communication technology.

The Forest Survey of India (FSI) categorizes burnt forest areas into three levels of fire intensity classes: mild, moderate, and heavy. The overall trend in area subjected to different fires is presented in Table 6.7. Over the recent years, the area affected by mild fires has been on a declining trend. In contrast, the areas impacted by both moderate and heavy fires have shown an increase. In 2022, forest fires contributed to an estimated 1253.65 $GgCO_2eq$ of Methane (CH_4) emissions and 191.93 $GgCO_2eq$ of Nitrous Oxide (N_2O) emissions.

Table 6.7 Trends in area subjected to forest fire during 2005 to 2022, quantity of biomass burnt annually and CH_4 and N_2O emissions

Year	Mild fire area		Moderate fire area		Heavy fire area		Total mass of available fuel burnt in tonnes dry matter	CH_4 emission in tonnes	CH_4 emissions in CO_2-Eq (tonnes)	CH_4 emissions in CO_2-Eq (Gg)	N_2O emissions in tonnes	N_2O emissions in CO_2-Eq (tonnes)	N_2O emissions in CO_2-Eq (Gg)
	Area subjected to mild fires in hectares	Biomass burnt (t/ha) in mild fire area	Area subjected to moderate fires in hectares	Biomass burnt (t/ha) in moderate fire area	Area subjected to heavy fires in hectares	Biomass burnt (t/ha) in heavy fire area							
2005	1847182	1.33	848665	4.01	172841	11.11	7780162	29097.81	814738.59	814.74	470.70	124735.45	124.74
2020	607704	1.37	870540	4.43	462431	13.29	10838517	40536.06	1135009.55	1135.01	655.73	173768.53	173.77
2021	6,71,625	1.43	9,42,600	4.41	5,59,500	12.62	12178180	45546.39	1275298.98	1275.30	736.78	195246.67	195.25
2022	6,58,995	1.43	9,08,413	4.41	5,56,500	12.62	11971494	44773.39	1253654.87	1253.65	724.28	191932.98	191.93

Source: FSI
*CO_2 e emissions for CH_4 = [Biomass burnt in tonnes * Combustion Factor (0.55) * Emission Factor (6.8)]/1000*
*CO_2 e emissions for N2 O = [Biomass burnt in tonnes * Combustion Factor (0.55) * Emission Factor (0.11)]/1000*
Conversion factor for CH_4 to CO_2 eq = 28 and Conversion factor for N2 O to CO_2 eq = 265

6.4.2.8. GHG Emissions and Removal Estimates in CO_2 eq for 2022

Table 6.8 provides estimates on India's forest carbon stock (comprising biomass carbon pools and soil organic carbon) for 2005, 2020, 2021 and 2022, along with the net annual change in carbon stock and its equivalent in CO_2 emissions/removals.

In 2022, India's Forestland continued to play a crucial role in Greenhouse Gas (GHG) removals, with a substantial increase in carbon stock. The total carbon stock in 2022 is estimated to be 7,326.775 MtC. This resulted in GHG removals of 151,341.67 $GgCO_2$. The carbon stock estimates for 2022 reflect the continuation of India's afforestation, reforestation, and sustainable forest management efforts, which have been steadily improving since 2018. This significant carbon sink capacity in the forestry sector helps offset emissions from other sectors and aligns with India's climate goals under its Nationally Determined Contributions (NDCs) to reduce the intensity of GHG emissionsand enhance carbon sinks. The trend in carbon removals indicate India's increasing commitment to climate action through the forestry and land-use sector.

Table 6.8 Carbon stock change and CO_2 emissions / removals from Forestland for the period 2005 to 2022

Year	Total Carbon Stock (MtC)	Total net annual change in carbon stock MtC during the year	Total net annual change carbon stock in $MtCO_2$ during the year	Total net change in Carbon stocks in $GgCO_2$
2005	6,926.00	6.00	22.00000000	22,000.00
2020	7,244.75	40.75	149.4166667	1,49,416.67
2021	7,285.50	40.75	149.4166667	1,49,416.67
2022	7,326.775	41.275	151.3416667	1,51,341.67

**The estimates for 2020 and 2022 is based on estimates for ISFR-2021 and ISFR-2023*

6.4.2.9. Trends in GHG Emission from Forestland from 2005 to 2022

The trends in GHG emissionsfor the period 2005, 2020, 2021 and 2022 are given in Table 6.9. This includes CO_2 removals and CH_4 and N_2O emissions expressed in terms of $GgCO_2$ eq. The total net CO_2 removals from Forestland is estimated to be 149,896.08 $GgCO_2$ during 2022. CO_2 removal dominated the inventory for Forestland with CH_4 and N_2O emissions being insignificant.

Table 6.9 Trends in CO_2, CH_4, N_2O and net GHG emissions from Forestland in $GgCO_2$ eq

Year	Net CO_2 removals in $GgCO_2$ eq	CH_4 emissions in $GgCO_2$ eq	N_2O emissions in $GgCO_2$ eq	Total net CO_2 removals in $GgCO_2$ eq
2005	22000.00	814.74	124.74	21,060.53
2020	149,416.67	1135.01	173.77	1,48,107.89
2021	149,416.67	1275.30	195.25	1,47,946.12
2022	151,341.67	1253.65	191.93	1,49,896.08

6.4.3. Flexibility applied

India has utilized the flexibility provision related to time-series reporting, reflecting a strategic approach that balances transparency commitments with practical implementation constraints. This selective reporting approach was necessitated by the unavailability of comprehensive activity data for certain historical periods, financial constraints associated with extensive annual estimations, and ongoing institutional capacity-building efforts. The applied flexibility ensures meaningful participation in global climate transparency while recognizing the technical and resource limitations inherent in developing comprehensive historical datasets. India remains committed to progressively expanding its time-series reporting in future BTRs as national data governance frameworks mature and institutional capacities are strengthened in alignment with BTR requirements.

6.4.4. Uncertainty Estimation for Forestland and Time-series Consistency

The uncertainty analysis for the LULUCF sector, based on data from FSI, highlights a combined uncertainty of 9.57% for Forestland emissions, which is influenced by 7.01% uncertainty in Activity Data and 6.51% uncertainty in Emission Factors. This combined uncertainty reflects the inherent challenges in accurately estimating emissions and removals, stemming from data collection variability and assumptions in Emission Factors (Table 6.10). While uncertainties remain, they are relatively low, supporting the reliability of the estimates. Continued efforts to improve data precision will further reduce these uncertainties in future inventories.

Table 6.10 Uncertainty estimates for Forestland category

Land Category	Gas	Base year emission	Year t (2022) emission	Activity data uncertainty	Emission factor uncertainty	Combined uncertainty $\sqrt{E^2 + F^2}$
A	B	C	D	E	F	G
LULUCF		$GgCO_2e$	$GgCO_2e$	%	%	%
Forestland	CO_2	-21,060.53	-149,896.08	7.01	6.51	9.57

6.4.5. Forestland Category Specific QA/QC and Verification

Systematic quality assurance and quality control (QA/QC) for the national inventory are conducted through workflow checks, benchmark checks, and external reviews.

The Forest Survey of India (FSI) performs its own quality checks by adhering to defined quality standards through concurrent monitoring at every step of the process. These quality standards are strictly followed according to predefined formats outlined in the ISFR 2021 manual. For Activity Data, FSI carries out thorough checks at multiple levels during the image interpretation process for forest type classifications. A dedicated QA/QC team monitors progress throughout the process, and a final round of QA/QC is conducted at FSI headquarters.

Global Forest Watch (GFW, 2024), a platform managed by the World Resources Institute (WRI), provides global satellite-based forest data using different methodologies from FSI. It uses satellite data at 30-m resolution to estimate tree cover (>10% canopy cover). Emissions, removals, and net flux reflect the annual average over the model period. Values are applicable to forest areas (canopy cover >30 percent and >5 m height) and areas with tree cover gain (Harris et al. 2021). Although methodology used by GFW is geared towards monitoring forest and tree cover loss especially in natural forests, they provide data for three years (2000, 2010 and 2020) for natural forests and plantations separately. Since FSI includes Trees Outside Forest areas (TOF), plantations, and certain degraded forests that show a degree of tree cover in their forest cover estimates, both the natural forests and plantations from GFW were combined for the benchmark assessment. Comparing the two datasets, an average 4.2% disparity is seen in the Activity Data. This difference can be attributed to the difference in methodology used, the definitions of forest and tree cover as well as the lack of total forest and tree cover data. Despite the disparity between the two methodologies, the margin of difference is low. The GFW dataset also provides estimates of net removals of GHG emissionsby tree cover. Although the year-to-year value is not given, an average per year estimate (from 2001 to 2023) has been provided (net removals of -88.1 $MtCO_2e$/year) which differs from the reported figure by 16%. This difference can be attributed to the global average emission factors used to estimate the carbon capture and emissions from Forestland (Harris et al. 2021). Another dataset that has been used to perform the benchmark assessment is provided by The Food and Agriculture Organization (FAO) of the United Nations which publishes the Global Forest Resources Assessment (FRA). This database provides forest cover estimates for various countries, including India. The FRA is a country-driven process and the assessments are based on reports prepared by officially nominated National Correspondents. The FAOSTAT land area figure for the year 2015 is used for all reference years. Food and Agriculture Organization of United Nations (FAO) monitors world's forests at five year intervals. In FAO's 2020 assessment, India's forest area was estimated to be around 77.218 Mha, similar to the FSI figure (difference of 6.9% in Activity Data). The average difference in the carbon stock estimates between inventory reported values and the FAO data is 6.5%. However, FAO's assessment uses a more globalized approach to defining and measuring forests. FSI uses India-specific definitions of forest cover, which include both natural forests and plantations, while FAO uses a global standard definition that does not always align with FSI's broader inclusion of TOF and plantations. Comparisons of both GFW and FAO database highlights the importance of region-specific estimates of Activity Data and Emission

Factors and the need for further investigations into more stratified approaches of estimating carbon capture potentials of Forestland.

6.4.6. Forestland Category Specific Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

6.4.7. Land Category-Specific Planed Improvements for Forestland

In this section, the current state of the inventory methods and practices and planned improvements are presented for improving the inventory of Forestland category.

6.4.7.1. Current State of Inventory Methods and Practices

Forestland area estimates: Forestland area estimates are made only for Forestland remaining Forestland based on remote sensing techniques, biennially. Reporting is not done separately for Forestland remaining Forestland and Land converted to Forestland. Currently, area estimates are available according to forest type and tree crown classes and at state and district level.

Emissions/removals of CO_2 were not estimated from Category 4.A.2. Land converted to forest land due to lack of activity data. While emissions/removals of CO_2 from 4.A. Total Forestland, 4.A.1. Forestland remaining forestland, Carbon stock change in living biomass, Losses were notified as 'Included Elsewhere' because 'Stock Difference Method' was used. Emissions/removals of CH_4, N_2O were not estimated from Category 4(IV).A.2. Biomass Burning from Land converted to forest land due to lack of activity data.

Carbon stock estimates: Currently carbon stock is estimated for all the carbon pools in Forestland and further, carbon stock estimates are available for different carbon pools for different forest types.

Carbon stocks in Trees Outside Forests: The biomass stock in TOF is estimated jointly by considering Cropland, Grassland and Settlements. No separate estimates of carbon stock is available for each of these land categories.

Carbon stock in Flooded land: Currently, no GHG estimates are made for Wetlands or Flooded lands and no carbon estimates are available for Forestland converted to Flooded lands.

Adoption of Tier-2 method: Currently India is adopting remote sensing based methods for monitoring the area under different land categories. Geo-spatial transitions from one land category to another for the past 20-years is lacking. India has not adopted Tier-3 or model-based approach.

6.4.7.2. Planned Improvements in Forestland GHG Inventory Assessments

Table 6.11 provides strategies, proposed for addressing the current limitations with respect to Activity Data and Emissions Factors to improve the GHG inventory for Forestland category for the future assessments.

Table 6.11 Forestland category-specific planned improvements

Land category-specific planned improvements	Strategy	Timeline
Separate area monitoring for - FL remaining FL and - Land converted to FL during the previous 20-year period - FL remaining FL and L converted to FL for different forest types namely Evergreen forests, Moist deciduous forests, Dry deciduous forests, Pine forests, etc.	- Remote sensing technique-based monitoring of area under Forestland remaining Forestland and Land converted to Forestland from 2004 to all the future inventory years. - It is planned to adopt geospatial tracking of land use change from non-forestland category to Forestland category on a biennial basis. - Attempts will be made to separately estimate area under Forestland remaining Forestland and Land converted to Forestland and also for different forest types such as	By 2030

Land category-specific planned improvements	Strategy	Timeline
	• Evergreen forests • Moist deciduous forests • Dry deciduous forests • Pine forests, etc.	
Separate monitoring for carbon stock of different carbon pools separately for - FL remaining FL and - Land converted to FL	- It is proposed to estimate the changes in carbon stock of different carbon pools separately for • FL remaining FL and • Land converted to FL	For 2026 inventory year
Carbon stocks in Trees Outside Forests	It is proposed to monitor biomass stock change in Trees Outside Forests separately for different non-forestland categories namely; - Cropland including its sub-Categories - Grassland including its sub-Categories - Settlements including its sub-Categories It is proposed to monitor biomass carbon stock change for Land remaining in same category and Land converted to other category - Cropland including Sub-Categories - Grassland including Sub-Categories - Settlements including Sub-Categories	2030
Biomass stock burnt in Grasslands	It is proposed to estimate biomass stock in Grasslands subjected to Grassland fires - According to Grasslands in different Agro-climatic zones - Grassland types - According to GL remaining GL and Land converted to GL	2030
Carbon stock in Flooded land	It is proposed to monitor Carbon stock in Forestland categories converted to Flooded land biennially for the future GHG inventory estimates - Carbon stock in Forestland converted to submerged land for reservoirs and lakes	2030
Plan for transition to Tier-3 modelling approach	India proposes transition from Tier – 2 to Tier – 3 based on modelling approach - Generate data required for modelling of carbon stocks and flows in Forestland, according to sub-categories - FL remaining FL and - Land converted to FL Modelling of carbon stocks and flows in forest sector	2030
Planned improvement for uncertainty assessment	Attempts will be made to reduce the uncertainties for Forestland category by establishing long-term monitoring of carbon pools in different forest types.	2030

6.5. Cropland

Cropland is the dominant land category in India, which includes net cropped / net sown area and fallow land, which are temporarily not under crops. Cropland accounts for 172.50 Mha of the total geographic area of India during 2022. Cropland category has been a dominant sink of carbon, contributing to net CO_2 removals during the recent GHG inventory submissions. In this chapter, details of the definitions, methods for estimating Activity Data and Emission Factors, methods for estimating area under Cropland, carbon stock changes, uncertainty estimates and planned improvements are presented.

6.5.1. Category Description

Croplands may be defined as those lands which are cultivated to produce food crops and related activities. This includes annual and perennial Croplands including Orchards and Agroforestry systems, which do not qualify as forests. Cropland includes all annual and perennial crops (which do not qualify as forest) as well as temporary fallow land (i.e., land left uncultivated for one or several years before being cultivated again). Annual crops may include cereals, pulses, oils seeds, vegetables, root crops, forages, etc. Perennial crops may include

trees and shrubs, in combination with herbaceous crops (e.g. agroforestry or orchards, vineyards and fruit plantations), which do not qualify as forests. CO_2 emissions/removals are estimated only for the perennial tree biomass component in the Croplands, along with SOC for all the Croplands. Activity Data and Emissions/removal Factors for Land converted to Cropland are not available. Therefore, GHG emissions/removals are estimated and reported for the Cropland category as a whole.

6.5.2. Methodological Issues

6.5.2.1. Monitoring of Area under Cropland Category

Area under Croplands are estimated on an annual basis under the Land Use and Land Cover program and reported in the Annual LULC Atlas by NRSC. The methodology for estimating area under Croplands is based on remote sensing techniques using satellite data. The details of the approach and methods for periodic monitoring of area under Croplands is given in Figure 6.3.1 and Section 6.3.2. The Croplands can be further stratified based on multiple criteria as provided by Ministry of Agriculture and Farmers Welfare, which are as follows;

1. Crop and non-cropland categories
   a. Net sown area
      i. Cereals, pulses, oil seeds, sugarcane, cotton, fruit orchards, etc.
   b. Fallow land and other categories
   c. Forestland
2. Irrigated land and Rainfed land
3. State-wise and district-wise.

6.5.2.2. Area Under Different Crops

Area under different crops according to Ministry of Agriculture and Farmers Welfare source is presented in this section. Area under cereals, pulses, oil seeds, sugarcane, cotton, etc. for the reporting periods is given in Table 6.12. It can be observed that cereals dominate the cropping pattern by accounting for 108 Mha during 2022. Further, Rice and Wheat dominate by accounting for 49.90 Mha and 34.80 Mha, respectively during 2022. Horticulture crops which include fruit orchards account for about 12.64 Mha. Area cropped in a given year depends on the rainfall pattern, irrigation water availability, market and availability of input material such as seeds. Rest of the land is left fallow and area under fallow varies from year to year. Out of the total area under crops, area under irrigated crops accounted for 40% during 2022. Rainfed agriculture dominates the cropping landscape in India.

Table 6.12 Trends in area under major crops in Mha

Crop Category	Crops	2005	2020	2021	2022
Cereals	Rice	41.82	48.12	50.44	49.90
	Wheat	23.76	35.51	35.44	34.80
	Maize	6.60	9.73	9.76	10.2
Total Cereals and Millets		99.72	107.98	109.94	108.73
Total Pulses		22.33	26.40	26.34	29.89
Oil Seeds		30.92	29.34	30.92	32.11
Sugarcane		4.65	5.31	5.93	6.50
Total Fibres		9.58	14.04	13.95	13.08
Total Fruits and Vegetables		9.31	11.66	12.40	12.64

Source:

i) For Area under major crops of 2005 data: Department of Economics, Statistics and Evaluation Division, Ministry of Agriculture and Farmers Welfare, GoI, 1996-97 to 2005-06, https://desagri.gov.in/documents-reports/land-use-statistics-at-a-glance/detailed-tables-state-wise-1996-97-to-2005-06/

ii) For Area under major crops of 2020, 2021 and 2022 data: Department of Economics, Statistics and Evaluation Division, Ministry of Agriculture and Farmers Welfare, GoI, 2023

(https://desagri.gov.in/document-report-category/land-use-statistics-at-a-glance/)

6.5.2.3. Trends in Area under Cropland from 2005 to 2022

Area under Cropland for Inventory estimation is provided by NRSC using remote sensing techniques and satellite monitoring data. Area data is also monitored and reported by Ministry of Agriculture and Farmers Welfare. For LULUCF GHG estimation, data from NRSC as given in Table 6.2.1 is considered.

Activity data: Activity Data is estimated by NRSC using remote sensing technology. Area under Cropland, is estimated to be 172.50 Mha during 2022. Cropland area has increased from 160.65 Mha during 2005 to 172.50 Mha during 2022 (Figure 6.11).

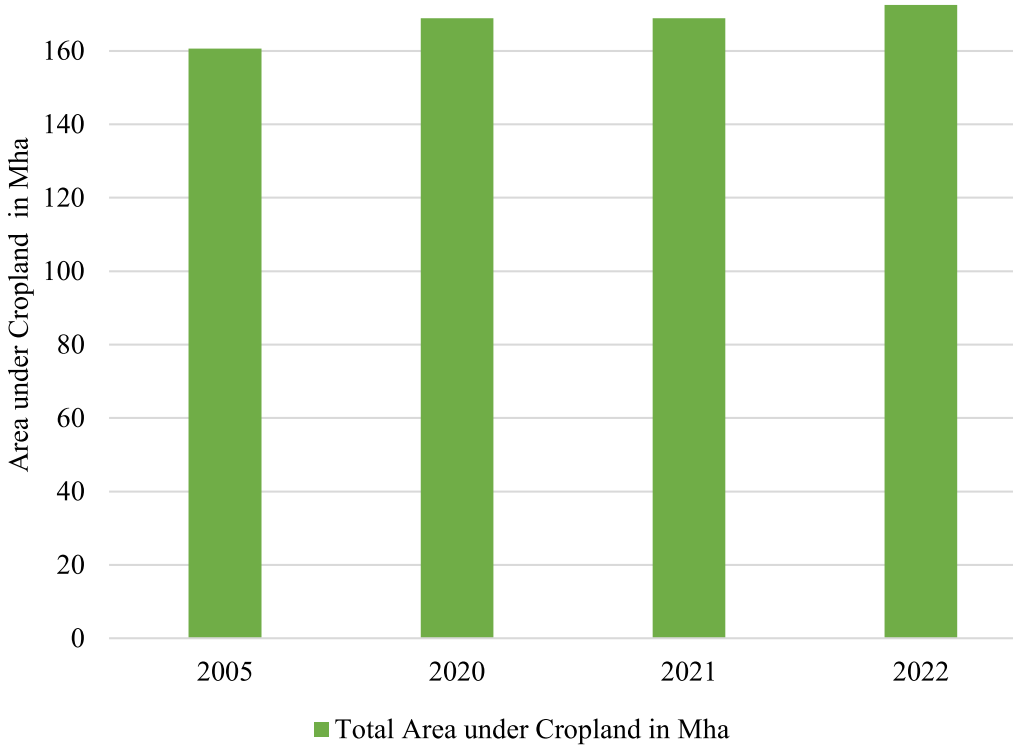


Figure 6.11 Trends in area under Cropland

Source: NRSC

6.5.2.4. Carbon Stock Change in Biomass and SOC in Cropland During 2022

Emission Factors: The two critical Emission Factors for GHG inventory in Cropland are annual rate of change in perennial biomass carbon stock and annual rate of change in soil carbon stock (SOC) on per hectare basis. The methods for estimating the perennial tree biomass carbon stocks in Croplands are similar to the methods adopted in BUR-4, for 2020 and Third National Communication for 2019 inventory, where biomass estimates from TOF (Trees Outside Forests) forms the basis for estimating net carbon stock change in Cropland. The Forest Survey of India periodically conducts inventories of Trees Outside Forests (TOF). Trees Outside Forests include tree cover comprising of small patches of trees (<1.0 ha) in plantations and woodlots, scattered trees and farm trees, homesteads and urban areas as well as trees along linear features such as road, canals and Cropland bunds. The State of Forest Reports provide the growing stock of TOF in cubic metres, for all land categories other than Forestland, including Croplands. NBSS&LUP provides the SOC stock change data based on periodic monitoring and literature review.

Carbon Stock Change in Biomass

FSI biennially estimates above ground biomass stock volume in meter cube including all non-Forestland categories namely Cropland, Grassland and Settlements. This is termed as Trees Outside Forests (TOF). Method for estimating the above ground biomass volume is given in Chapter 6.4. FSI provides a combined biomass stock

estimate in volume terms covering all non-forested lands. Since no separate estimate for biomass volume stock for Cropland category is available, the overall TOF biomass stock estimate is used to derive the rate of change in biomass carbon stock per hectare, which is used along with area under Cropland for estimating CO_2 emissions and removals for Cropland category. The method of estimation and calculations are provided in Table 6.13, which includes the following steps.

1. Consider the total above ground biomass stock in meter cubes estimated for TOF by FSI for all the area under non-forested land categories.
2. Expand the above ground biomass value to total tree biomass by considering Biomass Conversion and Expansion Factor of 0.9, which also includes the density of wood.
3. Estimate the root biomass from root:shoot ratio based on the IPCC default value of 0.27.
4. Calculate the total biomass for 2022 based on extrapolated values from ISFR 2021 and ISFR 2023.
5. Estimate the change in biomass carbon stock between the two periods.
6. Estimate the rate of change in biomass stock per hectare per year by considering the total change in biomass stock divided by the total area under Cropland, Grassland and Settlements.
7. Multiply rate of change in total biomass per hectare per year and the area under Cropland to obtain the net change in carbon stock during 2022, which will be converted to CO_2 removals.

It can be observed from Table 6.13 that the growing stock of biomass in TOF has marginally increased from 0.243 tC/ha/yr during 2020 to 0.245 tC/ha/yr during 2021 and again it is estimated to be 0.243 tC/ha/yr during 2022.

Soil Organic Carbon Stock

Soil Organic Carbon (SOC) stock change is estimated using the stock difference method. SOC values are estimated based on annual change in SOC stock obtained from different studies. NBSS&LUP of ICAR has estimated rate of change in soil carbon stock in Croplands based on 348 multiperiod studies, which included 145 primary measurements made at two periods at the same point and reported by ICAR institutions, and 167 peer reviewed studies for the Indian region. The rate of change in SOC is estimated to be 0.38 tC/ha/yr (Vasu and Tiwary, 2024). SOC rate of change values varied for different soil types from 0.27 tC/ha/yr for red soils to 0.49 tC/ha/yr for black soils. The rate of change used for estimation of net change in SOC stock for Croplands is estimated to be 0.38 tC/ha/yr during 2022. This value is slightly higher than the value used for the Third National Communication (0.367 tC/ha/yr).

Table 6.13 Trends in Biomass and Soil Carbon stocks in Trees Outside Forest (TOF) for Cropland

Description	Cropland			
	2005	2020	2021	2022
Total biomass stocks in Million cum	1616.25	1865.05	1950.75	2036.45
Total aboveground biomass (AGB) in Mt (BCEF of 0.9)	1454.625	1678.545	1755.675	1832.805
Total belowground biomass (BGB) in Mt (root shoot ratio: 0.27)	392.75	453.21	474.03	494.86
Total Biomass (AGB+BGB) in Mt	1847.37	2131.75	2229.71	2327.66
Total biomass carbon (AGB+BGB) in MtC (AGB+BGB in Mt X 0.5)	923.69	1065.8760	1114.8536	1163.8311
Change in biomass carbon stock in MtC/yr	-4.499	48.97755	48.97755	48.97755
Area (Mha) under CL + GL + SL	189.61	201.22	199.70	201.18
Rate of change in biomass carbon in tC/ha/yr	-0.024	0.243	0.245	0.243
Rate of change in SOC in tC/ha/yr for Cropland	0.36	0.38	0.38	0.38
Area under Cropland in Mha	160.65	168.93	168.89	172.50
Total change in biomass carbon stock in MtC for Cropland	-3.8118	41.1180	41.4212	41.9953
Total change in SOC stock in MtC for Cropland	57.8340	64.1934	64.17820	65.55000

Source: FSI for total biomass stock under TOF

6.5.2.5. Trends in CO_2 Emissions / Removals from Cropland

The perennial biomass and soil carbon stock change in Croplands is given in Table 6.14. The rate of change in perennial biomass stock of 0.243 tC/ha/yr and soil carbon rate of change of 0.38 tC/ha/yr during 2022 is used for estimating the net CO_2 emissions / removals from Croplands. It can be observed that Cropland is a net sink of 394,333.00 $GgCO_2$ during 2022, compared to 198,081.23 $GgCO_2$ during 2005. Soil carbon stock change dominates the net removal in Cropland by accounting for 66% of total removals during 2022.

Table 6.14 CO_2 emissions / removals from Cropland in $GgCO_2$ during 2005 to 2022

Year	Area in Mha	Change in biomass carbon stock (MtC)	Change in SOC stock (MtC)	Total change in biomass and soil carbon in Cropland (MtC)	Total net CO_2 removal in Cropland ($GgCO_2$)
2005	160.65	-3.8118472127	57.8340	54.022	1,98,081.23
2020	168.93	41.1180673963821	64.1934	105.311	3,86,142.05
2021	168.89	41.4212239334	64.1782	105.599	3,87,197.89
2022	172.50	41.9953642260662	65.5500	107.545	3,94,333.00

6.5.3. Flexibility applied

India has utilized the flexibility provision related to time-series reporting, reflecting a strategic approach that balances transparency commitments with practical implementation constraints. This selective reporting approach was necessitated by the unavailability of comprehensive activity data for certain historical periods, financial constraints associated with extensive annual estimations, and ongoing institutional capacity-building efforts. The applied flexibility ensures meaningful participation in global climate transparency while recognizing the technical and resource limitations inherent in developing comprehensive historical datasets. India remains committed to progressively expanding its time-series reporting in future BTRs as national data governance frameworks mature and institutional capacities are strengthened in alignment with BTR requirements.

6.5.4. Uncertainty Estimates for Cropland

The methodology followed for the uncertainty analysis in the Cropland category is same as outlined in Section 6.3.6. The Activity Data for this inventory were sourced from nationally recognized publications by the NRSC, and soil organic carbon data were obtained from ICAR (NBSS&LUP). The uncertainty analysis for the Cropland category within the LULUCF sector reveals a combined uncertainty of 24.70%, driven by an Activity Data uncertainty of 9.93% and a significantly higher Emission Factor uncertainty of 22.62% (Table 6.15). The high level of uncertainty underscores the need for improvements in data collection methods and the refinement of Emission Factors to enhance the accuracy of future Cropland emissions estimates.

Table 6.15 Uncertainty estimates for Cropland category

Land Category	Gas	Base year emission	Year t (2022) emission	Activity data uncertainty	Emission factor uncertainty	Combined uncertainty $\sqrt{E^2 + F^2}$
A	B	C	D	E	F	G
LULUCF		**$GgCO_2e$**	**$GgCO_2e$**	**%**	**%**	**%**
Cropland	CO_2	-1,98,081.23	-3,94,333.00	9.93	22.62	24.70

6.5.5. Category Specific QA/QC and Verification for Cropland

The QA/QC process for Cropland data involved thorough consistency checks between Activity Data provided by the Ministry of Agriculture and satellite data from the National Remote Sensing Centre (NRSC). By cross-referencing the two sources, the final Activity Data was selected from NRSC's satellite observations. This was then matched against agricultural statistics to ensure accurate ground truthing, providing a reliable and consistent dataset for Cropland analysis. The Emission Factor for biomass carbon in Cropland data was provided

by the Forest Survey of India (FSI), following the established methodology. FSI applies a rigorous in-house QA/QC process, ensuring the Emission Factor data is accurate and reliable, as described earlier in their multi-level quality assurance procedures.

6.5.6. Cropland Category Specific Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

6.5.7. Land Category-specific Planned Improvements for Cropland

In this section the current approach and methods used for generating Activity Data and Emission Factors, the limitations and planned improvements are presented.

6.5.7.1. Current Approach and Method for GHG Inventory in Cropland

The current approaches and methods for estimating the Activity Data and Emission Factors used in the GHG inventory are presented below.

Tier-2 and Modelling approach: Currently, India has adopted Tier-2 approach for GHG inventory based on country specific data. No modelling is adopted for GHG inventory estimation for Cropland.

Area estimates under Cropland: Currently area estimates for Croplands are made using remote sensing based methods. Area estimates for Cropland category is not made by tracking changes in land category geospatially.

Emissions/removals of CO_2 were not estimated from. 4.B.1. Cropland Remaining cropland, & Net carbon stock change in dead organic matter. Emissions/removals of CO_2 were not estimated from 4.B.2. Land converted to cropland due to lack of activity data. While emissions/removals of CO_2 from 4.B. Total Cropland, 4.B.1. Cropland remaining Cropland, Carbon stock change in living biomass, Losses were notified as 'Included Elsewhere' because 'Stock Difference Method' was used. Emissions/removals of CH_4 & N_2O from Biomass Burning 4(IV).B. Cropland reported in Agriculture Sector. It is mentioned as being included elsewhere.

Carbon stocks in Trees Outside Forests: The biomass carbon stock in TOF is estimated jointly considering Cropland, Grassland and Settlements. No separate estimates are available for Cropland biomass stock change.

Soil Organic Carbon estimation: SOC stock and stock change estimates are based on limited data points for Cropland from monitoring by NBSS&LUP and published reports and studies.

Modelling of SOC stock change: Currently, no modelling of SOC stocks and fluxes is made, and India is adopting Tier-2 approach.

6.5.7.2. Planned Improvements for Cropland GHG Inventory

Current approach, practices and limitations are given above and planned improvements to address the current limitations are given in Table 6.16.

Table 6.16 Cropland category specific planned improvements

Land category-specific Planned Improvements	Strategy	Timeline
Separate Area monitoring for - CL remaining CL and - Land converted to CL during the previous 20-year period - Area monitoring for different Cropland categories namely Agroforestry, Plantations and orchards, Row trees, individual trees, etc.	- Remote sensing technique-based monitoring of area under CL remaining CL and Land converted to CL at 1:50,000 scale from the period 2004 to the future inventory years. - It is planned to adopt geospatial tracking of land use change from non-cropland category to Cropland category on an annual basis. - Attempts will be made to separately estimate area under different categories of perennial biomass in Croplands namely	By 2030

Land category-specific Planned Improvements	Strategy	Timeline
	• Agroforestry, • Plantations and orchards, • Row trees: Cropland boundary or intercropping of trees with crops • Individual trees in Croplands	
Separate monitoring for above ground biomass stock change for - CL remaining CL and - Land converted to CL	Currently, above ground biomass volume stock is monitored for all non-forested land categories jointly for Cropland, Grassland and Settlements. - Attempts will be made to estimate the above ground biomass volume stock separately for CL remaining CL and Land converted to CL category. - Long-term monitoring plots will be set-up in different agro-climatic zones and cropping systems to monitor biomass and carbon stock changes.	For 2026 inventory year
Perennial biomass and Soil Carbon stocks monitoring for Croplands: Agroforestry, Plantations / Orchards (less than 1 ha in area), row trees, etc.	- Attempts will be made to separately estimate biomass carbon stock for different categories of perennial biomass in Croplands namely • Agroforestry, • Plantations and orchards, • Row trees: Cropland boundary or intercropping of trees with crops - Attempts will be made for periodic long-term monitoring of SOC stock changes in different Cropland categories.	2030
Plan for transition to Tier-3 modelling approach	- India is planning to graduate from Tier-2 to Tier-3, based on modelling. - Initial efforts have been initiated by considering modelling efforts done by other countries such as Canada and Australia. - Data required for modelling will be generated by ICAR institutions.	2030
Planned improvement for uncertainty estimates	Attempts will be made to reduce the uncertainties for Cropland category by establishing long-term monitoring of perennial biomass and soil carbon stock change.	2030

6.6. Grassland

6.6.1. Category Description

Grassland includes areas covered with grassy and herbaceous growth as well as degraded forests with less than 10% tree canopy density. In India, Grassland includes a large number of land categories other than Forestland and Cropland. These lands are used for livestock grazing or left barren and are subjected to fire and erosion. According to NRSC *(Annual LULC Report)*, Grasslands is defined as the areas of natural grass along with other vegetation, predominantly grass–like plants (Monocots) and non–grass–like herbs (except Lantana species which are to be classified as scrub). It includes natural/semi–natural grass/ grazing lands of Alpine/Sub–Alpine or temperate or sub– tropical or tropical zones, desertic areas and manmade grasslands. According to the Ministry of Agriculture, the categories included under Grassland area are i) Land not available for cultivation (area under non-agriculture use + barren and unculturable land) and ii) Other uncultivated land excluding fallow land (permanent pasture & other grazing land (Table 6.2.2).

6.6.2. Methodological Issue

6.6.2.1. Monitoring of Area under Grasslands

Area under Grasslands is estimated on an annual basis under the Land Use and Land Cover program and reported in the Annual LULC Atlas by NRSC. The methodology for estimating area under Grasslands is based on remote sensing techniques using satellite data. The details of the approach and methods for periodic monitoring of area under Grasslands are given in Section 6.3.2.

6.6.2.2. Trends in Area under Grassland from 2005 to 2022

Area under Grasslands is provided by NRSC using remote sensing techniques and satellite monitoring data. The details of the area under Grasslands are provided in Table 6.17. and Figure 6.12 and described below.

Activity Data: The area under Grassland was estimated to be 20.35 Mha for the year 2005. The area under Grasslands is varying and is estimated to be 18.03 Mha during 2022. GHG emissions/removals are estimated for Grassland category as a whole, as Activity Data and Emission Factors are not available for Grassland remaining Grassland and Land converted to Grassland category.

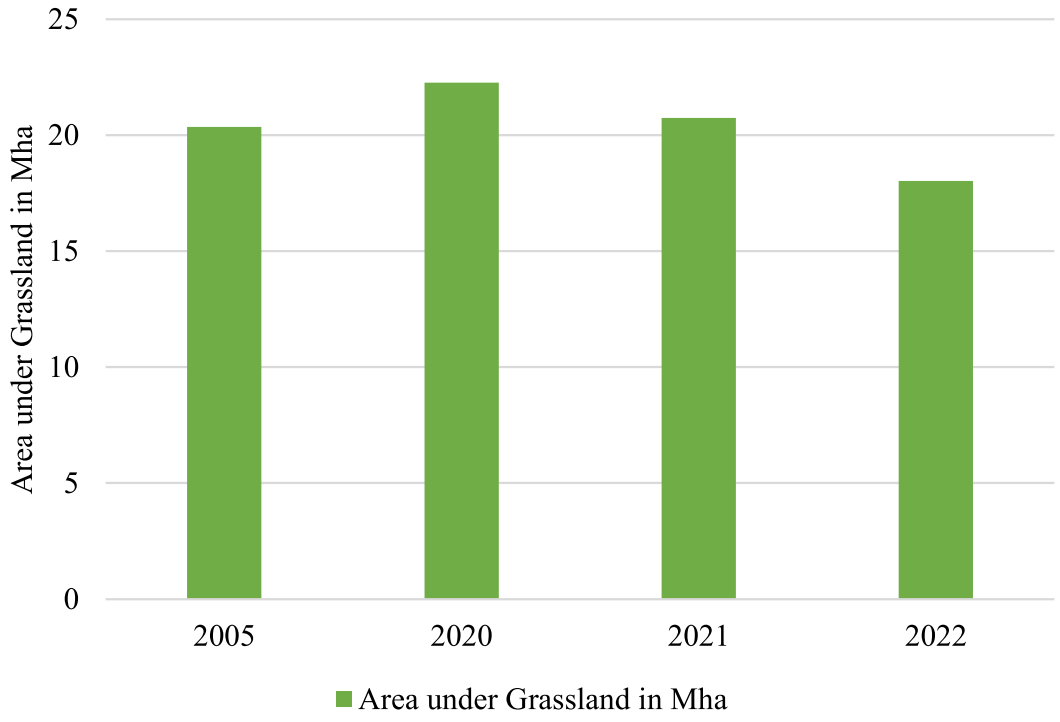


Figure 6.12 Trends in area under Grassland

Source: NRSC

6.6.2.3. Carbon Stock Change in Biomass and SOC in Grassland During 2022

Emission Factor: Emission Factors required for Grassland category include rate of change in perennial biomass carbon stock per hectare per year and rate of change in SOC stock per hectare per year.

Biomass carbon stock change: The main source of data for biomass carbon stock and stock change in Grasslands is from the study on Trees Outside Forests conducted by FSI biennially for non-forestland categories including Grassland, Cropland, and Settlements. Perennial biomass stock change in the Grassland category is estimated by using the method and source of data described for Croplands (Section 6.5.2.4). The perennial biomass stock change is estimated to be 0.243 tC/ha/yr during 2022. It can be observed from Table 6.17 that the growing stock of biomass in TOF was 1,616.25 million m3 during 2005 and it has increased to 2,036.45 million m3 during 2022. The rate of change in biomass stock was -0.023 during 2005 and it has increased to 0.243 tC/ha/yr during 2022.

SOC Stock change: An Emission Factor of -0.31 tC/ha/yr for SOC stock change for Grassland has been used in previous LULUCF sector GHG estimations and reporting. Since, no new additional Emission Factor data are available, the same value is used for 2022 also. SOC stock change is estimated to be -6.31 MtC during 2005 and -5.59 MtC during 2022.

Table 6.17 Trends in biomass and soil carbon stock in Trees Outside Forest (TOF) for Grassland

Description	Grasslands			
	2005	2020	2021	2022
Total biomass stocks in Million cum	1616.25	1865.05	1950.75	2036.45
Total aboveground biomass (AGB) in Mt (BCEF of 0.9)	1454.625	1678.545	1755.675	1832.805
Total belowground biomass (BGB) in Mt (root shoot ratio: 0.27)	392.74875	453.20715	474.03225	494.85735
Total Biomass (AGB+BGB) in Mt	1847.37375	2131.75215	2229.70725	2327.66235
Total biomass carbon (AGB+BGB) in MtC (AGB+BGB in Mt X 0.5)	923.686875	1065.876075	1114.853625	1163.831175
Change in biomass carbon stock in MtC/yr	-4.499	48.97755	48.97755	48.97755
Area (Mha) under CL + GL + SL	189.61	201.22	199.7	201.18
Rate of change in biomass carbon in tC/ha/yr	-0.023727	0.2434029917	0.24525563345	0.243451386
Rate of change in SOC in tC/ha/yr for Grassland	-0.31	-0.31	-0.31	-0.31
Area under Grassland in Mha	20.35	22.26	20.74	18.03
Total change in biomass carbon stock in MtC for Grassland	-0.48	5.42	5.09	4.39
Total change in SOC stock in MtC for Grassland	-6.31	-6.90	-6.43	-5.59

Source: FSI for total biomass stock under TOF

6.6.2.4. Trends in CO_2 Emissions / Removals from Grassland

The perennial biomass and soil carbon stock change in Grasslands is given in Table 6.18. The rate of change in perennial biomass stock of 0.243 tC/ha/year and soil carbon rate of change of -0.31 tC/ha/yr during 2022 is used for estimating the net emissions / removals from Grasslands (Table 6.6.2). It can be observed that Grassland is a net source of 4,399.53 $GgCO_2$ during 2022, compared to 24,901.64 $GgCO_2$ during 2005, due to decline in area under Grassland.

Table 6.18 CO_2 emissions / removals from Grassland in $GgCO_2$ during 2005 to 2022

Year	Area in Mha	Rate of change in biomass carbon (tC/ha/y)	Total biomass carbon stock change in MtC	Rate of change in SOC in tC/ ha/yr	Total SOC stock change in MtC	Total change in biomass and soil carbon stock (MtC)	CO_2 removals in Grassland ($GgCO_2$-e)
2005	20.35	-0.024	-0.483	-0.31	-6.309	-6.79	-24,901.64
2020	22.26	0.243	5.418	-0.31	-6.901	-1.48	-5,435.65
2021	20.74	0.245	5.087	-0.31	-6.429	-1.34	-4,923.59
2022	18.03	0.243	4.389	-0.31	-5.589	-1.20	-4,399.53

6.6.2.5. Direct and indirect nitrous oxide (N_2O) emissions from nitrogen (N) mineralization/immobilization associated with loss/gain of soil organic matter

National emissions of N_2O from managed soils in Grasslands, associated with the loss of soil organic matter, are reported based on the Tier 1 methodology, as detailed in the IPCC Guidelines. The N mineralisation associated with the loss of soil organic matter, resulting from land-use changes or management practices on mineral soils (FSOM), is estimated using this approach due to the lack of specific data on land cover, climatic conditions, soil types, or management practices.

To calculate the average annual loss of soil carbon, a carbon-to-nitrogen (C:N) ratio of 10 was applied. An Emission Factor of 0.005 was adopted (Table 6.19), in line with established literature (Bhatia et al., 2013). The indirect N_2O emissions due to leaching losses of mineralised N has been computed as a fraction of 5% of mineralised N.

Table 6.19 Direct and indirect nitrous oxide emissions from nitrogen mineralization in Grassland

Year	Area in Mha	Total SOC stock change in MtC	Direct N_2O emissions Mt	Indirect N_2O emissions Mt	Net N_2O emissions in $GgCO_2$ eq
2005	20.35	-6.309	-0.004957857	-0.000247893	-1379.52
2020	22.26	-6.901	-0.005421429	-0.000271071	-1508.51
2021	20.74	-6.429	-0.005052143	-0.000252607	-1405.76
2022	18.03	-5.589	-0.004392143	-0.000219607	-1222.11

Conversion factor for N_2O-N to N_2O: 44/28
Conversion factor for N2 O to CO_2 eq = 265

6.6.2.6. Trends in GHG emissions/ Removals from Grassland from 2005 to 2022

The trends in GHG emissionsfor the period 2005, 2020, 2021 and 2022 are given in Table 6.20. This includes CO_2 removals and N_2O emissions expressed in terms of $GgCO_2$ eq. The total net CO_2 removals from Grassland is estimated to be 5,621.64 $GgCO_2$ during 2022.

Table 6.20 Trends in CO_2 and N_2O and net GHG removals from Grassland in $GgCO_2$ eq

Year	Net CO_2 removals in $GgCO_2$ eq	N_2O emissions in $GgCO_2$ eq	Total net CO_2 removals in $GgCO_2$ eq
2005	-24,901.64	-1,379.52	-26,281.17
2020	-5,435.65	-1,508.51	-6,944.16
2021	-4,923.59	-1,405.76	-6,329.35
2022	-4,399.53	-1,222.11	-5,621.64

6.6.3. Flexibility applied

India has utilized the flexibility provision related to time-series reporting, reflecting a strategic approach that balances transparency commitments with practical implementation constraints. This selective reporting approach was necessitated by the unavailability of comprehensive activity data for certain historical periods, financial constraints associated with extensive annual estimations, and ongoing institutional capacity-building efforts. The applied flexibility ensures meaningful participation in global climate transparency while recognizing the technical and resource limitations inherent in developing comprehensive historical datasets. India remains committed to progressively expanding its time-series reporting in future BTRs as national data governance frameworks mature and institutional capacities are strengthened in alignment with BTR requirements.

6.6.4. Uncertainty Estimates for Grassland

The methodology followed for the uncertainty analysis in the Grassland category is the same as outlined in Section 6.3.6. The uncertainty analysis for Grassland emissions in the LULUCF sector shows a combined uncertainty of 73.77%, largely driven by the high Emission Factor uncertainty of 73.10%, with Activity Data uncertainty at 9.93% (Table 6.21). The contribution to the total national GHG emissionsfor Grassland is low. This highlights the need to refine Emission Factors and improve data accuracy for more reliable estimates in this category.

Table 6.21 Uncertainty estimates for Grassland

Land Category	Gas	Base year emission	Year t (2022) emission	Activity data uncertainty	Emission factor uncertainty	Combined uncertainty $\sqrt{E^2 + F^2}$
A	B	C	D	E	F	G
LULUCF		**$GgCO_2e$**	**$GgCO_2e$**	**%**	**%**	**%**
Grassland	CO_2	26,281.17	5,621.64	9.93	73.10	73.77

6.6.5. Category Specific QA/QC and Verification for Grassland

The QA/QC process for Grassland data involved using Emission Factors validated through internal consistency checks with national inventory data. Due to the variability in Grassland Emission Factors, additional QA/QC procedures were implemented, ensuring data accuracy by verifying units and confirming alignment with the Grassland category definitions used in the national inventory. The lack of proper Emission Factor estimates, especially for SOC in Grasslands has contributed to this huge disparity. Given the vital role Grasslands play in both livelihoods and biodiversity, and their often overlooked status as natural ecosystems, improving estimations for this category is critically important.

6.6.6. Grassland category specific recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

6.6.7. Land Category-specific Planed Improvements for Grassland

6.6.7.1. Current Approach and Method for GHG Inventory in Grassland

The current approaches and methods for estimating the Activity Data and Emission Factors used in the GHG inventory are listed below.

Tier-2 and Modelling approach: Currently, India has adopted Tier-2 approach for GHG inventory based on country specific data. No modelling is adopted for GHG inventory estimation for Grassland category.

Area estimates under Grassland: Currently area estimates are made using remote sensing based methods. Area estimate for Grassland category is not made by tracking changes in land category geospatially.

Emissions/removals of CO_2 were not estimated from 4.C.1. Grassland remaining grassland, Net carbon stock change in dead organic matter. Emissions/removals of CO_2 were not estimated from 4.C.2. Land converted to grassland due to lack of activity data. While emissions/removals of CO_2 from 4.C. Total grassland, 4.C.1. Grassland remaining grassland, Carbon stock change in living biomass, Losses were notified as 'Included Elsewhere' because 'Stock Difference Method' was used. Emissions/removals of CH_4, N_2O were not estimated from Grassland Due to Biomass Burning 4(IV).C Grassland, due to lack of activity data.

Carbon stocks in Trees Outside Forests: The biomass carbon stock in TOF is estimated jointly considering Cropland, Grassland and Settlements.

Soil Organic Carbon estimation: SOC stock and stock change estimates are based on limited data for Grassland. There is no new SOC stock or stock change data for Grassland category.

Modelling of SOC stock change: Currently, no modelling of SOC stocks and fluxes is made, and India is adopting Tier-2 approach.

6.6.7.2. Planned Improvements for Grassland GHG inventory

Current approach and practices are given above and planned improvements to address the current limitations are given in Table 6.22.

Table 6.22 Grassland category specific planned improvements

Land category-specific Planned Improvements	Strategy	Timeline
Separate Area monitoring for - GL remaining GL and - Land converted to GL during the previous 20-year period - Estimates for different Grassland categories to be selected for area monitoring in different agro-climatic or ecological zones	Remote sensing technique-based monitoring of area under GL remaining GL and Land converted to GL at 1:50,000 scale from 2004 to the future inventory years. - It is planned to adopt geospatial tracking of land use change from non-grassland category to grassland category on an annual basis. - Attempts will be made to separately estimate area under different Grassland types	By 2030
Separate monitoring for above ground biomass carbon stock change for - GL remaining GL and - Land converted to GL	Currently, above ground biomass volume stock is monitored for all non-forested land categories jointly for Cropland, Grassland and Settlements. - Attempts will be made to estimate the above ground biomass volume stock separately for GL remaining GL and Land converted to GL category. - Long-term monitoring plots will be set-up in different agro-climatic zones and grassland types to monitor biomass carbon stock changes.	For 2026 inventory year
Perennial biomass and Soil Carbon stocks monitoring for Grasslands in different agro-climatic zones	- Attempts will be made to separately estimate above ground biomass carbon stock for different categories of perennial biomass in Grasslands - Attempts will be made for periodic long-term monitoring of SOC stock changes in different Grassland categories.	2030
Estimation of GL area subjected to fire and biomass fuel burnt	- Attempts will be made for estimation of Grassland area subjected to fire and biomass fuel burnt on an annual basis using remote sensing data and field measurements of biomass stocks	2030
Plan for transition to Tier-3 modelling approach	- India is planning to graduate from Tier-2 to Tier-3, based on modelling. - Initial efforts have been initiated by considering modelling efforts done by other countries such as Canada and Australia. - Data required for modelling will be generated by ICAR institutions.	2030
Planned improvement for uncertainty estimates	Attempts will be made to reduce the uncertainties for Grassland category by establishing long-term monitoring of perennial biomass and soil carbon stock change.	2030

6.7. Wetlands

India is not estimating GHG emissions and removals from Wetland category due to absence of Activity Data. However, plans to undertake GHG inventory for Wetlands and the planned improvements to achieve inventory estimation are given in Table 6.23.

Table 6.23 Land category-specific planned improvements for Wetland (Flooded Land)

Land category-specific Planned Improvements	Strategies	Timeline
Adoption of IPCC 2013 Supplementary Guidelines for Wetlands	- It is proposed to adopt IPCC 2013 Supplementary Guidelines for Wetlands, where inventory for both FLL (Flooded Land) remaining FLL and Land converted to FLL will be estimated. - In addition to CO_2, CH_4 emissions will also be estimated	BTR-2, inventory

Land category-specific Planned Improvements	Strategies	Timeline
Separate monitoring of area under - Land converted to FLL - Flooded land remaining Flooded Land - Estimates for different FLL types such as large reservoirs / dams, minor irrigation tanks, artificial urban lakes and other water bodies	- Remote sensing-based monitoring of area under different flooded land categories such as large and small reservoirs / dams, minor irrigation tanks, artificial urban lakes and other water bodies is planned. - Monitoring and estimation of area under Flooded land from 2004 to 2024 and onwards annually - Adopting IPCC 2013 Supplementary Guidelines for estimating GHG inventory for Wetlands including Flooded Land remaining Flooded Land and Land converted to Flooded Land	By 2030
Methane emission estimates	- Based on IPCC 2013 Supplementary Wetland Guidelines, methane inventory will be monitored and estimated	By 2030
Estimation of uncertainty	It is proposed to estimate uncertainty by monitoring the area separately for FLL remaining FLL and Land converted to FLL	By 2030

6.8. Settlements

6.8.1. Category Description

Settlements land includes rural and urban habitats, infrastructure, mining area and other built-up area. Area under Settlements has been expanding in India due to population growth and urbanization. India has been reporting GHG emissionsand removals for the Settlements category by considering only Settlements remaining Settlements as a land category. India has not reported so far GHG emission/removal estimates separately for 'Settlement remaining Settlement' and 'Land converted to Settlement' due to lack of Emission Factors and Activity Data for the past 20 years. Thus, India is reporting Settlement as a category based on assessment of above ground biomass stock change estimated as part of Trees Outside Forests by FSI.

6.8.2. Methodological Issue

6.8.2.1. Monitoring of Area Under Settlements

NRSC monitors area under Settlements (Built-up area) on an annual basis at 1:250,000 scale and publishes in the *Annual LULC Atlas*. The remote sensing techniques are described in the earlier Section 6.3.2. Settlement is defined to include built-up land area with buildings (roofed structures), paved surfaces (roads, parking lots), commercial and industrial sites (ports, landfills, quarries, runways), and urban green areas (parks, gardens).

6.8.2.2. Trends in Area Under Settlements from 2005 to 2022

Area under Settlements is provided by NRSC using remote sensing techniques and satellite monitoring data. The details of the area under Settlements is provided in Table 6.24 and Figure 6.13. Area under Settlement has increased from 8.61 Mha in 2005 to 10.65 Mha in 2022.

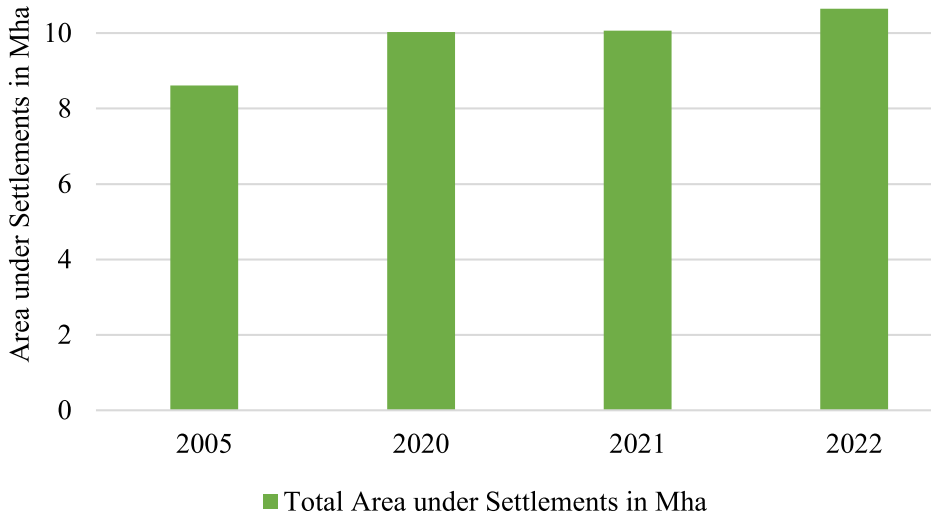


Figure 6.13 Trends in area under Settlements

Source: NRSC

6.8.2.3. Carbon Stock Change in Biomass for Settlements during 2022

Emission Factor: Emission Factor required for Settlements category includes only the rate of change in perennial biomass carbon stock per hectare per year.

Biomass carbon stock change: The main source of data for biomass carbon stock in Settlements is from the study on Trees Outside Forests conducted by FSI biennially for non-forestland categories including Settlements, Cropland, and Grasslands. Perennial biomass stock change in the Settlements category is estimated using the method and source of data described for Croplands (Section 6.5.2.4). The rate of change of perennial biomass carbon stock is estimated to be 0.243 tC/ha/yr during 2022.

It can be observed from Table 6.8.1 that the growing stock of biomass in TOF was 1,616.25 million m3 during 2005 and it has increased to 2,036.45 million m3 during 2022. The rate of change in biomass carbon stock was -0.024 tC/ha/yr during 2005 and it has changed to 0.243 tC/ha/yr during 2022.

SOC Stock Change: As per IPCC 2006 Guidelines, it is assumed that carbon stock inputs equal outputs in Settlement soil carbon stocks. Hence, there is no change in soil carbon stocks in Settlements Remaining Settlements. Thus, SOC stock change in Settlements category is not estimated.

Table 6.24 Trends in biomass carbon stock in Trees Outside Forest (TOF) for Settlements

Description	Settlements			
	2005	2020	2021	2022
Total biomass stocks in Million cum	1616.25	1865.05	1950.75	2036.45
Total aboveground biomass (AGB) in Mt (BCEF of 0.9)	1454.625	1678.545	1755.675	1832.805
Total belowground biomass (BGB) in Mt (root shoot ratio: 0.27)	392.74875	453.20715	474.03225	494.85735
Total Biomass (AGB+BGB) in Mt	1847.37375	2131.75215	2229.70725	2327.66235
Total biomass carbon (AGB+BGB) in MtC	923.686875	1065.876075	1114.853625	1163.831175
Change in biomass carbon stock in MtC/yr	-4.499	48.97755	48.97755	48.97755
Area (Mha) under CL + GL + SL	189.61	201.22	199.7	201.18
Rate of change in biomass carbon in tC/ha/yr	-0.02372	0.243402	0.245255	0.24345
Area under Settlements in Mha	8.61	10.03	10.07	10.65
Total change in biomass carbon stock in MtC for Settlements	-0.20430	2.44133	2.46972	2.59276

Source: FSI for total biomass stock under TOF

6.8.2.4. Trends in GHG emissions/ Removals from Settlements

The biomass carbon stock change of 0.243 tC/ha/yr is used to estimate the net change in carbon stock and CO_2 removals for Settlement land category, which is given in Table 6.8.1. It can be observed that the rate of change in biomass stock was negative at -0.023 tC/ha/yr during 2005, indicating a decline in biomass carbon stock. However, during 2020, 2021 and 2022, the rate of change in biomass carbon stock is showing a positive trend of 0.243 tC/ha/yr during 2022.

Thus, the net estimates for Settlement land category show a net removal of 9,506.78 $GgCO_2$ during 2022 (Table 6.25), indicating Settlements land category is a net sink, potentially due to expansion of urban settlements with avenue trees and parks and trees in residential area.

Table 6.25 Net CO_2 emissions/removals for Settlements category

Year	Area in Mha	Rate of Change in biomass carbon stock tC/ha/yr	Total change in biomass carbon stock in Settlement (MtC)	Total net CO_2 emissions / removals in $GgCO_2$
2005	8.61	-0.024	-0.20	-749.08
2020	10.03	0.243	2.44	8,951.55
2021	10.07	0.245	2.47	9,055.66
2022	10.65	0.243	2.59	9,506.78

6.8.3. Flexibility applied

India has utilized the flexibility provision related to time-series reporting, reflecting a strategic approach that balances transparency commitments with practical implementation constraints. This selective reporting approach was necessitated by the unavailability of comprehensive activity data for certain historical periods, financial constraints associated with extensive annual estimations, and ongoing institutional capacity-building efforts. The applied flexibility ensures meaningful participation in global climate transparency while recognizing the technical and resource limitations inherent in developing comprehensive historical datasets. India remains committed to progressively expanding its time-series reporting in future BTRs as national data governance frameworks mature and institutional capacities are strengthened in alignment with BTR requirements.

6.8.4. Uncertainty Estimates for Settlement

The methodology followed for the uncertainty analysis for the Settlements category is the same as outlined in Section 6.3.6. The uncertainty analysis for Settlements within the LULUCF sector indicates a combined uncertainty of 11.65%, derived from an Activity Data uncertainty of 9.93% and an Emission Factor uncertainty of 6.10%. Despite the moderate combined uncertainty, the contribution to the total national emissions uncertainty is minimal (Table 6.26). This suggests that uncertainties in the Settlements category have a negligible impact on the overall national inventory.

Table 6.26 Uncertainty estimates for Settlements category

Land Category	Gas	Base year emission	Year t (2022) emission	Activity data uncertainty	Emission factor uncertainty	Combined uncertainty $\sqrt{E^2 + F^2}$
A	B	C	D	E	F	G
LULUCF		$GgCO_2e$	$GgCO_2e$	%	%	%
Settlements	CO_2	749.08	-9,506.78	9.93	6.10	11.65

6.8.5. Category Specific QA/QC and Verification for Settlement

The QA/QC process for Settlements data included validating Emission Factors through internal checks against national inventory data. Due to the complexity of emissions in Settlements category, further QA/QC measures were implemented to ensure data accuracy. This involved verifying units and ensuring the data aligned with the category definitions of Settlements in the national inventory.

6.8.6. Settlements Category Specific Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

6.8.7. Land Category-specific planned Improvements for Settlement

6.8.7.1. Current Approach and Method for GHG Inventory in Settlements

The current approaches and methods for estimating the Activity Data and Emission Factors used in the GHG inventory are listed below.

Tier-2 and Modelling approach: Currently, India has adopted Tier-2 approach for GHG inventory based on country specific data. No modelling is adopted for GHG inventory estimation for Settlements category.

Area estimates under Settlements: Currently area estimates are made using remote sensing based methods. Area estimates for Settlements category is not made by tracking changes in land category geospatially. Currently, no Activity Data is available separately for Settlements remaining Settlements and Land converted to Settlements.

Emissions/removals of CO_2 were not estimated from 4.E.1. Settlements remaining settlements, Net carbon stock change in dead organic matter. Emissions/removals of CO_2 were not estimated from 4.E.2. Land converted to settlements due to lack of activity data. While emissions/removals of CO_2 from 4.E. Total Settlements, 4.E.1. Settlements remaining Settlements, Carbon stock change in living biomass, Losses were notified as 'Included Elsewhere' because 'Stock Difference Method' was used.

Carbon stocks in Trees Outside Forests: The biomass carbon stock in TOF is estimated jointly considering Cropland, Grassland and Settlements.

6.8.7.2. Planned Improvements for Settlements GHG inventory

Current approach and practices are given above and planned improvements to address the current limitations are given in Table 6.27.

Table 6.27 Settlement Land (SL) category specific planned improvements

Land category-specific Planned Improvements	Strategy	Timeline
Separate Area monitoring for - SL remaining SL and - Land converted to SL during the previous 20-year period - Estimates for different Settlements or built-up area categories such as large cities, infrastructure, towns and villages	- Remote sensing technique-based monitoring of area under SL remaining SL and Land converted to SL at 1:50,000 scale from 2004 to the future inventory years. - It is planned to adopt geospatial tracking of land use change from non-settlement category to Settlement category on an annual basis. - Attempts will be made to separately estimate area under different Settlement types	By 2030
Separate monitoring for above ground biomass carbon stock change for - SL remaining SL and - Land converted to SL	Currently, above ground biomass volume stock is monitored for all non-forested land categories jointly for Cropland, Grassland and Settlements. - Attempts will be made to estimate the above ground biomass volume stock separately for SL remaining SL and Land converted to SL category.	For 2024 inventory year
Perennial biomass carbon stocks monitoring for Settlements category	- Attempts will be made to separately estimate above ground biomass carbon stock for Settlements category	2030

Land category-specific Planned Improvements	Strategy	Timeline
SOC Stock change for SL	- It is proposed to initiate long term monitoring studies on SOC for different Settlements land categories.	2030
Plan for transition to Tier-3 modelling approach	- India is planning to graduate from Tier-2 to Tier-3, based on modelling.	2030
Planned improvement for uncertainty estimation	Attempts will be made to reduce the uncertainties for Settlements category by monitoring biomass stock changes in different Settlements categories periodically.	2030

6.9. Other Land

Other Land includes snow covered area, rocky surface, water bodies, extremely degraded land, deserts, etc. The Other Land area may support no or insignificant vegetation. According to IPCC 2006 Guidelines, carbon stock change or GHG emissionsneed not be estimated for "Other land remaining Other land". IPCC provides Guidelines for estimating GHG emissions from "Other Land converted to Settlements, Grasslands and Croplands." In India, area under Other Land is continuously declining during the period 2005 to 2022, this land category may be converted to Settlements, infrastructure, etc. The area under Other Land has declined from 69.96 Mha in 2005 to 55.94 Mha in 2022 (Figure 6.14).

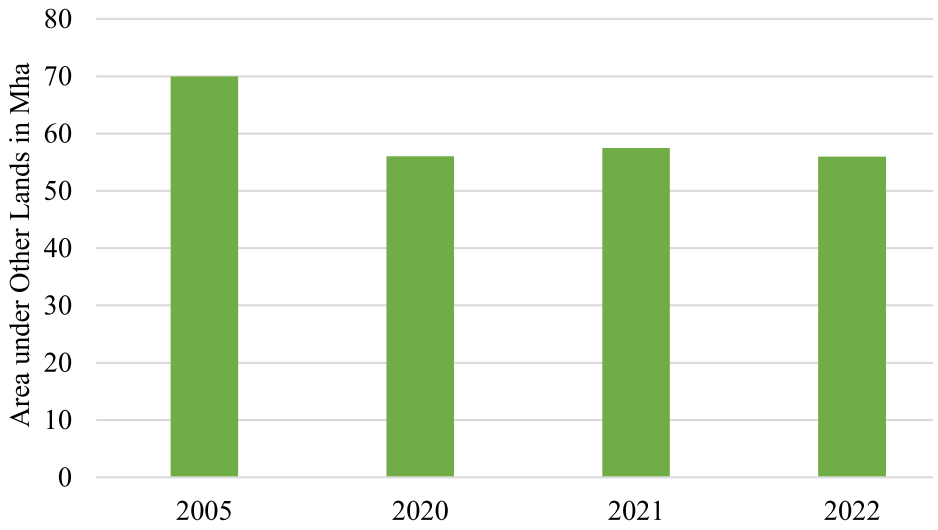


Figure 6.14 Trends in area under Other Lands

Source: NRSC

GHG emissions and CO_2 emissions and removals are not estimated for Other Land category in India, since this land category has no vegetation, and therefore has no implications for CO_2 emissions or removals.

6.10. Harvested Wood Products

6.10.1. Category Description

India had not reported GHG emissions/removals from HWP category till BUR-4, due to absence of Activity Data and Emission Factors. Harvested Wood Products (HWP) can play a significant role in the context of greenhouse gas emissions, both in terms of current levels and observed trends. The HWP categories included in the inventory process are as follows:

- Solid Wood

  - ➤ Sawn Wood: Wood produced from both domestic and imported roundwood, sawn lengthways, or by profile-chipping processes.
  - ➤ Wood Panel: An aggregate category comprising veneer sheets, plywood, particle board, and fibreboard.
- Paper and paperboard: The paper and paperboard category is an aggregate that includes a variety of products such as graphic papers, sanitary and household papers, packaging materials, and other types of paper and paperboard.
- For other solid wood products, the data is marked as "not estimated" (NE) due to insufficient data availability.

It is important to highlight that India is reporting carbon emissions/removals from the HWP pool, marking a significant step forward in enhancing the completeness of its emissions reporting within the LULUCF sector. These estimates provide a valuable understanding of the carbon dynamics associated with HWPs. As India continues to improve data collection and address gaps, particularly for missing product categories, the accuracy and comprehensiveness of future inventories will be greatly enhanced.

Due to lack of activity data, emissions/removals of CO_2 were not estimated for 4.G.1.c. Other solid wood Products. As approach B (production approach) was selected for estimation, Approach-A and Approach- C are mentioned as Not Estimated.

6.10.2. Methodological Issues

This assessment was conducted through the Production Approach (Approach B), which utilizes production data for wood products, in line with the IPCC's prescribed methodology for calculating emissions. In India, the contribution of HWP to emissions from sources and removals by sinks has been evaluated using the IPCC Inventory Software v2.93 supported by the Technical Support Unit (TSU) for IPCC Task Force on National Greenhouse Gas Inventories (TFI).

The Production Approach, as outlined in the IPCC 2006 Guidelines, focuses on estimating changes in carbon stocks specifically within a country's forest pool and the wood products pool derived from domestically harvested wood. This method only accounts for wood harvested within the reporting country and tracks the carbon stored in harvested wood products both domestically and abroad if exported. Importantly, the approach does not provide a full national inventory of wood carbon, as it excludes wood products manufactured from imported roundwood. The system boundary includes both the forest carbon pool (AFOLU) and the carbon transfer in the form of HWP, represented by various exchanges such as domestic and imported wood products in use or in solid waste disposal sites (SWDS). Carbon is released to the atmosphere from these pools either domestically (EDOM), from imports (EIM), or from exported products made from domestic wood (EEX DOM). Transfers of carbon in the form of HWP exports (PEX) and imports (PIM) are also captured within the system boundary, though it assumes no significant cross-border carbon transfers from the rest of AFOLU. The Production Approach allows countries to report carbon stock changes but is limited in that it may not indicate where these changes occur, especially when carbon stocks are stored in exported wood products. This makes it an approach focused on domestic production impact rather than a full accounting of all wood carbon stocks within national boundaries. The HWP contribution to the emissions/removals is calculated using equation below.

$$HWP\ contribution\ to\ \frac{CO_2}{yr} = \frac{-44}{12} x\ (H - \Delta C_{HWPDH})$$

Where H is the Annual Domestic Harvest and ΔC_HWPDH = (Var 2A + Var 2B).

Var 2A = Stock change of all HWPs in use from domestic harvest (Δ C HWP IU DH)

Var 2B = Stock change of HWP in SWDS from domestic harvest (Δ C HWP SWDS DH)

The annual changes in stock and carbon emissions associated with wood products and their management, focusing on the years 2005, 2020, 2021, and 2022 are carried out. Key variables include changes in the stock of wood products in use (HWP IU), annual imports and exports, domestic harvest, and carbon release associated with these products.

6.10.3. Source of Data for Different HWP Categories

Activity data: The ITSD (India Timber Supply and Demand) report offers a comprehensive analysis of the timber market dynamics in India (Kant, Promode, and Raman Nautiyal (2021)). Its primary objective is to provide a detailed understanding of how timber resources are managed, used, and projected to evolve in the coming years. This report encompasses the entire spectrum of timber-related activities, including domestic production, imports, exports, and the demand across various wood-based industries such as furniture, pulp and paper, and construction. To estimate the values within the report, several data sources are employed. For domestic production figures, data is gathered from state forest departments and the Forest Survey of India (FSI), which provide information on the volume of roundwood produced, including both coniferous and non-coniferous species. This data includes timber sourced from both state-owned forests and trees growing outside these areas. However, the dataset does not categorize the source between forests and Trees Outside Forests (TOF). According to the 'Wood is Good' report, the majority of the timber comes from TOF, with only a small portion sourced from forests (Shrivastava and Saxena (2017)). Trade data, including imports and exports, is sourced from the Directorate General of Commercial Intelligence and Statistics. This data shows the volume of timber products entering and leaving India, helping to identify trade balances and dependencies.

FAOSTAT provides annual statistics on the production and trade of forest products, with a focus on wood-based commodities such as roundwood, sawn wood, wood panels, pulp, and paper FAO (2023). These data are collected through an annual survey conducted by the FAO Forestry Division, in collaboration with the International Tropical Timber Organization (ITTO) ITTO (2022), Eurostat (the Statistical Office of the European Union), and the United Nations Economic Commission for Europe (UNECE). In cases where countries do not provide the required data via the FAO questionnaire, the FAO makes estimates based on available resources, such as trade journals, statistical yearbooks, or other relevant sources. If no reliable data can be obtained, the FAO uses historical data until updated information becomes available. The FAOSTAT-Forestry database covers production and trade data for roundwood and primary wood and paper products across all countries and territories worldwide. This also includes data on wood energy products like fuelwood, wood for charcoal, charcoal, and wood pellets.

The statistical information in the FAOSTAT database is primarily derived from country submissions through official questionnaires or publications. When official data are unavailable, FAO relies on estimates, utilizing the most accurate information accessible. In addition to the FAOSTAT database, the FAO Yearbook of Forest Products is a vital resource, offering detailed statistical data on forest products. It compiles annual data on production volumes and the value and quantity of trade for forest products across all countries and regions globally.

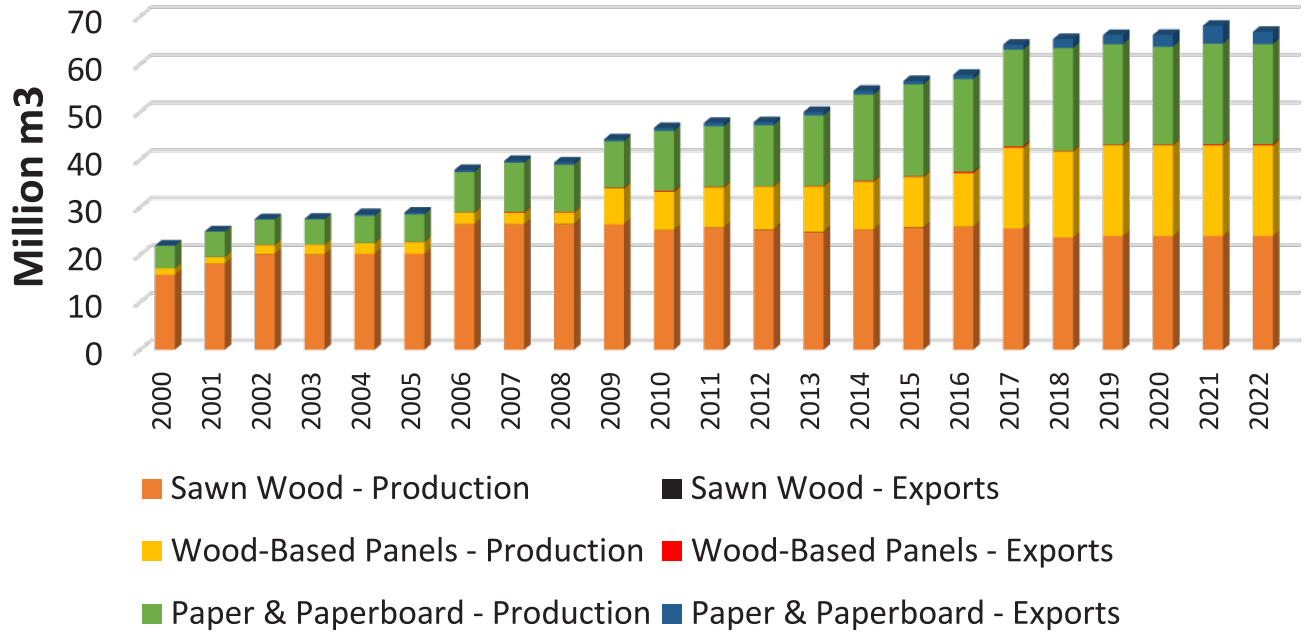


Figure 6.15 Activity Data for different wood products

Source: Kant and Nautiyal, 2021

The harvested wood data for the years 2009 to 2019 was sourced from the India Timber Supply and Demand 2010-2030 report. Data for the years 2005 to 2008, as well as 2020 to 2022, were extrapolated using the India Timber Supply and Demand (ITTO) data as a reference. The data for paper and paperboard, wood pulp, recycled paper, wood chips and particles, and wood residues were sourced from the FAOSTAT-Forestry online database for the years 2000 to 2022. The methodology is based on Chapter 12 of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, as well as Chapter 12 of the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. The Activity Data for different wood products for the period 1990 to 2022 is given in Figure 6.15. The stock of wood products is continuously increasing from 2005 to 2022.

6.10.4. GHG emissions/ Removals Estimate for HWP

The annual change in the stock of HWP in use produced from domestic harvest ($\Delta C_{HWP\,IU\,DH}$) followed an upward trajectory, increasing from 3,793.33 GgC in 2005 to 6,466.11 GgC in 2022 (Table 6.28). This suggests that domestic production has grown substantially over this period, reflecting increased harvest activities and the domestic use of locally sourced wood products. In terms of international trade, annual imports of wood, paper products, and related materials have surged from 784.4 GgC in 2005 to 1,095.29 GgC in 2022, highlighting the country's growing reliance on foreign materials to meet its wood product demands. In contrast, annual exports of these products have remained relatively small, showing a slight increase from 1.75 Gg C in 2005 to 2.41 Gg C in 2022. This indicates that India is a net importer of wood products, with most of its domestically harvested wood being utilized internally. Regarding carbon emissions, the release of carbon from HWP originating from domestic harvest ($\uparrow C_{HWP\,DH}$) has also declined from 75,315.31 $GgCO_2$ in 2005 to 72,978.34 $GgCO_2$ in 2022.

The overall contribution of HWP to AFOLU CO_2 emissions/removals is significant, indicating a net removal of CO_2 from the atmosphere. This contribution peaked at -25,986.16 $GgCO_2$ in 2020, reflecting an especially strong net removal in that year, and although it has decreased slightly since, it still stands at -23,709.07 $GgCO_2$ in 2022. This negative value shows that the HWP sector is acting as a carbon sink (Table 6.28 and Figure 6.16).

In summary, the total net change in carbon stock from HWP in use, particularly from domestic harvests, led to significant carbon removals, with sawn wood and wood panels contributing the largest share. Although the contribution of exported HWPs was relatively small, it still added to the overall carbon removals. The analysis highlights the important role of HWP in contributing to net carbon sink, aiding in the country's efforts to mitigate climate change by enhancing carbon storage through harvested wood products.

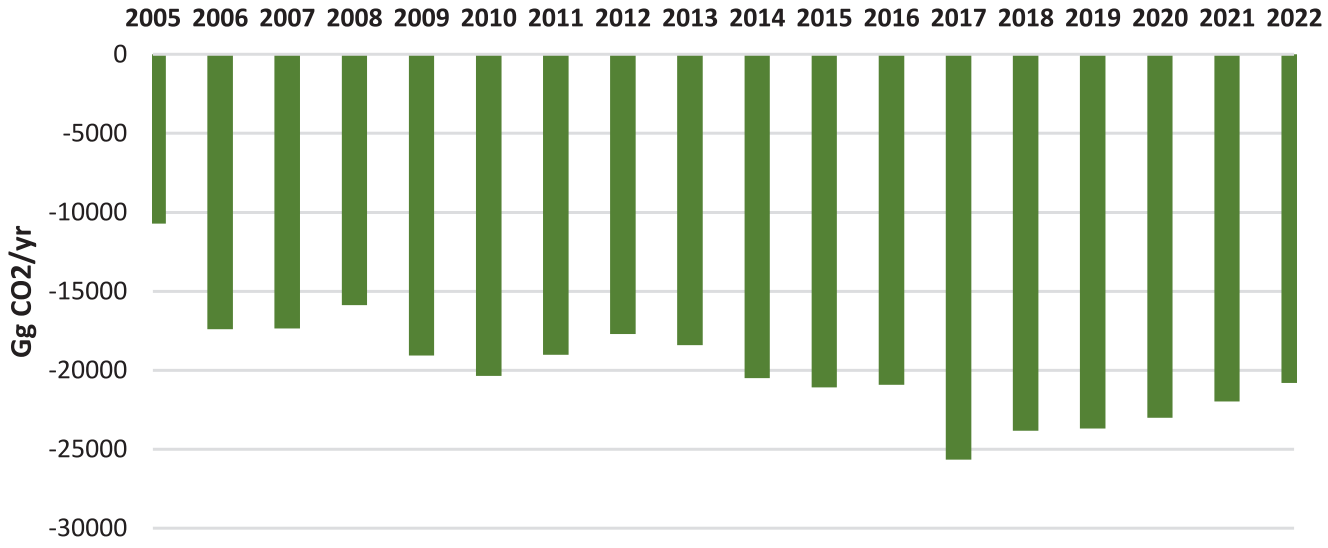


Figure 6.16 Trends in CO_2 emissions / removals from HWP

Table 6.28: Annual carbon HWP contribution to total LULUCF CO_2 emissions / removals

	Variable number							
	2A	2B	3	4	5	6	7	8
Inventory year	Annual Change in stock of HWP in use produced from domestic harvest	Annual Change in stock of HWP in SWDS produced from domestic harvest	Annual Imports of wood, and paper products + wood fuel, pulp, recovered paper, roundwood/ chips	Annual Exports of wood, and paper products + wood fuel, pulp, recovered paper, roundwood/ chips	Annual Domestic Harvest	Annual release of carbon to the atmosphere from HWP consumption (from fuelwood & products in use and products in SWDS)	HWP contribution to AFOLU CO_2 emissions	Approach used to estimate HWP contribution
	$\Delta C_{HWP\,IU\,DH}$	$\Delta C_{HWP\,SWDS\,DH}$	P_{IM}	P_{EX}	H	$\uparrow C_{HWP\,DC}$		
	GgC /yr						$GgCO_2$ /yr	
2005	3793.33	8.28	784.4	1.75	79,116.92	75,315.31	-13,908.88	Production
2020	7087.13	57.1	1,000.93	2.48	79,990.53	72,846.3	-25,986.16	
2021	7009.16	-32.72	1,102.89	2.48	79,740.83	72,764.39	-25,700.24	
2022	6466.11	47.01	1,095.29	2.41	79,491.46	72,978.34	-23,709.07	

6.10.5. Flexibility applied

India has utilized the flexibility provision related to time-series reporting, reflecting a strategic approach that balances transparency commitments with practical implementation constraints. This selective reporting approach was necessitated by the unavailability of comprehensive activity data for certain historical periods, financial constraints associated with extensive annual estimations, and ongoing institutional capacity-building efforts. The applied flexibility ensures meaningful participation in global climate transparency while recognizing the technical and resource limitations inherent in developing comprehensive historical datasets. India remains committed to progressively expanding its time-series reporting in future BTRs as national data governance frameworks mature and institutional capacities are strengthened in alignment with BTR requirements.

6.10.6. Uncertainty Estimation and Time-series Consistency

For Variable 2A (carbon stock changes in HWP pools from domestic harvest), a simplified assumption is made that the lifecycle of harvested wood in importing countries mirrors that of domestic usage. The time series data for Harvested Wood Products activity obtained from the UN FAO database are consistent throughout the period analysed. Data from the International Trade Statistics Database were extrapolated using information from the International Tropical Timber Organization databases. According to the guidance provided in the relevant chapter of the 2013 IPCC KP Supplement (IPCC et al., 2014a), the uncertainty associated with the FAO time series data is estimated to range between -25% and +5%. The uncertainty for the ITSD dataset is approximately ±8%. Taking these into account, the overall uncertainty for the data ranges from -16% to +8%.

We have used IPCC default values for the half-life and conversion factors for the assessment of CO_2 emission/ removal from the HWP pool. The IPCC guidelines specify that the uncertainty associated with the default half-life parameter is approximately ±50% of the default half-life value (IPCC 2006 table 12.6). Similarly, the IPCC 2006 guidelines indicate that the uncertainty in the default conversion factor is approximately ±25% for the volume-to-biomass conversion and ±10% for the biomass-to-carbon conversion, (IPCC 2006 table 12.4) resulting in a combined uncertainty of approximately ±56.78%.

6.10.7. HWP Category-specific QA/QC and Verification

There is a lack of studies discussing carbon sequestration in HWPs in India's forest sector. We conducted a detailed literature review and found one relevant study by Haripriya (2003). This study, focusing on the year 1993-94, assessed the carbon flow accounts for the Indian forest products sector, revealing a total carbon sink of 3,582 GgC. When converted, this amount corresponds to approximately 13,107 $MtCO_2$ (Haripriya, 2003). This figure aligns closely with our analysis, which estimates a total of 4,205.99 GgC for 1993.

6.10.8. HWP Category specific Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

6.10.9. HWP Category-specific Planned Improvements

In light of the ongoing enhancements to India's greenhouse gas (GHG) reporting framework, it is essential to focus on the monitoring of Harvested Wood Products (HWPs).

Monitoring of stocks and stock changes: Future initiatives will prioritize the enhancement of monitoring stocks and stock changes for various HWP products. Currently, some categories are missing from national data sources, which hampers our understanding of the full carbon dynamics associated with these products. Addressing these gaps will lead to more accurate assessments of carbon storage and emissions related to HWPs.

Monitoring of imports and exports: Another critical area for improvement is the monitoring of imports and exports of HWPs. Enhanced tracking of these flows will provide deeper insights into the lifecycle impacts of HWPs, ensuring a more comprehensive evaluation of their contribution to national and global carbon cycles.

This proposed planned improvement will not only strengthen India's reporting capabilities within the Land Use, Land-Use Change and Forestry (LULUCF) sector but also establish a solid foundation for future GHG accounting efforts.

6.11. Overall GHG Inventory for LULUCF Sector for 2022

LULUCF sector is a net sink during the period 2005 to 2022. During 2005, the total GHG emissionsfor LULUCF sector is estimated to be -206,020 $GgCO_2$ and -571,823 $GgCO_2$ during 2022 (Table 6.29). Thus, the LULUCF sector is net a sink of 571,823 $GgCO_2$ during 2022 and in the previous years.

Table 6.29 GHG emissionsfor 2022 and trends from 2005 to 2022 in $GgCO_2eq$

Years	Forestland	Cropland	Grassland	Settlements	Harvested Wood Products	Total
2005	-21,060.53	-198,081.23	26,281.17	749.08	-13,908.88	-2,06,020
2020	-148,107.89	-386,142.05	6,944.16	-8,951.55	-25,986.16	-5,62,243
2021	-147,946.12	-387,197.89	6,329.35	-9,055.66	-25,700.24	-5,63,571
2022	-149,896.08	-394,333.00	5,621.64	-9,506.78	-23,709.07	-5,71,823

Table 6.29 suggests that CO_2 sink of the LULUCF sector in India has increased from 206,020 $GgCO_2$ in 2005 to 571,823 $GgCO_2$ in 2022. Some of the potential factors contributing to enhancement of carbon sink in land use sectors are as follows:

1. Area under Forestland has increased continuously from 69.16 Mha in 2005 to 71.61 Mha in 2022, due to implementation of forest conservation measures, afforestation / reforestation, plantation forestry and agroforestry programs. This directly contributes to enhanced carbon stock.
2. The biomass stock in Cropland, Grassland and Settlements have been increasing due to increase in TOF biomass stock, due to increased tree planting under agroforestry, expansion of fruit orchards and urban greening programs.

3. Area under Settlement land is increasing due to urbanization. Generally new urban habitats are associated with increased tree planting as avenue trees, in home gardens and parks.

4. Cropland SOC is increasing at 0.38 tC/ha/yr due to manure application, irrigated cropping and improved agriculture practices. Further, area under Cropland has increased from 160 Mha in 2005 to 172.5 Mha in 2022, which is causing additional sequestration in the form of soil organic carbon.

5. HWP is added as a new reporting category, since the Activity Data is available now, which has also contributed to the sink. The in-country production of HWP has been increasing rapidly, from 6,513.56 m^3 in 1990 to 59,830.66 m^3 in 2022, contributing to an increase in carbon stocks.

CHAPTER-7

WASTE

WASTE

7.1. Overview of the sector (e.g. quantitative overview and description, including trends and methodological tiers by category) and background information

India's waste sector (Sector 5), accounts for emissions of three greenhouse gases: carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). These emissions are reported across four main categories:

(i) Solid waste disposal (5A),

(ii) Biological treatment of solid waste (5B),

(iii) Incineration and open burning of waste (5C), and

(iv) Wastewater treatment and discharge (5D).

Emission estimates for all categories are prepared in accordance with the 2006 IPCC Guidelines, applying both Tier 1 and Tier 2 methodologies [IPCC, 2006]. Both country-specific and default emission factors are used, depending on data availability and applicability. A detailed summary of the methods and emission factors applied is presented in Table 1.1.

For each category and its respective sub-categories, the following elements are described in this section: an overview of the activity, methodological approaches and data sources, identification of key categories, assessment of uncertainties and time-series consistency, flexibilities availed, quality assurance and quality control procedures, any recalculations undertaken, and planned improvements for future inventory cycles.

In 2022, India's waste sector emitted approximately 93,842 Gg CO_2 equivalent, contributing 2.76% to the country's net greenhouse gas (GHG) emissions, excluding emissions from LULUCF [MoEFCC, 2021]. This represents a 51.21% increase from 2005 levels, which stood at 62,061 Gg CO_2e.

Methane (CH_4) and nitrous oxide (N_2O) were the dominant GHGs emitted from this sector in 2022, accounting for 77,726 Gg CO_2e and 15,617 Gg CO_2e, respectively. Together, they contributed significantly to national GHG totals, with CH_4 comprising nearly 15% and N_2O about 12%. In contrast, carbon dioxide (CO_2) emissions from the sector were minimal at 498 Gg, amounting to only 0.02% of India's total reported CO_2 emissions [MoEFCC, 2021]. From 2005 to 2020, emissions from the waste sector rose by 48.44%. A slight decline of 2.5% was observed in 2021, followed by a 4.5% increase in 2022 [MoEFCC, 2021]. These trends underline the growing contribution of the waste sector to India's overall emissions profile and highlight the need for strengthened waste management strategies, particularly in methane capture and treatment infrastructure.

Table 7.1: Total direct GHG emissions from different sub-categories gas-wise from Waste sector (2005, 2020, 2021 and 2022) in Gg CO_2e

	5A (Gg CO_2e)		5B (Gg CO_2e)		5C (Gg CO_2e)	5D (Gg CO_2e)		Total emissions, Gg CO_2e
Year	CH_4	N_2O	CH_4	N_2O	CO_2	CH_4	N_2O	
2005	10799.88	0.00	0.00	0.00	712.08	39570.27	10978.40	62060.64
2020	25522.84	0.00	168.84	0.00	479.28	50641.53	15311.14	92123.63
2021	26580.58	0.00	199.02	0.00	489.07	47107.74	15474.51	89850.92
2022	27523.30	0.00	208.91	0.00	498.33	49993.88	15617.33	93841.75

India, has experienced significant changes due to urbanization and industrialization, directly impacting waste generation. In the early years of post-independence, waste management was underdeveloped, with informal practices and limited infrastructure. Waste generation was low during the 1950s and 1960s, with disposal mainly through uncontrolled dumping. However, from the 1980s, urbanization led to a dramatic increase in waste, with per capita generation rising alongside consumption and economic growth [World Economic Forum, 2021]. Urban areas, characterized by high population density and economic activities, produce more waste per capita due to increased consumption and diverse waste streams, such as packaging and electronics. Rural areas, however, generate less waste per capita, with a higher proportion of biodegradable materials that are recycled or repurposed through practices like composting and cattle feeding [FAO, 2017]. India's diverse climates and cultural practices impact waste composition.

Between 2005 and 2022, the composition of greenhouse gas (GHG) emissions from India's waste sector has remained relatively stable in terms of the proportional contribution of individual gases. In 2005, carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) accounted for 1.15%, 81.16%, and 17.69% of total GHG emissions from the waste sector, respectively. By 2022, the shares of these gases were 0.53% (CO_2), 82.83% (CH_4), and 16.64% (N_2O).

Despite the minimal change in their relative shares, the absolute emissions of each gas followed distinct trends during this period. CO_2 emissions from the waste sector declined by 30%, while CH_4 and N_2O emissions increased by 54.31% and 42.25%, respectively.

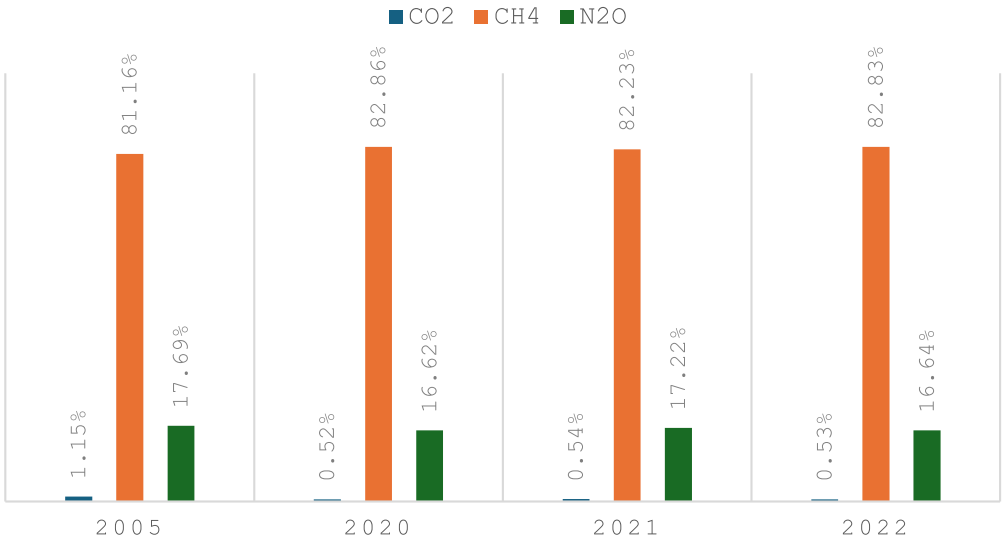


Figure 7.1 Share of each gas of total GHG emissions from waste sector for 2005, 2020, 2021 and 2022

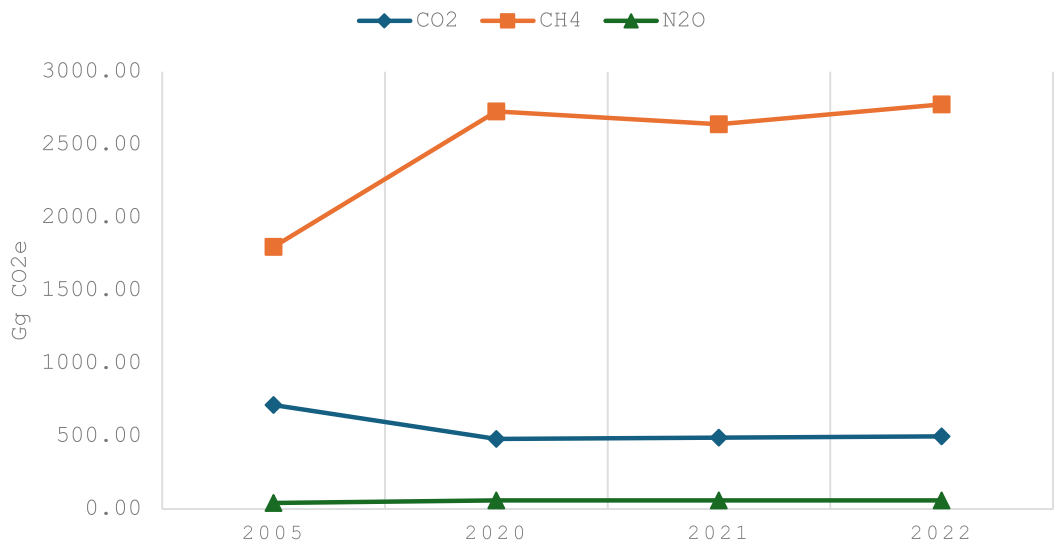


Figure 7.2 Direct GHG emissions from waste sector

Category 5D 'Wastewater treatment and discharge' remained the dominant source of direct GHG emissions within the waste sector throughout the time series, contributing 63.8% in 2005, and 69.9% in 2022, with intermediate shares of 71.6% in 2020 and 69.7% in 2021 [MoEFCC, 2021]. This was followed by Category 5A 'Solid waste disposal', which saw an increasing trend in its share, from 17.4% in 2005 to 29.3% in 2022. Emissions from Category 5C 'Incineration and open burning of waste' remained relatively low, accounting for 1.1% in 2005 and 0.5% in each of the years 2020, 2021, and 2022. Category 5B 'Biological treatment of solid waste' contributed 0% in 2005, and a marginal 0.2% in subsequent years (2020–2022).

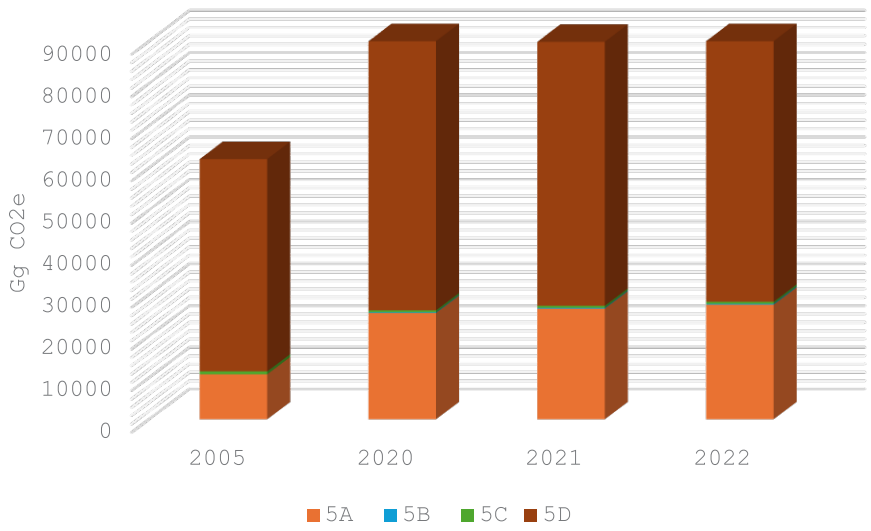


Figure 7.3 Breakdown of direct GHG emissions from Waste sector by source category

Table 7.2 : Direct GHG emissionsby category and their share in the total sectoral emissions (2005, 2020, 2021 and 2022)

Year	5A (Gg CO_2e)	5B (Gg CO_2e)	5C (Gg CO_2e)	5D (Gg CO_2e)	5A (% of total)	5B (% of total)	5C (% of total)	5D (% of total)
2005	10799.88	0	712.08	50548.68	17.4%	0.0%	1.1%	81.5%
2020	25522.84	168.84	479.2806	65952.67	27.7%	0.2%	0.5%	71.6%

Year	5A (Gg CO_2e)	5B (Gg CO_2e)	5C (Gg CO_2e)	5D (Gg CO_2e)	5A (% of total)	5B (% of total)	5C (% of total)	5D (% of total)
2021	26580.58	199.024	489.07	62582.25	29.6%	0.2%	0.5%	69.7%
2022	27523.3	208.908	498.3328	65611.21	29.3%	0.2%	0.5%	69.9%

GHG emissions estimations from the waste sector sub-categories 5A (Solid Waste Disposal), 5B (Biological Treatment of Solid Waste), 5C (Incineration and Open Burning of Waste), and 5D (Wastewater Treatment and Discharge), were estimated using a combination of Tier 1 and Tier 2 methodologies, in accordance with the 2006 IPCC Guidelines. The estimation employed both default emission factors provided in the IPCC 2006 Guidelines and country-specific emission factors, as presented in Table 7.3. A detailed explanation of the methodologies and emission factors used for each sub-category is provided in the subsequent sections of the waste sector chapter.

Table 7.3 Estimation methods used in the estimation of GHG emissionsof the waste sector

Source/Sink Categories	Gas	Method Used	Emission factor
5.A.1.a. Anaerobic	CH_4	T2	D
5.A.2. Unmanaged waste disposal sites	CH_4	T1	D
5.A.3. Uncategorized waste disposal sites	CH_4	T1	D
5.B.1.a. Municipal solid waste	CH_4	T2	D
5.C.2.b.i. Municipal solid waste	CO_2	T1	D
5.C.1.b.ii.3. Clinical waste	CO_2	T2	D
5.D.1. Domestic wastewater	CH_4	T2	D
5.D.1. Domestic wastewater	N_2O	T1	D
5.D.2. Industrial wastewater	CH_4	T2	D, CS

7.2. Solid waste disposal (CRT 5.A), including detailed information on:

Category description and background

The Solid Waste Disposal category involves the final placement of waste in landfills and dumpsites, where the anaerobic decomposition of organic matter produces significant amounts of CH_4 and CO_2. In India, there is a marked difference between Rural and Urban lifestyles with rural population generating substantially less per capita solid waste. In addition, existence of MSW dumps is rural areas is minimal as most of the organic waste is recycled as cattle feed and farm compost. Also, MSW is relatively scattered, and moreover shallow waste depths of disposal do not induce anaerobic conditions. These conditions are responsible for low level of methane emissions in rural areas. On the other hand, urban population produces much higher per capita MSW and thus the generation of organic fraction is relatively high. Urban areas are constrained for recycling of organic matter. Hence, MSW related methane emissions are mostly from urban areas in India. In India, before the 1990s, most solid waste was disposed of in unmanaged dumpsites, lacking proper scientific design or management. Despite these developments, a significant portion of waste is still disposed of in unmanaged or poorly managed sites, contributing to methane emissions.

Data from the CPCB indicates that there are 2,452 dumpsites across the country, as reported by State Pollution Control Boards (SPCBs) and Pollution Control Committees (PCCs). Out of these, 366 dumpsites have been reclaimed, and 27 have been converted into landfills. Additionally, 1,244 sites have been identified for landfill development, 669 landfills have been constructed, 135 are under construction, 645 are operational, 10 have been exhausted, and 11 have been capped (CPCB, 2022). CPCB has provided data on per capita waste generation from 2014 to 2022, before that waste accounting was not reported at national level. For years prior to 2014, average IPCC default for India has been considered.

CH_4 emissions from MSW decomposition at SWDS were estimated using the IPCC FOD model for a complete historic time series starting in the year 1990. Default IPCC parameters were adopted in terms of degradable organic carbon (DOC), fraction of DOC dissimilated (DOCf), and CH_4 generation rate constant (k) for each waste

component. The default 6-month delay time, 50% fraction of CH_4 in developed biogas, and tropical dry climate zone were also adopted. The following steps represent the estimation methods for methane emission, based on the FOD as given in IPCC Guidelines, 2006.

7.2.1. Managed waste disposal sites (5.A.1)

Category description

Anaerobic disposal sites in India include sanitary landfills where waste decomposition occurs without the presence of oxygen. These sites are significant contributors to methane (CH_4) emissions due to anaerobic degradation of organic waste components. The estimation for this category utilizes data sourced from the CPCB. Even though the sanitary landfills have been operational since many years, national level reporting is done since few years. Managed sites only constitute a small fraction of total SWDS in India. The amount of waste generated and percentage of landfilled for inventory years 2020, 2021 and 2022 in India as per CPCB reports.

In India, national level reporting of specific sites coming under this head i.e. semi-aerobic sites are not available. Sites are classified only as landfills (considered as managed anaerobic) and dumpsites (unmanaged). Such sites may be present in India, but ground level data is currently not available, which will be updated in the subsequent BTR. In India, national level reporting of specific sites coming under this head i.e. active aeration sites are not available. Sites are classified only as landfills (considered as managed anaerobic) and dumpsites (unmanaged). As per expert estimates, no such sites exist in India.

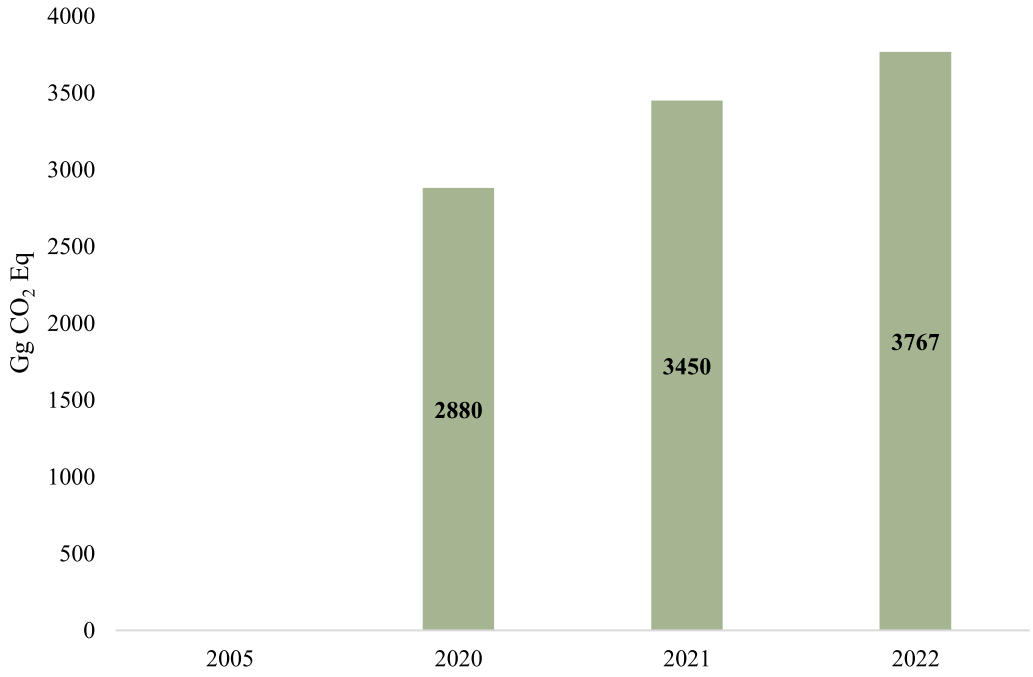


Figure 7.4: GHG emissions from Managed waste disposal sites (5.A.1) in 2005, 2020-2022

Methodological issues

The default Methane Correction factor used for estimation of methane for these anaerobic managed sites is 1.0. Oxidation factor of 0.1 was used as the waste is covered with soil during landfilling operations. The methane emissions from managed sanitary landfills for the year 2020, 2021 and 2022 are estimated to be 2880 Gg CO_2 eq, 3449.75 Gg CO_2 eq, and 3767.37 Gg CO_2 Eq respectively. For anaerobic landfills, a Tier II methodology is applied using the FOD model to estimate methane emissions. The model factors in data such as the fraction of degradable organic carbon (DOC), and methane correction factors (MCF) specific to the Indian context. Challenges arise due to limited availability of historical waste data, variability in waste composition, and inconsistent site management practices. Default IPCC values are often used to compensate for the lack of localized data, which can lead to uncertainties in emission estimates.

For anaerobic landfills, a Tier II methodology is applied using the FOD model to estimate methane emissions. The model factors in data such as the fraction of degradable organic carbon (DOC), and methane correction factors (MCF) specific to the Indian context. Challenges arise due to limited availability of historical waste data, variability in waste composition, and inconsistent site management practices. Default IPCC values are often used to compensate for the lack of localized data, which can lead to uncertainties in emission estimates.

NO notation key is used for Anaerobic (5.A.1.a), Semi-Aerobic (5.A.1.b) and Active Aeration (5.A.1.c) in 2005 as engineered landfill sites were mostly non-operational in India and waste was disposed in open dumps. In 2020, 2021 and 2022, NO Notation key is used for Semi-Aerobic (5.A.1.b) and Active Aeration (5.A.1.c) as landfill related data in India were incomplete or inconsistent across these three years.

Table 7.4 Activity data for Managed waste disposal sites in kt for 2005, 2020-2022

Source/Sink Categories	Unit	2005	2020	2021	2022
Annual waste at the SWDS	kt	NO	11132.6	7625.4	10593.2

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

A quantitative uncertainty analysis for this category was conducted using the Tier 1 approach from the 2006 IPCC Guidelines. For each category and gas, a detailed analysis is conducted for the starting and latest reporting years, highlighting the main contributors to overall uncertainty.

Time-series consistency is a cornerstone of the inventory process. For the reported years, consistent methodologies and data sources have been applied to the greatest extent possible to ensure that trends reflect actual changes in emissions.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

7.2.2. Unmanaged waste disposal sites (5.A.2)

Category description

Unmanaged waste disposal sites, often referred to as dumpsites, are the predominant waste disposal method in India. These sites lack any scientific design or gas collection systems, leading to uncontrolled methane emissions. As of 2022, CPCB reported 2,452 dumpsites across India, with many lacking proper capping or leachate management. Despite efforts to reclaim some sites, the bulk of urban waste continues to be disposed of in unmanaged dumps.

Emissions from disposal of MSW on dumpsites i.e. unmanaged sites for the inventory years is given as follows:

- 2005 – 9,945.04 Gg of CO_2 Eq
- 2020 – 18,572.71 Gg of CO_2 Eq
- 2021 – 18,765.36 Gg of CO_2 Eq
- 2022 – 19,062.43 Gg of CO_2 Eq

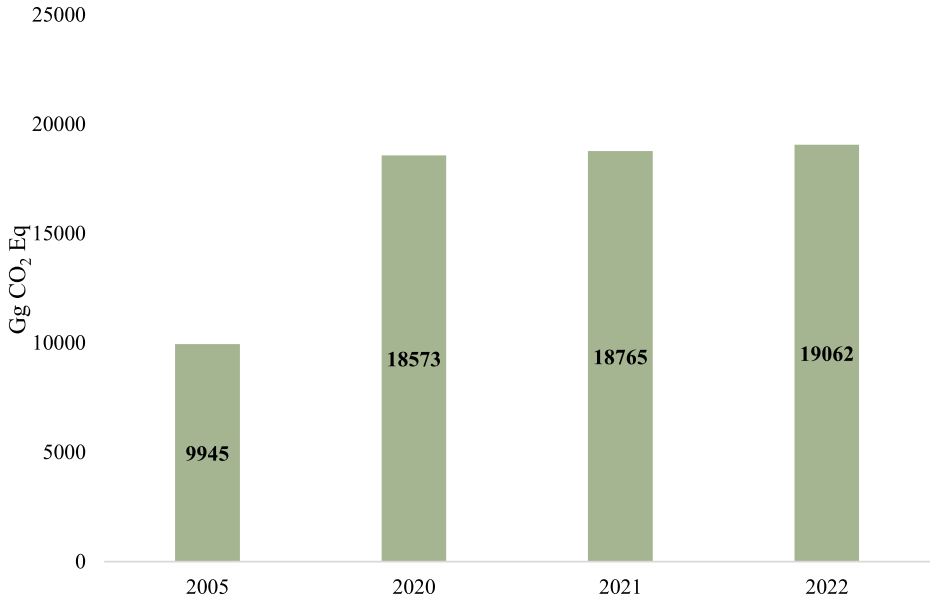


Figure 7.5: GHG emissions from Unmanaged waste disposal sites (5.A.2) in 2005, 2020-2022

Methodological issues

The FOD model is used to estimate methane emissions with IPCC default values for unmanaged sites due to the lack of site-specific data. Activity data is derived from CPCB's reports, supplemented by expert judgment for years with missing data.

Due to absence of well structured datasets and comprehensive methane emission data it has been marked as NE. However, more detailed data is gathered for the subsequent BTRs.

Table 7.5 Activity data for Unmanaged waste disposal sites in kt for 2005, 2020-2022

Source/Sink Categories	Unit	2005	2020	2021	2022
Annual waste at the SWDS	kt	38835.06	29962.28	33839.70	32928.48
MCF		0.40	0.45	0.45	0.46

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

A quantitative uncertainty analysis for this category was conducted using the Tier 1 approach from the 2006 IPCC Guidelines. For each category and gas, a detailed analysis is conducted for the starting and latest reporting years, highlighting the main contributors to overall uncertainty.

Time-series consistency is a cornerstone of the inventory process. For the reported years, consistent methodologies and data sources have been applied to the greatest extent possible to ensure that trends reflect actual changes in emissions.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

7.2.3. Uncategorized waste disposal sites (5.A.3)

Category description

Uncategorized waste disposal sites encompass waste streams that are not clearly defined under the conventional landfill categories, such as sanitary landfill or dumpsites. Disposal of industrial waste is classified under uncategorized waste disposal as no national level reporting is done. The estimates done are based on literature and expert judgement. Industrial waste generation was estimated from the production data of the waste types - paper & pulp, C&D, Food, beverage & tobacco, and textile. For inventory years 2020, 2021, 2022, total production data was available from which waste generation was estimated. 30% of waste from industries is considered to be going into the uncategorized SWDS as per expert judgement. However, several technological interventions have taken place in recent years in India. The percentage of industrial waste going to SWDS may be an over-estimation as many waste processing facilities were incorporated in the system such as recycling and reutilization leading to less waste being disposed of at SWDS, which is not reflected in this BTR, and will be subsequently updated in next BTR. Due to a lack of comprehensive data on the volume and disposal practices of these industrial wastes, they have been grouped under uncategorized SWDS.

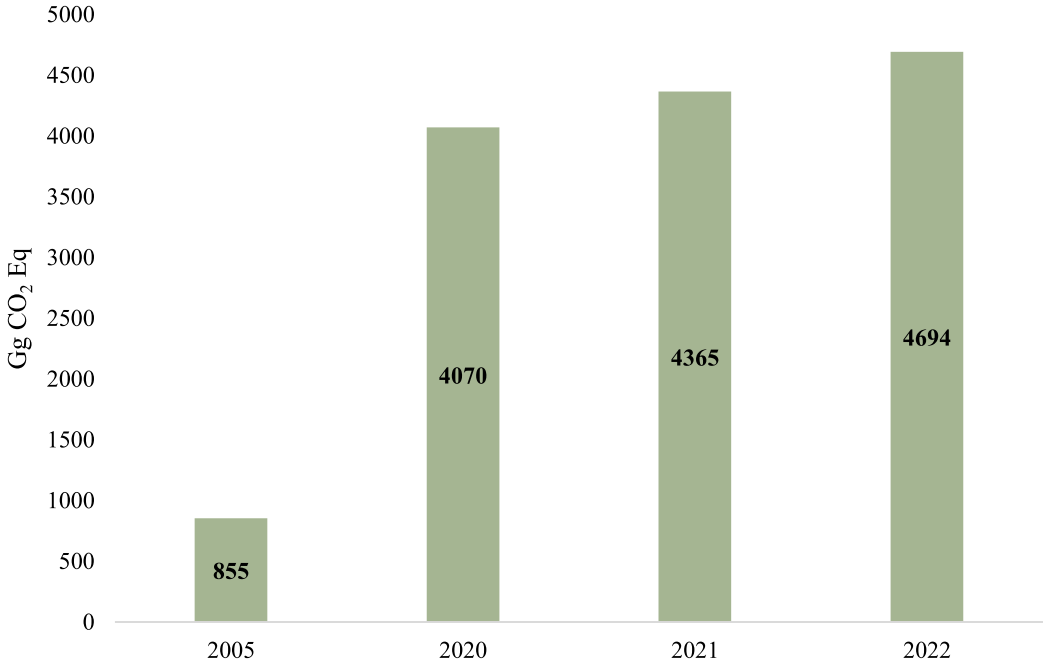


Figure 7.6 : GHG emissions from Uncategorized waste disposal sites (5.A.3) in 2005, 2020-2022

Methodological issues

The primary challenge in estimating GHG emissions from uncategorized waste disposal sites lies in the lack of reliable activity data, particularly for industrial waste streams. The absence of detailed records on waste generation, composition, and disposal practices in the aforementioned industries at national level necessitates the use of generalized assumptions. Application of default IPCC emission factors due to the unavailability of country-specific data may lead to over or under estimation of GHGs.

Data segregation between managed and unmanaged disposal sites was not maintained during 2005, and unclassified dumps could not be distinctly categorized, justifying the use of NE.

Table 7.6 : Activity data for Uncategorized waste disposal sites in kt for 2005, 2020-2022

Source/Sink Categories	Unit	2005	2020	2021	2022
Annual waste at the SWDS	kt	2953.38	10431.92	11402.17	12072.494
MCF		0.6	0.6	0.6	0.6

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 (“Information on Flexibility”) of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

The significant uncertainties in this category arise from the absence of quantitative data on industrial waste streams and inconsistent reporting by industries. These uncertainties are compounded by the variability in waste management practices across different regions and sectors. To maintain time-series consistency, the same estimation approach and default emission factors are applied uniformly across the inventory years. However, the uncertainty margin is expected to be higher due to the generalized assumptions and lack of site-specific data. The uncertainty for estimation of methane emissions from disposal of industrial wastes on SWDS is -75% to +75%.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India’s first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

7.3. Biological treatment of solid waste (5.B)

Category description and background

The category "Biological Treatment of Solid Waste" (5.B) under the IPCC framework refers to the decomposition of organic solid waste through biological processes, primarily in controlled environments. This category includes treatment methods such as composting, and anaerobic digestion, aimed at stabilizing organic matter. These methods are employed to reduce waste volume, mitigate methane emissions, and generate valuable by-products

like compost and biogas. Composting facilities, bio-methanation plants, and small-scale vermicomposting units are common across urban and rural areas in India, particularly for managing food waste, green waste, and agricultural residues.

Biological treatment of solid waste in India also contributes to the country's climate action commitments by reducing methane emissions from uncontrolled decomposition in landfills. By diverting biodegradable waste from landfills to treatment facilities, the potential for methane generation is significantly curtailed, thus contributing to the country's broader GHG mitigation targets under the Paris Agreement. Overall, while India has made progress in establishing composting and anaerobic digestion facilities, there is still considerable scope for expanding capacity, improving operational efficiencies, and integrating advanced technologies to enhance the contribution of biological treatment to sustainable waste management and climate change mitigation.

7.3.1. Composting (5.B.1)

Category description and background

India has a long history of composting, both at the household and community levels. The Government of India has been promoting composting as part of the Swachh Bharat Mission, encouraging cities to set up decentralized composting units. Composting (5.B.1) within the IPCC framework focuses on the aerobic treatment of biodegradable components of MSW. In India, composting plays a significant role in the management of organic waste, which constitutes a significant amount in the total MSW generated in the country. The high organic content, primarily from food scraps, vegetable peels, garden waste, and other biodegradable materials, makes composting a highly relevant waste management strategy in the Indian context. The process involves controlled aerobic decomposition by microorganisms, resulting in nutrient-rich compost, which can be used as a soil conditioner in agriculture and horticulture.

There has been a noticeable trend towards adopting innovative composting methods, such as in-vessel composting and aerobic composters in high-rise apartments, schools, and commercial complexes. This shift aligns with India's commitment to sustainable waste management and reducing landfill dependence. The future of composting in India hinges on improving source segregation practices, increasing public participation, and scaling up decentralized composting solutions to achieve a circular economy in waste management.

7.3.1.1. Municipal solid waste (5.B.1.a.)

Category description

The CPCB reports on the status of capacity of the composting facilities across India. Moreover, it has been reported that composting accounts for about 10% of the MSW treatments in India (Cao et al., 2023; Pujara et al., 2019). Therefore the activity data used for the emissions calculations is currently based on considering the 10% of total MSW treated. However, the composting rate is expected to increase in the coming future as many integrated solid waste management facilities are being implemented at community and regional levels. The emission factor used is IPCC default for wet waste.

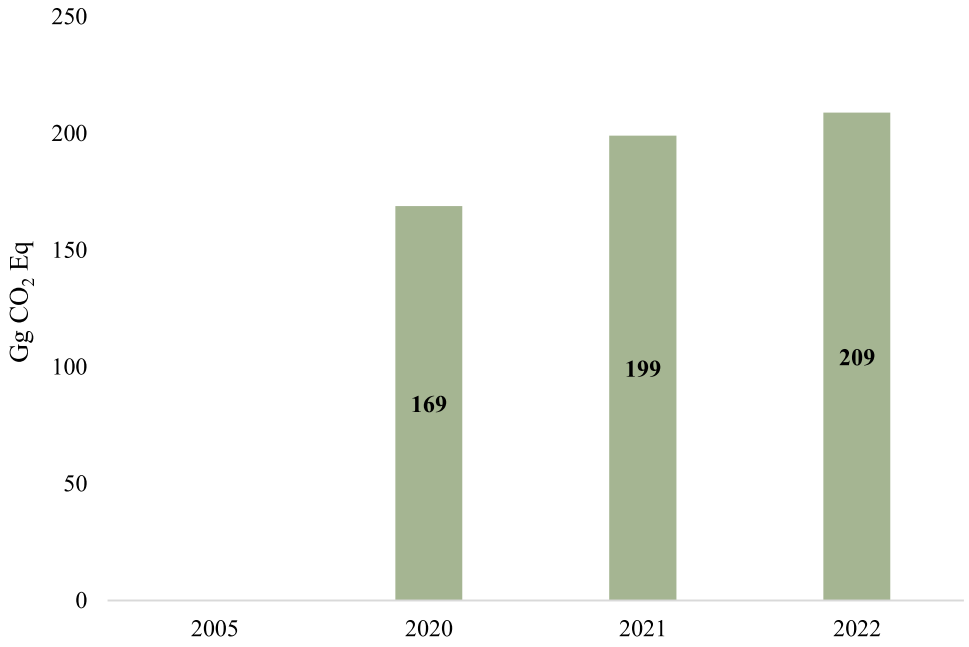


Figure 7.7 : GHG emissions from Municipal solid waste (5.B.1.a.) in 2005, 2020-2022

Methodological issues

Composting practices in India are highly variable due to differences in temperature, moisture levels, and types of organic waste. This variability can significantly affect methane emissions, leading to potential inaccuracies in GHG estimations. Additionally, a substantial portion of composting is handled by the informal sector, whose activities are often unreported, resulting in gaps in data and potential underestimation of emissions. The use of IPCC default emission factors may not fully reflect the local conditions and technological efficiencies.

Formal composting systems were extremely limited and largely unrecorded in 2005. Small-scale or informal composting activities existed but lacked quantifiable data, leading to NO for large-scale operations and NE for unquantified minor activities. However, from the year 2020 onwards, data monitoring and calculations have been done.

Table 7.7 : Activity data for Municipal solid waste in kt dm for 2005, 2020-2022

Source/Sink Categories	Unit	2005	2020	2021	2022
Annual waste amount treated	(kt dm)	NO	1,508.06	1,777.08	1,865.21

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 (“Information on Flexibility”) of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

A quantitative uncertainty analysis for this category was conducted using the Tier 1 approach from the 2006 IPCC Guidelines. For each category and gas, a detailed analysis is conducted for the starting and latest reporting years, highlighting the main contributors to overall uncertainty.

Time-series consistency is a cornerstone of the inventory process. For the reported years, consistent methodologies and data sources have been applied to the greatest extent possible to ensure that trends reflect actual changes in emissions.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

7.3.2. Anaerobic digestion at biogas facilities (5.B.2)

Category description

Anaerobic digestion (AD) at biogas facilities (5.B.2) involves the biological breakdown of organic matter in the absence of oxygen, resulting in the production of biogas. This process is highly effective in managing the organic fraction of MSW, agricultural waste, and other biodegradable materials. In India, the focus on anaerobic digestion aligns with the country's commitment to sustainable waste management and renewable energy generation, particularly in response to its increasing waste generation due to rapid urbanization and population growth.

The Indian government's policies, like the Solid Waste Management Rules, 2016, emphasize decentralized waste treatment solutions, including the use of biogas plants to process organic waste. Anaerobic digestion is particularly advantageous as it not only reduces the volume of waste sent to landfills but also generates biogas, which can be utilized for cooking, electricity generation, or as a transportation fuel in the form of Compressed Biogas (CBG). The residue from the digestion process, known as digestate, can be used as a nutrient-rich organic fertilizer, further contributing to agricultural sustainability.

7.3.2.1. Municipal solid waste (5.B.2.a.)

Category description

Anaerobic digestion is less common in India compared to composting but is gaining momentum in urban areas and among large-scale waste generators such as hotels and markets. Similar to composting, the amount of waste processed through anaerobic biogas facilities is also mentioned in the CPCB report. The emission factors used for estimation are default for weight waste. For anaerobic digestion, the emission factor used was default which was 0.8 g CH_4/kg of waste treated. For years 2020, 2021, 2022, biogas generation data is provided by CPCB, which is ultimately used for the recovery of energy, hence all the methane generated in biogas digestion is considered in methane recovery. Thus, the net methane emissions from this category were zero. The biogas generated is utilized as energy, thus mitigating methane emissions.

Methodological issues

Similar to composting, anaerobic digestion practices vary across India, impacting the accuracy of methane emission estimates. The default emission factors may not reflect the diverse feedstocks, treatment durations, and technological efficiencies of Indian facilities. Additionally, small-scale biogas plants, particularly in rural areas, often operate without systematic reporting, leading to potential data gaps.

Dedicated biogas plants for municipal solid waste were negligible before the National Biogas and Manure Management Programme expanded in later years. The absence of such facilities and lack of activity data justified NO and NE.

Table 7.8: Activity data for Municipal solid waste in kt dm for 2005, 2020-2022

Source/Sink Categories	Unit	2005	2020	2021	2022
Annual waste amount treated	(kt dm)	NO,NE	299.67	277.75	889.14

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

A quantitative uncertainty analysis for this category was conducted using the Tier 1 approach from the 2006 IPCC Guidelines. For each category and gas, a detailed analysis is conducted for the starting and latest reporting years, highlighting the main contributors to overall uncertainty.

Time-series consistency is a cornerstone of the inventory process. For the reported years, consistent methodologies and data sources have been applied to the greatest extent possible to ensure that trends reflect actual changes in emissions.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

7.4. Incineration and open burning of waste (5.C)

Category description

Incineration and Open Burning of Solid Waste involve the combustion of waste materials, either in controlled environments (incineration) or uncontrolled settings (open burning). The detail of each category is mentioned in detail in the corresponding sections.

7.4.1. Waste incineration (5.C.1)

Category description and background

Incineration serves as a key method for waste disposal, especially for types of waste that are challenging to treat through other methods, such as hazardous, clinical, and certain MSW. Waste incineration significantly reduces waste volume and can generate energy, supporting waste-to-energy (WtE) projects. However, this practice faces challenges like high operational costs, technical inefficiencies, and public concerns over air pollution.

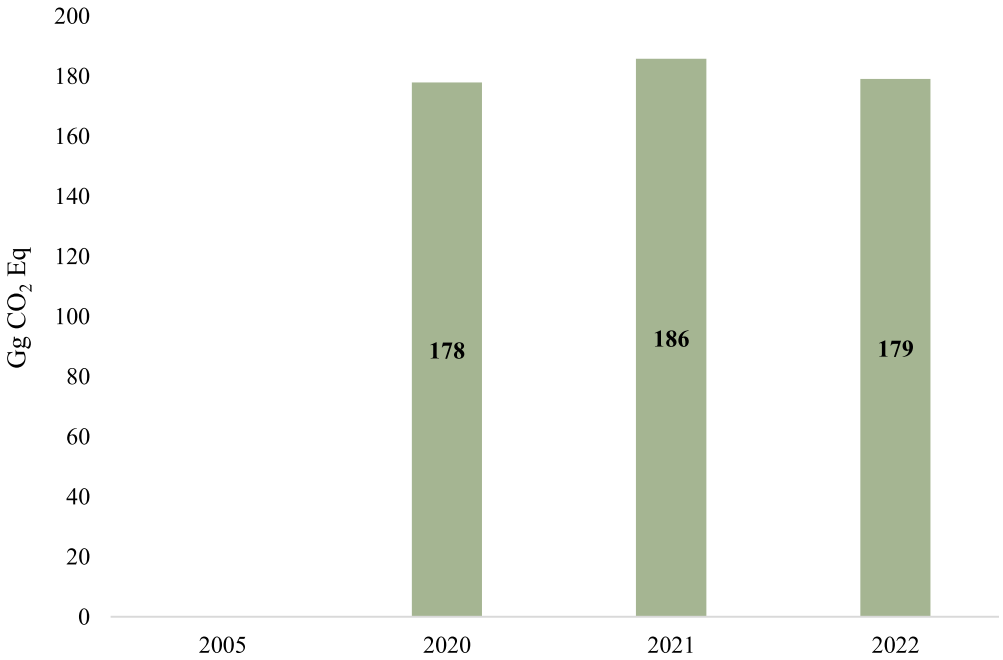


Figure 7.8 GHG emissions from Waste incineration (5.C.1) in 2005, 2020-2022

7.4.1.1. Biogenic (5.C.1.a)

Category description and background

Biogenic waste incineration (5.C.1.a) refers to the combustion of organic, biodegradable materials derived from plants and animals, such as food waste, garden waste, and untreated wood. In the Indian context, biogenic waste forms a significant portion of MSW. This high organic content presents an opportunity for WtE projects that utilize incineration to reduce waste volumes while generating electricity or heat. The adoption of incineration technology in India has been limited due to high capital costs, operational challenges, and public opposition due to concerns over air pollution. The existing WtE plants in cities like Delhi and Hyderabad primarily focus on mixed waste, which includes biogenic components but also non-biodegradable waste. To promote sustainable waste management, India's Swachh Bharat Mission and National WtE Policy emphasize developing incineration infrastructure for segregated organic waste. However, greater emphasis on waste segregation at the source and improved emission controls are needed to expand biogenic waste incineration sustainably. Biogenic MSW in India primarily includes organic components such as food waste, garden waste, paper, and cardboard. These wastes are incinerated mainly in WtE plants, where they are used to produce energy. The biogenic content reduces the net carbon footprint of incineration, as it primarily generates biogenic CO_2, which is considered part of the natural carbon cycle.

There were no centralized municipal solid waste incineration systems in India in 2005. Although sporadic open burning occurred, systematic national data were not available; therefore, these were marked as Not Occurring (NO) for that inventory year. Emissions from open burning of waste were already accounted for under municipal solid waste treatment processes (5B) to avoid double counting hence IE has been used to mark these emissions. These notations are used for the section 5.C.1 & 5.C.2. respectively.

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 7 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

A quantitative uncertainty analysis for this category was conducted using the Tier 1 approach from the 2006 IPCC Guidelines. For each category and gas, a detailed analysis is conducted for the starting and latest reporting years, highlighting the main contributors to overall uncertainty.

Time-series consistency is a cornerstone of the inventory process. For the reported years, consistent methodologies and data sources have been applied to the greatest extent possible to ensure that trends reflect actual changes in emissions.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

7.4.1.2. Non-biogenic (5.C.1.b)

Category description and background

Non-biogenic waste incineration (5.C.1.b) involves the combustion of non-biodegradable, fossil-fuel-derived materials, such as plastics, rubber, synthetic textiles, and other inorganic waste. In India, non-biogenic waste accounts largely due to rapid urbanization and increased use of plastic products. Incinerating non-biogenic waste is primarily aimed at reducing landfill volumes and mitigating environmental pollution, particularly in urban areas where landfill space is limited.

While incineration of non-biogenic waste helps in waste volume reduction, it raises concerns over GHG emissions, such as CO_2, and other pollutants like dioxins and furans, which pose health and environmental risks. India's current waste-to-energy (WtE) infrastructure often mixes biogenic and non-biogenic waste due to inadequate segregation practices. To address this, policies like the Plastic Waste Management Rules, 2016 and Extended Producer Responsibility (EPR) are being strengthened to promote better segregation and sustainable disposal of non-biogenic waste through incineration technologies with advanced emission controls.

Non-biogenic MSW primarily consists of plastics, synthetic textiles, and other non-biodegradable materials. These are often incinerated in WtE plants, particularly in urban areas, to reduce landfill loads and generate energy. The MSW in many places is first converted into RDF and then incinerated. In India, since MSW incineration generated energy, the emissions are considered in the energy sector. Non-biogenic hazardous wastes include synthetic chemicals, heavy metals, and non-biodegradable hazardous industrial residues. Emissions from incineration of hazardous waste are not estimated in this BTR due to unavailability of data for choosing suitable emission factors. Non-biogenic clinical waste includes items like synthetic gloves, plastic syringes, and other disposable medical supplies. These are incinerated to prevent the spread of infections and ensure sanitary disposal. Amount of clinical waste incinerated, default emission factors used for estimation and CO_2 emissions from incineration of clinical waste which are of fossil origin are applicable.

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

A quantitative uncertainty analysis for this category was conducted using the Tier 1 approach from the 2006 IPCC Guidelines. For each category and gas, a detailed analysis is conducted for the starting and latest reporting years, highlighting the main contributors to overall uncertainty.

Time-series consistency is a cornerstone of the inventory process. For the reported years, consistent methodologies and data sources have been applied to the greatest extent possible to ensure that trends reflect actual changes in emissions.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

7.4.2. Open burning of waste (5.C.2)

Category description and background

Open burning of waste (5.C.2) refers to the uncontrolled combustion of solid waste, often in open areas, without pollution controls. In India, this practice is prevalent in rural and peri-urban areas due to inadequate waste collection and disposal infrastructure. Open burning is commonly used to dispose of mixed MSW, agricultural residues, and non-recyclable materials. This leads to significant emissions of greenhouse gases (GHGs) like CO_2 and CH_4, along with air pollutants such as particulate matter (PM), black carbon, and volatile organic compounds (VOCs).

The IPCC 2006 guidelines categorize emissions from open burning under the waste sector, emphasizing its environmental and health impacts. In India, open burning contributes to air quality deterioration, particularly in winter months, exacerbating issues like smog in cities. Open burning has reduced considerably due to several awareness programs and initiatives. About 2% of total waste generated is burned in open since implementation of Solid waste management rules and Swachh Bharat Mission. This number is an estimated based on observations of experts. Most of the waste burned is sweeping or yard litter waste and wood, which accounts for about 70 % of the waste burned. The waste burned sometimes consists of paper, plastics, sometimes clothes are often burned by some people.

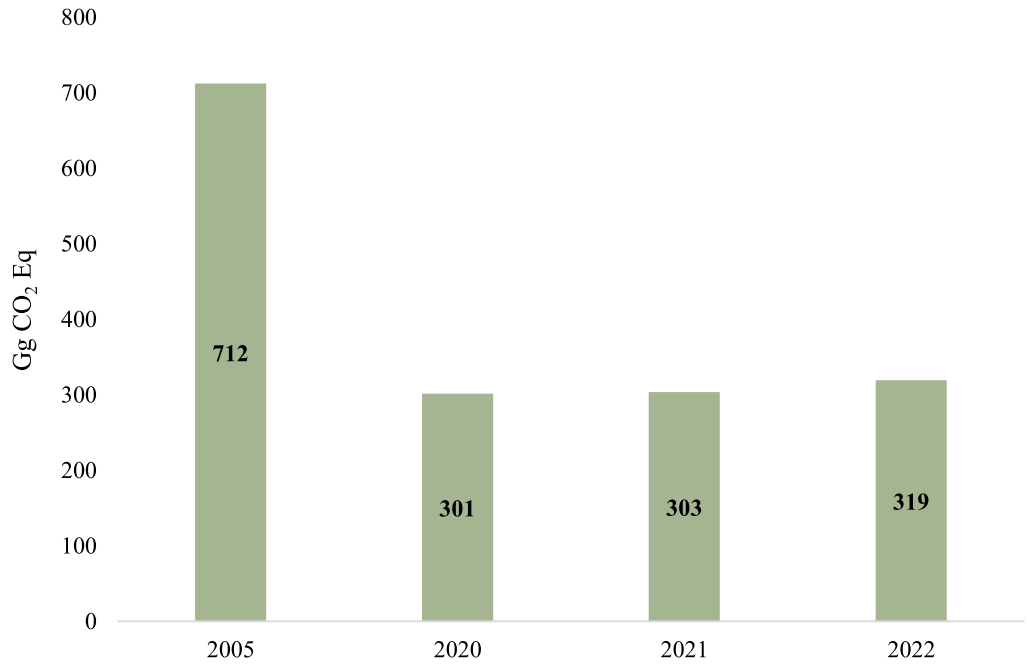


Figure 7.9 GHG emissions from Open burning of waste (5.C.2) in 2005, 2020-2022

7.4.2.1. Biogenic (5.C.2.a)

Category description and background

Biogenic waste includes organic materials such as food waste, agricultural residues, and garden trimmings that are prone to open burning in India. These materials, when burned, release GHGs like CO_2 along with particulate matter (PM) and other pollutants. The burning of biogenic waste is commonly seen in rural areas, where it serves as a convenient disposal method despite its environmental impacts.

Municipal solid waste (MSW) comprises organic materials like kitchen waste, paper, textiles, and yard trimmings. About 70% of the total MSW burned is of biogenic nature. Open burning of MSW is frequently observed at vacant plots, and even along roadsides due to limited waste collection services and lack of awareness among communities about its adverse effects. The emissions from biogenic origin are, however, not reported in the national inventory.

Non-biogenic waste includes materials such as plastics, rubber, and synthetic textiles that release harmful pollutants like dioxins, furans, and heavy metals when burned. In India, non-biogenic waste burning is a significant source of pollution due to the improper disposal of non-recyclable plastics and industrial waste.

There were no centralized municipal solid waste incineration systems in India in 2005. Although sporadic open burning occurred, systematic national data were not available; therefore, these were marked as Not Occurring (NO) for that inventory year. Emissions from open burning of waste were already accounted for under municipal solid waste treatment processes (5B) to avoid double counting hence IE has been used to mark these emissions for this section as well.

Non-biogenic MSW includes plastics, synthetic fibers, and other inorganic materials that are often burned in open areas, especially in urban slums and peri-urban regions where waste management services are inadequate. The MSW burned has about 70% of biogenic substances such as garden yard waste and street litter; the remaining 30% accounts paper, plastics, and clothes giving rise to fossil or non-biogenic CO_2 emissions.

Table 7.9: Default emission factors used for estimation of CO_2 emissions from open burning

Type of Waste	Dry Matter Content (Fraction)	Fraction of Carbon in Dry Matter (Fraction)	Fraction of Fossil Carbon in Total Carbon	Oxidation Factor (Fraction)
Garden and Park	0.4	0.49	0	0.58
Wood	0.85	0.5	0	0.58
Paper and Cardboard	0.9	0.46	0.01	0.58
Plastic	1	0.75	1	0.58
Textile	0.8	0.5	0.2	0.58

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

A quantitative uncertainty analysis for this category was conducted using the Tier 1 approach from the 2006 IPCC Guidelines. For each category and gas, a detailed analysis is conducted for the starting and latest reporting years, highlighting the main contributors to overall uncertainty.

Time-series consistency is a cornerstone of the inventory process. For the reported years, consistent methodologies and data sources have been applied to the greatest extent possible to ensure that trends reflect actual changes in emissions.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

7.5. Wastewater treatment and discharge (5.D)

Category description

The waste sector contributed 2.7 % of the total GHG emissions from India in the year 2016 as per the Third Biennial Update Report. It was dominated by emissions from wastewater (78.9%) followed by solid waste. GHG emissions from wastewater are one of the major emitters of methane and nitrous oxide gases. Wastewater emits methane and nitrous oxide gases by design, inefficient operations, or as a by-product of the wastewater management systems. Wastewater management systems including collection, treatment, and discharge systems can sharply differ between countries (Figure 7.10) and are also emitted from disposal points with or without treatment. Domestic wastewater originates from household water use. Other wastewater sources could be mixed with domestic wastewater such as commercial and industrial wastewater in cities and towns. Also, treatment and discharge systems can differ for rural and urban users as well as high-income and low-income urban users. Industrial wastewater is generated during water use and from production.

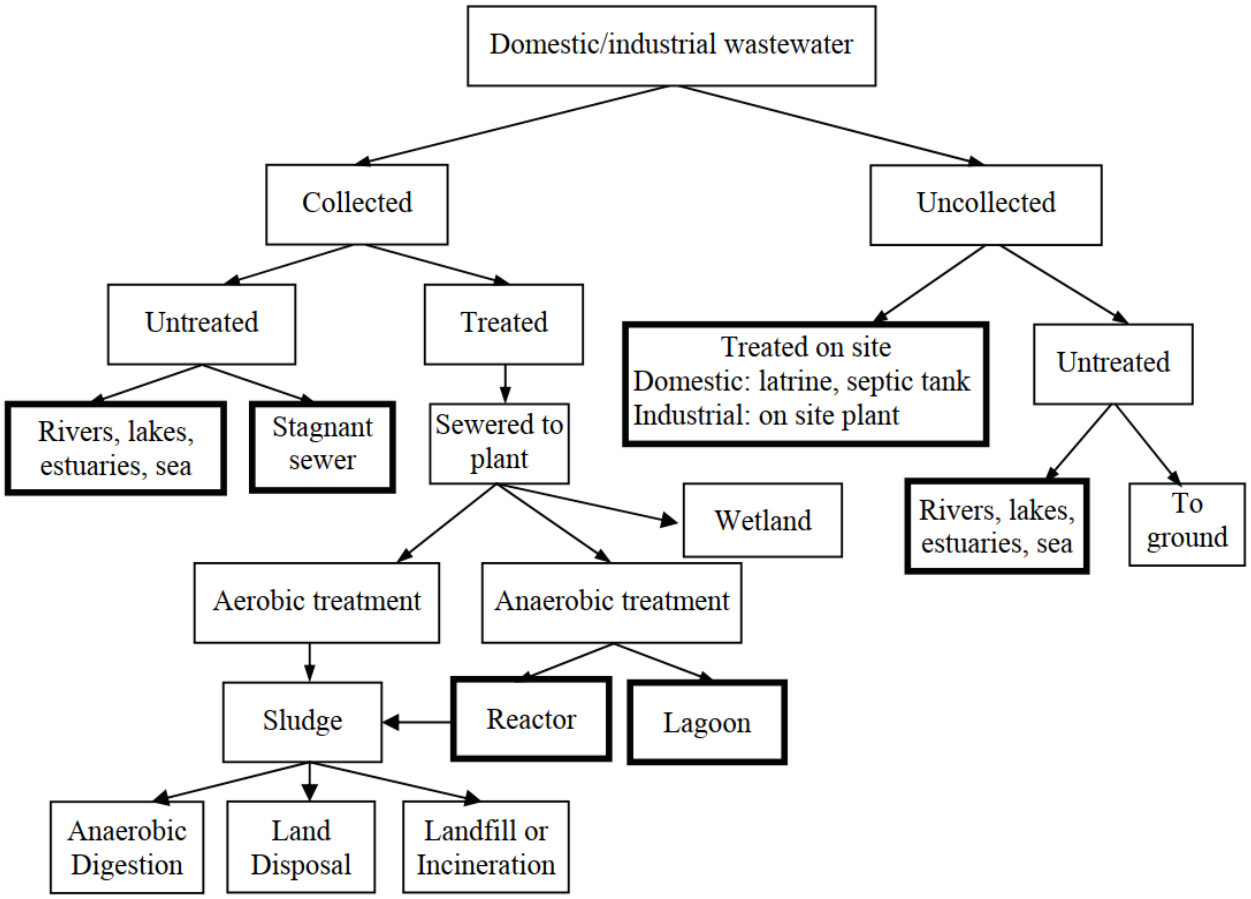


Figure 7.10 : Wastewater Treatment Systems and Discharge Pathways

Emissions particularly, methane and nitrous oxide emissions occur when wastewater and its sludge components break down anaerobically. CH_4 generation is mainly determined by the amount of degradable organic material in wastewater, temperature, and treatment system type. Temperature increases the rate of CH_4 generation. This is especially critical in hotter regions. India has varied climatic zones from temperate to tropical climates with temperatures ranging below 0^0C to 52^0C. At temperatures below 15°C, methanogens are inactive and the wastewater handling systems such as the lagoon mostly function as a sedimentation tank, reducing CH_4 production. However, as the temperature climbs beyond 15°C, CH_4 production is enhanced. The amount of degradable organic content in the wastewater mostly determines its CH_4 production potential followed by pH, oxidation-reduction potential, and hydrological conditions. Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) are common criteria for measuring the organic component of the wastewater. Under the same conditions, wastewater with higher BOD/COD concentrations have higher potential for CH_4 generation.

The CH_4 and N_2O emissions from domestic and industrial wastewater treatment and discharge are reported under “Wastewater Treatment and Discharge (5.D.)” in the CRT table. IPCC 2006 Guidelines define 2 sources of wastewater viz., domestic (5.D.1) and industrial wastewater (5.D.2) for reporting the methane and nitrous oxide emissions for the country. In the BTR reporting format for wastewater treatment and discharge, 3 rows of information are necessary to be provided for reporting the country's emissions. The condensed information are prepared by the use of Excel or IPCC software to fill the estimates at the respective emission sources. Additional emission information also is to be provided if the respective country emits (5.D.3) from other sources of waste sector.

The occurrence of methane and nitrous oxide emissions from both sources in India and the general treatment pathway practiced in India. IPCC guidelines 2006 for National Greenhouse Gas Inventories have been used with different Tiers of data used to assess the numbers for the GHGs. Emissions of CH_4 and N_2O from this source are calculated using India's specific activity data and default value by the decision tree of the 2006 IPCC Guidelines (Page 6.10, Fig. 6.2). Emissions are a function of activity data (fraction of urbanization, treatment pathways, methane recovery) and emission factors (maximum methane producing capacity and methane conversion factor). The following section provides the basic equation to estimate the GHGs from domestic and industrial wastewater.

7.5.1. Domestic wastewater (5.D.1)

Category description

Domestic wastewater is generated from rural and urban settings in India and is handled through 5 different treatment pathways such as septic tanks, latrines, and others in decentralized treatment systems and treatment systems through a sewer network in a centralized treatment system. A part of the domestic wastewaters generated do reach the environment such as surface water bodies, and soil, with and without treatment, and are also likely to contribute to emissions in quantities not ascertained so far.

India's urban centers have witnessed unprecedented growth. India's population, 1.38 billion (as of 2020), is now fast converging on cities in search of a better source of income generation and quality of life. According to recent estimates, 35% of the total population (483 million) is concentrated in urban centers. Some parts of the generated wastewater are untreated and may reach the nearest waterways or land. According to the data from the Joint Monitoring Programme of the UN, the domestic wastewater handling system in the country has improved over the last decade in rural and urban areas in India.. Incedentally, the rural fraction of the country has reduced from 71% in the year 2005 (IPCC, 2006 Guidelines) to 64% in 2022, Ministry of Jal Shakti, Government of India. About 1093 sewage treatment plants (STPs) operate in the country treating 26869 MLD of urban wastewater and another 538 STPs of capacity 9799 MLD capacities are under various states of construction and renovation.

Out of the total 1631 nos of STPs, about 95.3% are designed based on an aerobic system for a treatment capacity of 32, 618 MLD. Only about 76 plants operate under anaerobic route for a capacity of 3,562 MLD (4.7%). 95% of rural domestic wastewater treatment is treated through latrines, septic tanks, and other modes of black water treatment as of 2022. Black water is any waste from toilets or urinals. The balance is grey water that is generated from sinks, showers, bathtubs, and washing machines and usually discharged into the nearest environment in the case of rural centers while it is discharged into sewer systems in urban centres. Grey water is generally less contaminated than black water and is what is discharged from households and commercial centres. Black water and grey water comprise domestic sewage which is treated in urban centres. So what is uncollected and untreated from Indian wastewater into the environment is generally of grey water nature discharged into the natural water bodies with few exceptions of industrial and other wastewaters mixing. Black water is the major source of methane emissions due to high organic and suspended solids content from faecal and urine contamination. In recent times, India has focused on reusing treated sewage and initiated the reuse of treated sewage in horticulture, irrigation, noncontact impoundments, and washing and utilization for industrial activities. Above 3% or 1.8 billion litres of domestic wastewater generated in India is reused as per NITI Ayog report, 2023.

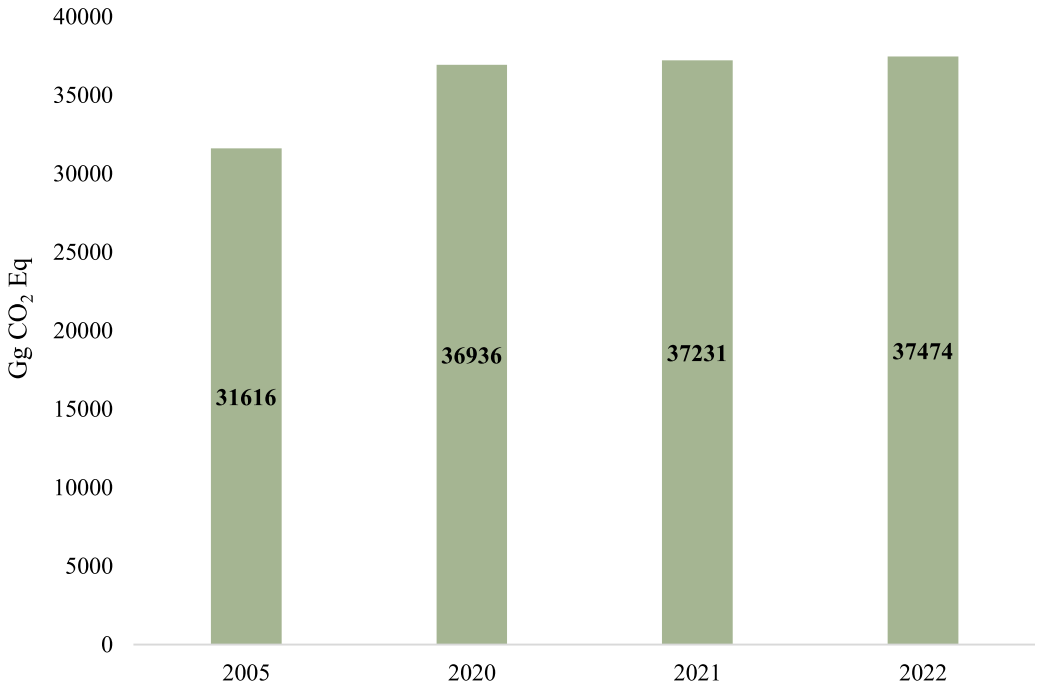


Figure 7.11 : GHG emissions from Domestic wastewater (5.D.1) in 2005, 2020-2022

Methodological issues

All efforts have been undertaken to report domestic wastewater emissions based on existing data available in the country. Despite this data from the rural fraction of the domestic wastewater generated has more uncertainty due to focus on urban centres and as elaborated in the previous para. However, the total domestic wastewater emissions which include both urban and rural centres with time line have been used considering the IPCC 2006 GL using improved fractions of urban, and rural contribution and different treatment pathways. Relevant default emission factors have been used to arrive at the GHG estimates. The major activity data for emission estimation are the factors that affect methane emission from wastewater. It includes the organic content of wastewater (BOD), Population, treatment pathway, and methane-producing capacity. The 2006 IPCC Guidelines methodology recommends using fractions of the population in three income groups (Rural, Urban high, and Urban low) for the estimations based on the discharge and treatment pathways available to them. The population data on urban and rural fractions were sought from the Project "Population Projections for India and States 2011 – 2036".

The amount of degradable organic fraction (BOD/COD) in the wastewater is the main factor in regulating the quantity of methane production. Degradable organic material in wastewater can be estimated by multiplying BOD in the domestic wastewater and the quantity of wastewater generated per day. Biological Oxygen Demand (BOD) values are taken from the Second National Communication, @41 grams/person/day (gpd), whereas IPCC guidelines also provide a range of 27-41gpd. The value of 41 gpd was estimated from India's wastewater composition. The country-specific values have been estimated from the CPCB data on urban wastewater characteristics and the population served.

Maximum CH_4-producing capacity is the maximum amount of methane that can be produced from a specific quantity of organics in wastewater. The 2006 IPCC Guidelines suggest using country-specific data. However, as the maximum methane-producing capacity is not available for the country, the IPCC default value of 0.6 kg CH_4/kg BOD is used.

The MCF represents a portion of a specific degradable organic material in wastewater that will eventually decay in an anaerobic process. MCF indicates the degree to which the system is anaerobic. The MCF value varies according to the type of discharge method and technology utilized in centralized wastewater treatment plants. In this assessment, the value of MCF is based on Table 6.3 of the IPCC 2006 guidelines. The 2006 IPCC Guidelines do not propose the MCF value for primary treatment (methane generated in stagnant sewers and methane from grit chambers).

The data for the population fraction is sourced from "The Report of The Technical Group on Population Projections, 2020, by the National Commission on Population Ministry of Health & Family Welfare, New Delhi, GOI. The data was provided in the above report as Rural and Urban fractions. This data was used for the activity data such as Urbanization and Treatment Pathways for the years 2005, 2020, 2021, and 2022. However, as the fraction of the population in the income group in the inventory year was not available for the year 2005 for generating the time series, default values of IPCC Guidelines (Table 6.5 of IPCC 2006) were used for the year 2005.

The degree of utilization of treatment or discharge pathway or system represents a percentage of the population that is served by each wastewater treatment system. Domestic wastewater from households is discharged and treated in methods such as septic tanks, different configurations of latrines or sewer systems connected to sewage treatment plants or discharged into the environment such as soil and surface waters., Besides there are other types of discharge and treatment pathways such as decentralized treatment systems e.g., ecosan. There is a fraction of wastewater that is not treated or has no treatment pathway available referred to as none in the 2006 Guidelines. The domestic wastewater collected by sewer is treated in a centralized wastewater treatment plant or discharged directly into the recipient environment as mentioned earlier in this section. The septic tank was used to treat domestic wastewater on-site in most households in recent years in urban and rural settings. In rural areas, some parts of the wastewater were treated onsite by latrine or septic tanks and most of the grey wastewater is not collected and discharged directly into nearby water bodies. However, as the fraction of the discharge and treatment pathways for the income group (i,j) in the inventory year was not available for all the years, default values of IPCC Guidelines (Table 6.5 of IPCC 2006) were used.

Part of the domestic wastewater contains organic matter in the form of solids. The solids are expected to settle during the handling of the wastewater or in a treatment system intended or unintended. The fraction of organic components removed as sludge in the respective inventory year (kg BOD/yr) is considered as 5% of the wastewater estimated based on expert judgment. However, in practice, some fraction of solids generated from all the treatment pathways such as septic tanks, latrines and sewage treatment plants are disposed into land.

In general, CH_4 is generated in the treatment systems when it is handled under anaerobic conditions either intended for treatment such as anaerobic digesters, or inefficient aerobic processes. Chapter 6, section 6.2.2.4 says that methane recovery should be included only if there are sufficient facility-specific data. In this case, recovery is taken as zero for the year 2005 as data is unavailable. However, for the methane recovery for the years 2020, 2021, and 2022, the data for the quantum of methane recovered is available in the form of the treatment capacity per day of the anaerobic treatment system in India. Hence, expert judgment for methane recovery from such facilities is taken at 10% (Swachh Bharat Mission https://sbmurban.org/swachh-bharat-mission-progess).

Methane emissions estimated for the Indian population based on the above methodology for the years 2005, 2020, 2021, and 2022 ranged between 737.06 to 780.61 kilotons per year (average of 765 kilotons per year). The increase in domestic wastewater methane emissions from 2005 to 2022 is a net increase of 5.81%.

Table 7.10:. Estimated Domestic Wastewater CH_4 emissions for the years 2005, 2020, 2021 and 2022

Year	Population	TOW (kt BOD/yr)	S (kt BOD/yr)	Total CH_4 Emission	Recovery	Net Emissions
				(kt)		
2005	1,082,768,000	775.85	38.79	737.06	-	737.1
2020	1,348,616,000	903.29	45.16	858.14	85.81	772.3
2021	1,363,006,000	908.78	45.44	863.34	86.34	777.0
2022	1,375,586,000	913.0	45.65	867.34	86.73	780.6

The NE Notation Key is used in the CRT of 5.D.2 activity data for the inventory year and is not available, as nitrogen is assessed only in certain industries for regulatory purposes and not for the estimation of GHG emissions. This activity data would be undertaken in further BTRs.

The NA Notation Key, which is used in the CRT as 5.D.3, indicates that this sector is not monitored in the national inventory. This activity data would be undertaken in further BTRs.

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

A quantitative uncertainty analysis for this category was conducted using the Tier 1 approach from the 2006 IPCC Guidelines. For each category and gas, a detailed analysis is conducted for the starting and latest reporting years, highlighting the main contributors to overall uncertainty.

Time-series consistency is a cornerstone of the inventory process. For the reported years, consistent methodologies and data sources have been applied to the greatest extent possible to ensure that trends reflect actual changes in emissions.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

7.5.2. Industrial wastewater (5.D.2)

Category description

India is a rapidly developing nation and stands at a critical juncture in balancing economic growth with environmental sustainability. Industrialization in India picked up speed in the last decade with rapid capacity expansions of the existing industries and new industrial houses set up in the export processing zones across the country. Proportional growth in water consumption and subsequent wastewater generation has raised methane generation in the country from potential methane-emitting industries. India saw varied trends in industrial and domestic methane emissions, reflecting the complexities of managing a burgeoning economy alongside environmental obligations. 2020 saw unprecedented changes due to the COVID-19 pandemic, which led to significant reductions in industrial activity and, consequently, a temporary dip in emissions. Lockdowns and restricted mobility caused a notable decline in energy consumption and transportation-related emissions, providing a unique, albeit brief, perspective on potential pathways to emission reductions. The following chapter contains brief details of industries considered for industrial methane emissions. Table 7.5.1 presents the treatment types employed in the industry in recent years besides methane conversion factor and recovery for the industrial emissions.

In general, Indian industries have on-site treatment systems, typically comprised of biological treatment operations for wastewaters with high organic load and chemical/biological combination for low organic wastewaters with other pollutants dominating the streams. Industries that are established in cities or towns may use their on-site treatment through an individual effluent treatment plant or a common effluent treatment. Few industries discharge into domestic sewer systems based on the regulatory permit for discharge. However, the industrial wastewater quantification is not documented and methane emissions from sewer systems should be accounted for as part of domestic wastewater emissions or emissions from STP. Besides, Indian Industries follow Zero Liquid Discharge (ZLD), although not a blanket national law, but mandated by SPCBs in sensitive sectors/areas (e.g., Tamil Nadu for textiles/tanneries; other states/industrial clusters via consent/EC conditions). CPCB/MoEF&CC charters allow SPCBs (with CPCB approval) to mandate ZLD in critical zones. The National Green Tribunal has cautioned that industries cannot “dispose” effluent on land under the guise of irrigation; any use must be controlled, standards-compliant, and formally approved by the respective State Pollution Control Boards.

This section focuses on estimating CH_4 emissions from on-site industrial wastewater treatment. CH_4 is only produced from industrial wastewater with significant carbon loading that is treated under intended or unintended anaerobic conditions. Organic substances in industrial wastewater are commonly quantified using COD, which is the measurement used here. Other variables that are considered for emission estimates are production process, unit wastewater generated per tonne of product, treatment route (aerobic vs anaerobic), and methane recovery. The major methane emitting/generating industries are considered for emissions and in few of the industries have lower organic loads, due to probable methane emissions during operations. These industries include Alcohol, Coffee, Dairy Products, Fruits and Juices, Meat Industry, Organic Chemicals, Petroleum, Plastic and Resins, Pulp & Paper, Sea Food Processing, Soap & Detergents, Starch Production, Sugar Refining, Tannery, Vegetable Oils, and Vegetables.

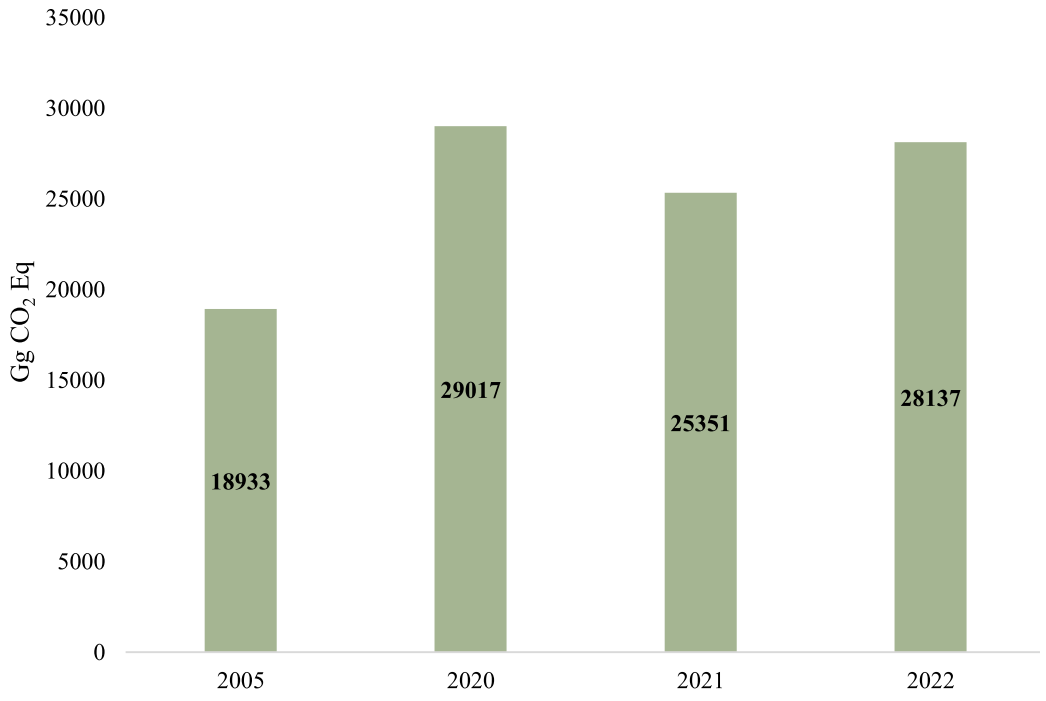


Figure 7.12 GHG emissions from Industrial wastewater (5.D.2) in 2005, 2020-2022

Alcohol

The distillery sector is one of the important sectors in India, with end users from three segments- potable alcohol, chemical sector (industrial use in manufacturing various chemicals), and fuel ethanol for blending with petrol. The range of products from distilleries includes industrial alcohols, spirits, absolute alcohol, beverage alcohol, etc. Beverage alcohol industries utilize different grains, malted barley, and molasses as raw materials. Industrial alcohol industry: Utilize exclusively blackstrap molasses. These products are achieved by a biochemical process of fermentation by yeast, using carbohydrates as raw materials and all products contain ethyl alcohol in different proportions. Two main types of raw materials are used for alcohol production.

— Starchy materials such as barley, rye, wheat, corn, rice, and potatoes.

— Sugars such as blackstrap molasses, fruits, sugar, and beet.

Pollutants & treatment in India: Very high strength of BOD/COD (stillage/spentwash), corrosive, colour and high TDS.

Typical treatment: Biomethanation (anaerobic digestion) ➞ aerobic polishing ➞ MEE/Dryer or land-application in limited cases. Large distilleries often combine biomethanation + MEE. Upto 70% biogas could be recovered in general.

Status: Many large distilleries have ETPs and biomethanation but smaller units remain problematic; CPCB has directions for spent wash management.

Coffee

Coffee production, particularly during the wet processing of beans, generates substantial amounts of wastewater containing high organic loads. The coffee industry in India faces significant challenges concerning methane (CH_4) emissions from wastewater effluents, a by-product of coffee processing. When this wastewater is inadequately treated, it undergoes anaerobic decomposition, leading to the release of methane (Coffee Board of India, 2019). In regions such as Karnataka and Kerala, where coffee cultivation is concentrated, these emissions were particularly noteworthy (Indian Coffee, 2020). Despite some advancements in wastewater management practices, including the adoption of anaerobic digesters and biogas recovery systems, the overall effectiveness remained limited.

Pollutants & treatment in India: High BOD/COD, tannins, colour resistant to degradation.

Typical treatment: Common on-estate measures: equalization, settling ponds, anaerobic treatment + aerobic polishing + decolorization/adsorption treatment methods.

Status: Many rural/wet-process mills still discharge untreated or to simple lagoons; adoption of structured ETPs is increasing in export-oriented clusters but uneven.

Dairy

In 2020, the dairy industry in India emerged as a notable contributor to methane (CH_4) emissions, primarily through the discharge of untreated or inadequately treated wastewater effluents. The sector produces substantial quantities of high-organic-content wastewater from processes such as milk processing, cheese production, and cleaning operations. These emissions not only contributed to India's overall greenhouse gas inventory but also highlighted the pressing need for enhanced wastewater treatment practices in the dairy sector to mitigate the environmental impact and move towards more sustainable production methods. This high methane output is largely attributed to the anaerobic decomposition of organic matter, such as milk solids and fats, in wastewater. The effluents from dairy processing plants often lack sufficient treatment, leading to the formation of methane in open lagoons or anaerobic ponds, which are commonly used for wastewater management.

Pollutants & treatment in India: High BOD, fats/oils/grease.

Typical treatment: Grease traps ➞ equalization ➞ biological (SBR/ASP) ➞ tertiary polishing; CPCB has industry guidance for dairy ETPs.

Status: Most medium/large dairies have ETPs and many reuse treated water for cleaning/cooling; small dairy clusters are variable.

Challenges / reuse: Old treatment systems use anaerobic treatment systems, grease management.

Fruit & Juice

India is a significant player in fruit juice manufacturing due to its diverse agricultural landscape, producing a wide variety of tropical and temperate fruits. Several regions serve as hubs for fruit juice manufacturing such as Gujarat, Himachal Pradesh, Jammu & Kashmir, Karnataka, Maharashtra, Tamil Nadu, Uttar Pradesh, and West Bengal. This industry is known for producing large volumes of wastewater rich in organic content such as sugars, pulp residues, and fruit peels. The high organic load in the wastewater, when inadequately treated, undergoes anaerobic digestion, leading to substantial methane emissions.

Pollutants & treatment in India: Sugar/pectin loads.

Typical treatment: Anaerobic/aerobic biological treatment, DAF and filtration for solids; electrochemical / AOP used in pilots for colour/odour. Best for methane recovery + wastewater reclamation (irrigation reuse after polishing).

Status: Larger processors and export units use ETPs; many small/seasonal processors rely on lagoons or discharge to drains.

Meat Industry (Poultry & Slaughterhouse)

The meat industry in India was a significant source of methane (CH_4) emissions, primarily due to the management of wastewater effluents from processing operations. The industry, which is one of the largest in the world, generates substantial amounts of nutrient-rich wastewater containing organic materials like blood, bone, offal, feathers, and manure. This wastewater, estimated to be around 4 million cubic meters annually, undergoes anaerobic decomposition when not properly treated, releasing approximately 92,590 tonnes of methane in the year 2022. The high organic load in the wastewater creates ideal conditions for methane-producing bacteria, especially in regions like Andhra Pradesh and Tamil Nadu.

Pollutants & treatment in India: Blood, high BOD, pathogens, Free Oil and Grease.

Typical treatment: Primary screening ➞ grease/blood recovery ➞ anaerobic digestion ➞ aerobic polishing + disinfection as per CPCB slaughterhouse guidelines.

Status: municipal modernisations (model abattoirs with ETPs and biogas) are being rolled out, but many small/ illegal abattoirs still discharge untreated. Recent state projects show improvements for reuse and biogas production in larger plants.

Organic Chemicals

Chemicals are essential to our day-to-day life. Organic chemicals have played a vital role in providing inputs to other industrial sectors such as paints, adhesives, pharmaceuticals, dyestuffs, and intermediates, this industry covers a wide spectrum of chemicals. Some of the key sub-segments include; Acetic acid, Methanol, Formaldehyde, Acetone, Acetic Anhydride, phenol, and Nitrobenzene. Methanol, acetic acid, formaldehyde, and phenol constitute more than 60% of India's domestic production of organic chemicals. The basic organic chemical manufacturing industry is essential for the broader chemical manufacturing industry. Basic organic chemicals industries play a vital role in providing chemicals and intermediates as inputs to other sectors, like paints, adhesives, pharmaceuticals, dyestuffs, leather chemicals, pesticides, alcohol, or ethanol, turpentine (except mineral turpentine), and several organic dyes or pigments.

Pollutants & treatment in India: Variable (toxic organics, solvents, phenols);

Typical treatment: Source segregation, solvent recovery, physico-chemical treatment (adsorption, Advanced Oxidation Process), biological treatment for biodegradable fractions.

Status: Large chemical complexes typically have advanced on-site treatment and closed systems; many small units rely on CETPs with mixed performance. The presence of toxic and inhibitory compounds can upset bio-degradation, hence less preferred for anaerobic biodegradation. Sludge is hazardous and hence requires special disposal.

Petroleum

The sector, integral to India's energy infrastructure, produces substantial quantities of wastewater containing a complex mix of hydrocarbons, organic compounds, and chemical additives from activities such as oil refining and petrochemical production. India has petroleum refineries in almost every state. In recent years, most of the petroleum refineries have gone for capacity augmentation. The wastewater, when improperly treated, undergoes anaerobic decomposition, leading to methane emissions in lesser quantities. Major industrial hubs like Gujarat and Maharashtra, where oil refineries and petrochemical plants are concentrated, are anticipated to contribute to emissions.

Pollutants & treatment in India: Oil & grease, BTEX, phenols, ammonia

Typical treatment: API separators → oil recovery → flotation → biological (for dissolved organics) → tertiary polishing; CPCB prescribes closed handling for contaminated streams.

Status: refineries and large terminals generally comply with modern ETPs and reuse (cooling/boiler); smaller operations and historical sites present legacy contamination. High reuse potential of process water and anaerobic route is less preferred. Sludge's are incinerated in most refineries with no energy recovery.

Plastic & Resins

The plastic and resin industries in India have a minor role in the generation of methane (CH_4) emissions owing to the production in large volumes in the country which generates subsequent wastewater containing organic solvents, monomers, and residual chemicals from processes such as polymerization, extrusion, and molding.

Pollutants & treatment in India: Residual monomers/solvents, suspended solids;

Typical treatment: Source segregation, solvent recovery/distillation, physico-chemical then biological for biodegradable fractions.

Status: Solvent recovery and recycling are economically incentivized; small units relying on CETPs sometimes fail to meet norms. Reuse of solvent and emphasis on in-plant recycling of the treated wastewater.

Sea Food Processing

This sector is vital to India's economy and food security and produces significant volumes of seafood for the local and international markets. Seafood wastes, unlike municipal wastes, have more proteins and other nitrogenous materials, responsible for rapid putrefaction. In coastal regions like Kerala, Tamil Nadu, and Andhra Pradesh, where seafood processing is concentrated, water is essential for various pre-processing steps such as cleaning, beheading, filleting, scaling, peeling, cooking, icing, and also for cold chain systems to overcome the perishable nature of captured fishery products at various stages of handling. Water is also required for the storage and transportation of raw and processed products. Processing consumes large volumes of freshwater approximately an amount of 10–40 m^3 per ton of raw material processed as per research reports.

Pollutants & treatment in India: High BOD, solids, salt; CPCB guidance exists for sea food effluent.

Typical treatment: Screening ➞ equalization ➞ DAF/grease removal ➞ aerobic/anaerobic biological treatment ➞ disinfection.

Status: Export-oriented plants near ports generally comply; many small coastal units discharge inadequately into municipal drains or coastal waters.

Soaps & Detergent

Soaps and detergent industry in India was a notable contributor to methane (CH_4) emissions through the discharge of wastewater effluents. This sector, essential for household and industrial cleaning needs, generates significant volumes of wastewater containing organic compounds, surfactants, and chemical additives from manufacturing processes. Inadequate treatment of this wastewater results in anaerobic decomposition, releasing methane into the atmosphere.

Pollutants & treatment in India: Surfactants, high FOG, COD; nutrients especially phosphates.

Typical treatment: FOG separation, biological treatment (specialized microbes), tertiary phosphate removal/ adsorption where required.

Status: Medium/large manufacturers have ETPs and in-plant recycling; small units rely on CETPs or inadequate discharge.

Starch

Wastewater from starch industries in India presents similar environmental challenges as those from vegetable industries. Starch industries, which produce starch from crops like corn, wheat, and potatoes, generate wastewater containing organic matter, nutrients, and potentially harmful substances like pesticides and heavy metals. Wastewater from starch industries typically undergoes treatment to reduce its pollutant levels before discharge. Treatment technologies may include physical processes (e.g., sedimentation, filtration), biological processes (e.g., aerobic or anaerobic digestion), and chemical processes (e.g., coagulation, oxidation). Effluent treatment plants (ETPs) are commonly used to treat industrial wastewater.

Pollutants & treatment in India: High TSS/starch fines and BOD;

Typical treatment: Screening ➞ DAF ➞ biological treatment (aerobic/anaerobic) and recovery of starch where economic, good potential for recovery of starch and biogas upto 70%.

Status: Many larger units implement DAF and biological treatment; smaller units use lagoons or direct discharge in some regions.

Sugar

The sugar industry in India played a significant role in methane (CH_4) emissions through the management of wastewater effluents. With India being one of the largest producers of sugar globally, this industry generates substantial volumes of wastewater containing organic compounds like sugar residues, molasses, and other processing by-products. When this wastewater is not adequately treated, it undergoes anaerobic decomposition, leading to the release of methane into the atmosphere. Regions with high concentrations of sugar production, such as Maharashtra, Uttar Pradesh, and Karnataka, experienced substantial methane emissions due to inadequate treatment practices.

Pollutants & treatment in India: High BOD/COD (molasses wash/vinasse);

Typical treatment: Anaerobic digestion (UASB/biomethanation) → aerobic polishing; industry widely trials/ captures biogas. Energy recovery through biogas production is common.

Status: Many sugar mills in India have biomethanation units (especially in sugarcane belt).

Tannery

Tanneries, which process animal hides and skins to produce leather, generate substantial volumes of wastewater containing organic compounds such as tannins, fats, and chemical residues. The industry receives skin and hides from slaughterhouses in local areas preserved with huge quantities of salt. Being highly organic, methane is expected to be emitted if the wastewater is handled under anaerobic conditions. Regions with high concentrations of tanneries, such as Tamil Nadu, Uttar Pradesh, and West Bengal, are anticipated to emit significant methane emissions.

Pollutants & treatment in India: High BOD/TSS, sulfides, chromium (Cr^{3+}) — CPCB has sector specific guidelines (chromium recovery, sulfide oxidation).

Typical treatment: Beamhouse segregation → chrome precipitation & recovery → primary → secondary (CETP in many clusters).

Status: Major tannery hubs (e.g., Vaniyambadi, Kanpur, Kolkata, and Chennai) use CETP, Common Chrome Recovery Plants, but CETP performance and segregation are problematic.

Vegetable Oils

The vegetable oil industry, which encompasses the production of various cooking oils such as soybean, palm, and sunflower oil, generates substantial volumes of wastewater containing organic compounds like fatty acids, glycerol, and plant residues. When this wastewater is not adequately treated, it undergoes anaerobic decomposition, leading to the release of methane into the atmosphere. Regions with high concentrations of vegetable oil production, such as Maharashtra, Andhra Pradesh, and Telangana, experienced substantial methane emissions due to inadequate treatment practices.

Pollutants & treatment in India: High FOG, spent bleaching earth (solid waste);

Typical treatment: Oil/water separation, soap recovery, biological treatment for residuals.

Status: Most medium/large refineries have ETPs and in-plant recovery; spent earth disposal is a recurring issue.

Vegetable Processing

The management of wastewater from vegetable industries in India is a significant environmental concern. Vegetable processing generates large volumes of wastewater containing organic matter, nutrients, and sometimes toxic substances such as pesticides and heavy metals. The Indian government has established regulations for industrial wastewater discharge, including those specific to the vegetable processing industry. These regulations set limits on various pollutants to protect water quality and public health. Common treatment technologies include physical processes like sedimentation and filtration, biological processes such as aerobic or anaerobic digestion, and chemical processes like coagulation and disinfection. The following section elaborates, on the methodology to estimate methane emissions from Indian Industrial Wastewaters.

Pollutants & treatment in India: Starches/sugars, TSS, biodegradable organics;

Typical treatment: Screening → primary settling → biological polishing; solids often composted, good potential for reuse/irrigation after polishing.

Status: Larger processors / export units compliant; smaller units often discharge to drains or use minimal treatment.

Methodological issues

The major activity data for emission estimation are the factors that affect methane emission from industrial wastewaters which includes the organic content of wastewater (COD), treatment pathway and methane-producing capacity, and unit wastewater generation per tonne of produce. The activity data is explained further in this section.

Annual Production

The most important activity data in the estimate equation comes from outside of the expert domain vis-à-vis variables such as emission factors, treatment pathways, and gas recovery. The annual production from the respective industrial sector information is sourced from the Ministry of Statistics and Programme Implementation (MoSPI), Central Statistical Organisation, Centre for Monitoring Indian Economy. Wherever the data is not available, it is interpolated or extrapolated.

Maximum Methane Producing Capacity (Bo)

Maximum CH_4-producing capacity is the maximum amount of methane that can be produced from a specific quantity of organic substrate present in the wastewater. India is in the initial stage of completing country-specific data on emission factors hence, at this stage, the 2006 IPCC Guidelines is used for the estimate. Since the maximum methane-producing capacity of the Indian industry is not available, the default value is proposed as @0.25 kg CH_4/kg COD. Developing country-specific emission factors and approaching Tier 3 methods would enable understanding of over or under-estimation of the gases through the use of default values.

Methane Correction Factor (MCF)

The MCF represents a part of a given degradable organic material in wastewater that will eventually degrade in an anaerobic process. MCF is an indication of the extent to which the system is anaerobic. The MCF value depends on the type of discharge pathway and the type of technology used in centralized wastewater treatment plants. In this estimation, the values are taken from Table 6.8 of IPCC 2006 GL.

Organics Removed as Sludge (S)

Indian industries have effluent treatment plants within the respective industry for the treatment of their wastewater. The effluent treatment plants are designed to remove solids from the wastewater in their primary and secondary treatment. Based on expert judgment, about 5% of solids are removed from the wastewater treated in the effluent treatment plant. 5% solids removed as sludge is on the higher side of the range between 2 to 5%. India doesn't yet have standards classifying sludge for reuse and is classified as Hazardous Waste. At present, sludge is dried and packed into bags, or used for landfilling. Few industries process as provided hereunder. Industries are increasingly finding ways to reuse and recycle sludge for sustainable purposes. The management of sludge depends on its composition, as some sludge can be hazardous, while others are rich in organic matter and nutrients. Here are several ways industrial sludge has been used in India in recent times, such as soil amendment for agriculture and land application, Cement and Brick Manufacturing, Construction Materials, Energy Recovery (Biogas Production), and what is not recoverable is sent to Secured Landfill. Industrial sludge in India is increasingly being repurposed into eco-friendly ways, turning waste into a valuable resource for a sustainable and circular economy.

Recovery of Methane (R)

Methane recovery from wastewater in Indian industries is gaining attention due to its potential for energy generation and reducing greenhouse gas emissions. Wastewater from industries like Food Processing, Distilleries, Dairies, Pulp & Paper, and sugar mills often contains a high concentration of organic matter, which can be broken down anaerobically to produce biogas. The Indian government encourages methane recovery projects through various policies and incentives. For instance, the Ministry of New and Renewable Energy (MNRE) provides financial support for biogas projects, and there are Clean Development Mechanism (CDM) opportunities for industries that reduce methane emissions. The following industries recover methane for its use viz., Alcohol, dairy, meat, sugar, and tannery. These industries use methane recovered from wastewater through anaerobic digestion. The biogas generated is often used to power boilers and for electricity generation.

Table 7.11: Estimated Methane Recovery and Net Methane Emissions from Industrial Wastewater

Methane Recovery Emissions for the year, Gg				Net Methane Emissions for the year, Gg			
2005	2020	2021	2022	2005	2020	2021	2022
676.2	1036.3	905.4	1207.5	541.9	1132.4	1207.9	1004.9

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

A quantitative uncertainty analysis for this category was conducted using the Tier 1 approach from the 2006 IPCC Guidelines. For each category and gas, a detailed analysis is conducted for the starting and latest reporting years, highlighting the main contributors to overall uncertainty.

Time-series consistency is a cornerstone of the inventory process. For the reported years, consistent methodologies and data sources have been applied to the greatest extent possible to ensure that trends reflect actual changes in emissions.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

7.5.3. Other (5.D.3)

Category description

Nitrous oxide is another greenhouse gas that occurs as a by-product of the biochemical oxidation of ammonia to nitrate in the wastewater management system. The process occurs in two steps: converting ammonia into nitrite by Nitrosomonas bacteria and then converting nitrite into nitrate by Nitro-bacter bacteria.

Methodological issues

Nitrous oxide emission occurs as direct and indirect emissions. Direct emissions come from wastewater treatment plants, and indirect emissions come from wastewater after disposing of effluents into lakes, rivers, and seas. Nitrous oxide emissions from domestic wastewater are estimated according to the following methodology given in the IPCC 2006 Guidelines.

The major activity data for nitrous oxide are per capita protein consumption, population, and degree of treatment.

Human Population (P)

The IPCC 2006 Guidelines recommended the fractions of the population in three income groups for estimation of nitrous oxide emission from domestic wastewater because availability and choice of sewage disposal system are dependent on income and population density. The population considered for the domestic wastewater methane emissions has been used for nitrous oxide estimation for the years 2005, 2020, 2021, and 2022.

Protein Consumption (grams/capita/day)

Per capita protein consumption intake is one of the major activity data for nitrous oxide emissions. This data was collected from the joint report submitted by the Ministry of Statistics and Programme Implementation and the World Food Programme in 2019. India's average protein intake values for Rural and Urban were 60.7 and 60.3 grams/capita/day. The per capita data is converted to annual consumption of protein which is derived as 22.72 kg protein/capita/year for the years 2020, 2021 and 2022, and 20.29 kg protein/capita for the year 2005 as relevant data was available for the year. National per capita protein consumption was last reported in the last census year 2011. Projections were made for the years 2020 to 2022 (Source: NSS Report No.540: Nutritional Intake in India).

FNRP

It is a fraction of nitrogen in protein (FNPR). The default value of 0.16 N/kg proteins as suggested in the IPCC 2006 Guidelines was used.

FNON-CON

It is a factor for non-consumed protein added to the wastewater. The default value for non-consumed protein discharged to wastewater pathways is 1.4 for countries with garbage disposal facilities as recommended in the IPCC 2006 Guideline. For developing countries like India, a value of 1.1, is used as it has no garbage disposal facility.

FIND-COM

It is a factor used for industrial and commercial co-discharged protein in the sewer system. Wastewater from industrial and commercial sources, which discharges into the sewer, may also contain protein. This default value is mentioned as 1.25 in IPCC 2006 Guidelines and is based on data in Metcalf & Eddy's book (year) Table 2.6.

N SLUDGE

It is a fraction of the removal of nitrogen from sludge. Sewage sludge typically contains around 6-8% nitrogen on a dry weight basis. On a wet basis, the organic nitrogen is converted into nitrous oxide if sufficient anaerobicity is available. The default value is zero as suggested by the IPCC 2006 Guideline for Nitrogen in sludge.

Nitrous oxide (N_2O) emissions from domestic wastewater are a growing environmental concern in India, primarily due to population growth, urbanization, and inadequate wastewater treatment infrastructure. N_2O is a potent greenhouse gas, and its emissions are linked to the nitrogen cycle, especially through biological nitrogen removal processes (nitrification and denitrification) in wastewater treatment.

Nitrous oxide emissions follow a similar trend as methane rise in India, with major reasons as briefed above. Tier 1 method has been adopted for N_2O assessment with major contributing variables being population and to a lesser extent per capita protein. Other variables in the methodology equation are constants. Non-availability of the variables is likely to affect the accuracy of the estimates as country-specific values are not used and is likely to increase uncertainty. One of the major improvement plans for nitrous oxide estimates could be collecting and collating national data on the above parameters of the nitrous oxide emissions formula of the IPCC 2006 Guidelines.

Table 7.12 : Estimated Domestic Wastewater Nitrous Oxide Emissions

Year	Population	Per Capita Protein (Kg/Person/Year)	Total Nitrogen Effluent (KgN/Year)	N_2O Emission (Gg N_2O / Year)
2005	1082768000	20.29	5,27,26,47,052	41.43
2020	1347121000	22.72	7,35,35,47,218	57.78
2021	1363006000	22.72	7,43,20,11,022	58.39
2022	1375586000	22.72	7,42,29,00,000	58.93
Assumptions: Fnpr (kg N/Kg protein) =0.16; Emission Factor Kg N_2O- N Kg N = 0.005; Fnon-com fraction of non-consumption protein =1.1; Find-com =1.25				

Flexibility applied

Detailed information regarding the specific provisions and justification for the flexibility applied is provided in Chapter 5 ("Information on Flexibility") of this Biennial Transparency Report.

Uncertainty assessment and time-series consistency

A quantitative uncertainty analysis for this category was conducted using the Tier 1 approach from the 2006 IPCC Guidelines. For each category and gas, a detailed analysis is conducted for the starting and latest reporting years, highlighting the main contributors to overall uncertainty.

Time-series consistency is a cornerstone of the inventory process. For the reported years, consistent methodologies and data sources have been applied to the greatest extent possible to ensure that trends reflect actual changes in emissions.

QA/QC and verification

The comprehensive QA/QC program implemented encompasses a series of systematic procedures, including routine checks on data input, calculations, and reporting. Level 1 QC activities are performed by the inventory compilers, involving general methods for checking consistency and correctness of data. Level 2 QC activities, including expert reviews, are conducted by personnel not directly involved in the inventory compilation process but possessing the necessary expertise. All documentation related to QA/QC activities, including checklists, review comments, and records of implemented corrective actions, is meticulously maintained for transparency and future reference.

Recalculations

As this is India's first BTR submission, no recalculations have been performed for this category.

Planned Improvements

Specific planned improvements include, but are not limited to, efforts to collect more granular and higher-quality activity data, research and development of country-specific emission factors, capacity-building initiatives for inventory compilers, and the exploration of higher-tier methodologies where feasible.

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