Environmental Protection Agency
An Ghníomhaireacht um Chaomhnú Comhshaoil

Ireland's National Inventory Report 2024

Greenhouse Gas Emissions 1990-2022

IRELAND

NATIONAL INVENTORY REPORT 2024

GREENHOUSE GAS EMISSIONS 1990 - 2022
REPORTED TO THE UNITED NATIONS
FRAMEWORK CONVENTION
ON CLIMATE CHANGE

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EXECUTIVE SUMMARY

ES.1 Background

The present report constitutes Ireland's National Inventory Report for 2024 and refers to the greenhouse gas inventory time-series for the years 1990-2022.

The estimates presented here were estimated in accordance with the guidelines in Annex I of the decision using methodologies provided in the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (IPCC 2006) and GWPs as listed in the Column 'GWP 100-year' in Table 8.A.1 of Appendix 8.A of the report 'Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change'. The Common Reporting Format (CRF) tables reported in this submission were generated by the CRF Reporter [AR5] software and submitted via the UNFCCC submission portal and are in accordance with Annex II of the decision. The UNFCCC guidelines require that Parties prepare a National Inventory Report (NIR) as one of the key components of their annual submissions to the UNFCCC secretariat. The purpose of the NIR is to describe the input data, methodologies, emission factors, quality assurance and quality control procedures and other information underlying the inventory compilation for greenhouse gases and to give details of any recalculations of inventories previously submitted. It is needed to assess the transparency, completeness and overall quality of the inventories as part of the rigorous on-going technical review of submissions from Annex I Parties. The structure of this report is consistent with the Appendix in Annex I of Decision 24/CP.19.

The present report is the official submission of Ireland for 2024 under the UNFCCC.

The NIR is prepared according to the Appendix in Annex I to Decision 24/CP.19. Part I includes sections describing the national system for inventory preparation and management, emission trends, key emission categories, recalculations and on-going improvements. In addition, detailed documentation of methods, activity data and emission factors used for each of the five source categories, as defined by the Intergovernmental Panel on Climate Change (IPCC), are included. The report contains several annexes, which include calculation sheets, activity data, emission factors and other appropriate reference material to support the descriptions of inventory estimation methods given in both Part I and Part II and to provide adequate transparency for review purposes, as required by the UNFCCC reporting guidelines.

The Environmental Protection Agency has overall responsibility for the national greenhouse gas inventory in Ireland's national system, which was established in 2007 under Article 5 of the Kyoto Protocol. The EPA Office of Evidence and Assessment (OEA) performs the role of inventory agency in Ireland and undertakes all aspects of inventory preparation and management as well as the reporting of Ireland's submissions annually in accordance with the requirements Regulation (EU) 2018/1999 of the European Parliament and of the Council and the UNFCCC. In addition to complying with the UNFCCC reporting guidelines, the 2024 NIR is intended to inform Irish Government departments and institutions involved in the national system, as well as other relevant stakeholders in Ireland, of the level of emissions and the state-of-the-art of Irish greenhouse gas inventories. The in-depth analysis of key categories and the up-to-date data on emissions trends provides essential information for the implementation of the Climate Action and Low Carbon Development (Amendment) Act 2021 and the development of emissions projections. The detailed NIR, together with activities provided for in the national system, allows data providers to become fully aware of the importance of their contributions to the inventory process and it serves to identify areas where improvements in input data can be achieved.

European Union's Effort Sharing Regulation (EU 2018/842) established binding annual targets for Member States for the period 2021–2030. These targets cover emissions from most sectors not included in the EU Emissions Trading System (EU ETS), such as transport (except aviation and international maritime shipping), buildings, agriculture and waste. Ireland's binding target (revised 2023) is set out in Annex I of the decision and limits emissions to -42 per cent compared to 2005 greenhouse gas levels. Ireland's actual annual emissions allocations (AEAs) for each year of the period 2021 to 2030 are set out in Annex II to Decision 2020/2126.

ES.2 Summary of National Emission and Removal-related Trends

In 2022, total emissions of greenhouse gases including indirect emissions from solvent use (without *LULUCF*) in Ireland were 60,604.9 kt CO_2 equivalent, which is 9.7 per cent higher than emissions in 1990 as presented in Figure ES.1.

The total for 2022 is 15.2 per cent lower than the peak of 71,476.9 kt CO_2 equivalent in 2001 when emissions reached a maximum following a period of unprecedented economic growth. The *Energy* sector accounted for 56.5 per cent of total emissions in 2022, *Agriculture* contributed 37.0 per cent while a further 5.0 per cent emanated from *Industrial Processes and Product Use* and 1.4 per cent was due to *Waste*. Emissions of CO_2 accounted for 60.6 per cent of the national total in 2022, with CH_4 and N_2O contributing 29.1 per cent and 9.1 per cent, respectively. The combined emissions of HFC, PFC, SF_6 and NF_3 accounted for 1.2 per cent of total emissions in 2022.

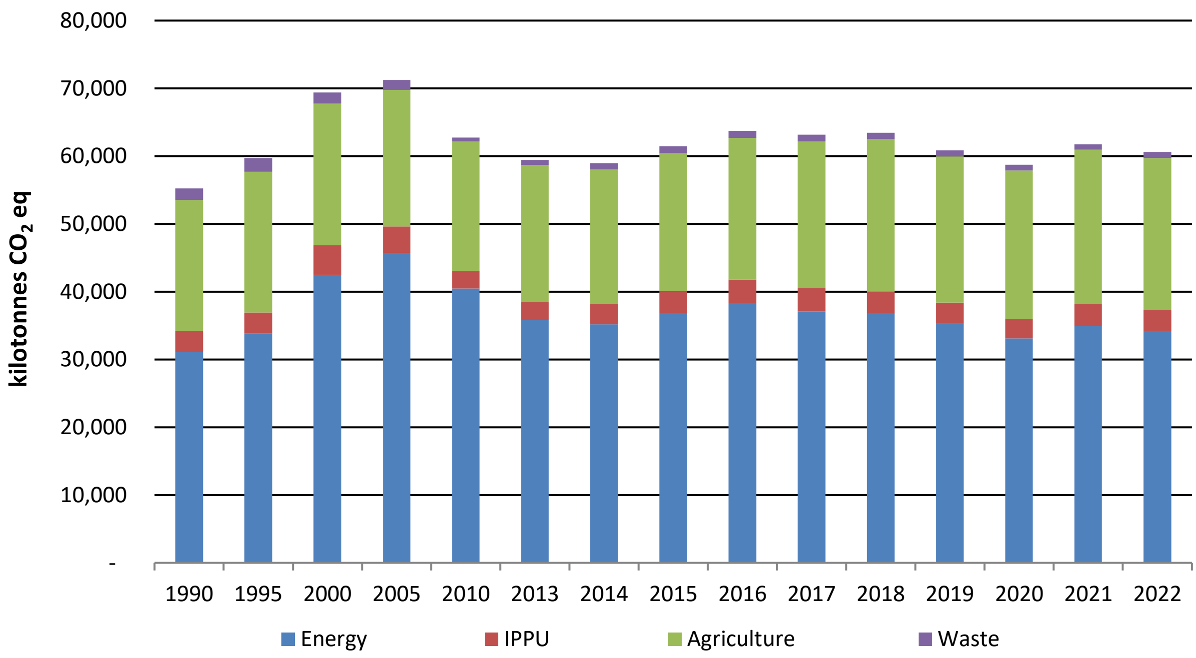


Figure ES.1 National total Greenhouse Gas emissions (excluding LULUCF) 1990-2022

An approach 1 level assessment of emission source categories (ranking on the basis of their contribution to total emissions) identified 29 key categories in 2022 (excluding the *LULUCF* sector). There were 18 key categories of CO_2, accounting for 58.5 per cent of total emissions. There were seven key categories of CH_4, three key categories of N_2O and 1 key category of HFC in level assessment, which accounted for 28.1 per cent, 7.7 per cent and 1.0 per cent of total emissions, respectively. The results of the approach 1 key category analysis clearly show the impact of CO_2 emissions from energy consumption on total emissions in Ireland. These combustion sources of CO_2 emissions accounted for 16 out of 29 key categories identified by level assessment in 2022 or 54.3 per cent of total emissions. The top ten key categories contributed 73.9 per cent of total emissions in 2022 with emissions of CO_2 from the combustion of liquid fuels by road traffic being the single largest source, accounting for 18.2 per cent of the total national emissions.

The application of uncertainty analysis for Irish greenhouse gas inventories using the IPCC approach indicates an overall level uncertainty of 3.50 per cent in the 2022 inventory (excluding the LULUCF sector) and a trend uncertainty of 2.28 per cent for the period 1990 to 2022. These values are determined largely by the low uncertainty in the estimates of CO_2 emissions from the energy sector, which is the major source category in Ireland and for which the input data and methodologies are most reliable. The 60.6 per cent of emissions contributed by CO_2 in 2022 are estimated to have an uncertainty of 1.27 per cent. Emissions of CH_4 from 3.A Enteric Fermentation and N_2O from 3.D.1 Direct N_2O Emissions from Managed Soils sectors combined account for the majority of the level uncertainty (contributing 93.9 per cent and 83.8 per cent, respectively to each gas uncertainty) in the 2022 inventory. The impact of HFC, PFC, SF_6 and NF_3 on inventory uncertainty in the year 2022 was negligible (0.60 per cent) because they account for only 1.2 per cent of total emissions.

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

Chapter 2 of the NIR describes the trends in Ireland's time-series of greenhouse gas inventories for the years 1990 through 2022. The emissions time-series is available as a complete set of Common Reporting Format (CRF) files, generated by the online CRF Reporter GHG inventory software web application, to be used for annual data submissions to the European Union and the UNFCCC secretariat. The annual inventories are complete with respect to both the coverage of the seven direct greenhouse gases for which information is required and the coverage of the five IPCC source categories. Some recalculations have again been undertaken for the purposes of the 2024 submission and the latest inventories for the years 1990-2022 indicate revisions and improvements in some areas due to these recalculations.

Fuel combustion in the Energy sector is the principal source of emissions in Ireland and major increases in fuel use have driven the increase in emissions in the 1990-2022 time-series. The largest increase took place in transport with an increase of 128.5 per cent on 1990 levels, while there were increases of 5.6 per cent from the manufacturing industry and construction sector. Emissions from energy industries, were 10.9 per cent below 1990 levels in 2022. The emissions from Agriculture sector, the other main source category, increased during the 1990s until 1998 and then decreased to 2011. In recent years emissions have increased again and are now 16.5 per cent above 1990 levels in 2022. As the emissions from energy increased, the contribution of agriculture to total national emissions decreased from 34.9 per cent in 1990 to 28.0 per cent in 2008. In recent years, emissions from

Agriculture have been increasing and the share of the national total emissions is now 37.0 per cent in 2022. Over the period 1990-2022 total national emissions grew by 9.7 per cent with emissions increasing in sectors; Energy up 10.3 per cent, Agriculture up 16.5 per cent, and decreasing in the IPPU sector, down 5.3 per cent and the Waste sector, down 48.6 per cent.

ES.4 Indirect Greenhouse Gases

The inventory reporting process requires the inclusion of a number of gases whose indirect effects are also relevant to the assessment of human-induced impacts on climate. They include sulphur dioxide (SO_2), nitrogen oxides (NO_X), carbon monoxide (CO) and non-methane volatile organic compounds (NMVOC). Emissions of SO_2 contribute to the formation of aerosols, which may offset the effects of greenhouse gases, while CO, NO_X and NMVOC are precursors of ozone, another naturally occurring greenhouse gas. This NIR does not describe the methods used to estimate emissions of SO_2, NO_X, CO and NMVOC but the annual emissions estimates over the period 1990-2022 are included in the submission.

Indirect CO_2 emissions from NMVOCs from solvent use (category 2.D.3 and 2.H in the IPPU sector) are included in Ireland's national total for greenhouse gas emissions to be consistent with reporting under the Kyoto Protocol for the first commitment period (previous CRF sector 3, solvent and other product use).

The emissions of most of the indirect gases have decreased substantially in the period 1990-2022 under various forms of control legislation emanating from the European Commission and the Convention on Long Range Transboundary Air Pollution. The reductions achieved between 1990 and 2022 in Ireland are of the order of 94.9 per cent in the case of SO_2, 81.9 per cent for CO and 44.0 per cent for NO_X and 29.4 per cent for NMVOC.

Chapter 1 Introduction

1.1 Background and Context

This report constitutes Ireland's National Inventory Report (NIR), for the years 1990-2022, as required under the United Nations Framework Convention on Climate Change.

The objective of the NIR is to describe the methodologies, input data, background information and the entire process of inventory compilation for greenhouse gases and to give explanations for any improvements and recalculations of the inventories reported in previous submissions. The report is a key component of the UN review process which assesses the transparency, completeness and overall quality of the inventories from Annex I Parties.

1.2 Introduction and Reporting Requirements under the UNFCCC

The United Nations Framework Convention on Climate Change (UNFCCC) (Articles 4 and 12), hereafter referred to as the Convention, requires Annex I Parties to develop, publish and make available to the Conference of the Parties (COP), the Convention's implementation body, their national inventories of emissions and removals of all greenhouse gases not controlled by the Montreal Protocol. The revision of the UNFCCC Reporting Guidelines on annual inventories for Parties included in Annex I to the Convention (Decision 24/CP.19), hereafter referred to as the UNFCCC reporting guidelines, describe the scope and reporting of the emissions inventories. They specify the methodologies and procedures to be followed for submitting consistent and comparable data on an annual basis in a timely, efficient and transparent manner to meet the needs of the Convention. Under the UNFCCC reporting guidelines, Parties are required to compile a National Inventory Report (NIR) and up-to-date annual inventories in an electronic Common Reporting Format (CRF) as the key components of their annual submissions.

The NIR is compiled according to the structure adopted by the Appendix to Annex I of Decision 24/CP.19. and includes sections describing the national system for inventory preparation and management, emission trends, key emission categories, recalculations and on-going improvements. In addition, detailed documentation of methods, activity data and emission factors used for each of the five source categories as defined by the Intergovernmental Panel on Climate Change (IPCC) is provided.

The NIR addresses the full range of reporting requirements related to annual inventories set down in the UNFCCC reporting guidelines and responds to issues identified in the UNFCCC annual review process. Furthermore, the report captures the cyclical nature of the reporting process and clarifies the chronology of changes and revisions that are part of normal inventory development, including those that are implemented in response to the UNFCCC review process. In this way, the report continues to improve the basis for technical assessment and expert review of Irish greenhouse gas inventories. An attempt has been made to provide all the primary inventory information, including calculations as appropriate, to facilitate replication of the emission estimates for the most recent year of the inventory time-series so that the annual submission is fully transparent.

In addition to complying with the UNFCCC reporting guidelines, the report is intended to inform Government Departments, national institutions and other stakeholders of the state of the art of Irish greenhouse gas inventories as they address the challenges to comply with commitments under the European Union's Effort Sharing Regulation (EU 2018/842). In this context, it provides some additional background on relevant emission sources in Ireland, the common reporting format and other issues for the benefit of those not entirely familiar with the agreed content of the NIR or the general reporting requirements under the Convention. The report is also aimed at all the key data providers, with a view to making them fully aware of the importance of their contributions to the inventory process and to provide a means of identifying areas where improvements in input data and or emission factors may be possible. The in-depth analysis of key categories and the up-to-date data on emissions trends provides essential information for the implementation of the Climate Action and Low Carbon Development Act (Number 46 of 2015) and the development of greenhouse gas emissions projections.

The NIR is updated annually in accordance with the UNFCCC guidelines and is published on the web site of the EPA [https://www.epa.ie/ghg/]. Such updating is necessary to keep the UNFCCC secretariat and other interested parties informed of the status of Irish greenhouse gas inventories and to document on-going improvements, recalculations and other developments affecting the estimates of emissions. The structure of the report is designed to facilitate year-on-year revision in a manner that allows for systematic and efficient assessment of progress towards the achievement of greenhouse gas emission inventories that meet the guiding principles of transparency, accuracy, completeness, comparability and consistency (TACCC).

1.2.1 Scope of Greenhouse Gas Inventories

1.2.1.1 Greenhouse Gases and Global Warming Potential

The full range of greenhouse gases for which emissions data are required under the Convention is given in Table 5.3.1 of Annex 5.3. It includes carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), the most widely known and most ubiquitous of the anthropogenic greenhouse gases, along with 19 hydrofluorocarbons (HFC), 9 perfluorocarbons (PFC), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3). The global warming potentials (GWPs) of the various greenhouse gases vary greatly and are as listed in the Column 'GWP 100-year' in Table 8.A.1 of Appendix 8.A of the report 'Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change'. The GWP of a gas is a measure of the cumulative warming over a specified time period, e.g. 100 years, resulting from a unit mass of the gas emitted at the beginning of that time period, expressed relative to an absolute GWP of 1 for the reference gas carbon dioxide (IUCC, 1998). The mass emission of any gas multiplied by its GWP gives the equivalent emission of the gas as carbon dioxide. Therefore, while CO_2, CH_4 and N_2O are important because they are normally emitted in large amounts, HFCs, PFCs, SF_6 and NF_3 are included in the inventory process mainly because of their comparatively much larger GWP values.

The inventory reporting process allows for the inclusion of a number of additional gases whose indirect effects are also relevant to the assessment of human-induced impacts on climate. These include sulphur dioxide (SO_2), nitrogen oxides (NO_X), carbon monoxide (CO) and non-methane volatile organic compounds (NMVOC). Emissions of SO_2 contribute to the formation of aerosols, which may offset the effects of greenhouse gases, while CO, NO_X and NMVOC are precursors of ozone formation, another naturally occurring greenhouse gas. This NIR does not describe the methods used to estimate emissions of SO_2, NO_X, CO and NMVOC but up-to-date estimates of total emissions are included for information purposes. These estimates are taken from Ireland's submission to the Convention on Long

Range Transboundary Air Pollution (CLRTAP), which are produced annually in a manner that is fully consistent with the inventory for greenhouse gases.

1.2.1.2 Common Reporting Format

Greenhouse gas emissions are reported under the Convention in a multi-level reporting format adopted by the Intergovernmental Panel on Climate Change (IPCC). This is a standard table format that forms the basis of the new Common Reporting Format (CRF), Annex II to the UNFCCC reporting guidelines, which assigns all potential sources of emissions and removals of a Party's national total to five Level 1 broad source categories. A further category is provided for the reporting of any additional sources that may be specific to individual Parties. Table 5.3.2 of Annex 5.3 lists the Level 1 and Level 2 source/sink categories. Level 2 source/sink categories are further sub divided to a finer level of disaggregation, level 3. The Level 3 categories are detailed in the description of category coverage and inventory methods and data in the respective sectoral chapters of this NIR. The computation of emissions is usually undertaken at Level 3 or lower, using further appropriate disaggregation (for example, by using fuel type in the case of combustion sources under 1.A Energy-Fuel Combustion) while summary results are normally published at Level 2.

The IPCC reporting format also includes a number of Memo Item entries. These items refer to sources of emissions whose contributions are not included in a Party's national total emissions but which are to be reported because of their importance in relation to the overall assessment of emissions and for comparisons among Parties.

The national total of emissions that is commonly used under the Convention excludes the estimates for the Land Use Land-Use Change and Forestry (LULUCF) sector in Table 5.3.2 of Annex 5.3. Ireland's national total also includes indirect CO_2 emissions from NMVOCs from solvent use and food and beverages sectors (category 2.D.3 and 2.H.2 in the IPPU sector) to be consistent with historic reporting (previous CRF sector 3, solvent and other product use).

1.3 National Inventory Arrangements

1.3.1 Institutional, Legal and Procedural Arrangements

The Environmental Protection Agency is required to establish and maintain databases of information on the environment and to disseminate such information to interested parties (Section 52 of the Environmental Protection Agency Act of 1992 (DOE, 1992). The Act states that the Agency must provide, of its own volition or upon request, information and advice to Ministers of the Government in the performance of their duties (Section 55). This includes making available such data and materials as are necessary to comply with Ireland's reporting obligations and commitments within the framework of international agreements. These requirements are the regulatory basis on which the EPA prepares annual inventories of greenhouse gases and other important emissions to air in Ireland. It is in this context that in 1995 the then Department of the Environment, Community and Local Government (DECLG) (now Department of the Environment, Climate and Communications (DECC)) designated the EPA as the inventory agency with responsibility for the submission of emissions data to the UNFCCC Secretariat and to the Secretariat for the Convention on Long-Range Transboundary Air Pollution (CLRTAP).

The establishment of Ireland's national inventory system was completed by Government Decision in early 2007, building on the framework that had been applied for many years. The EPA's Office of

Evidence and Assessment (OEA) is the designated inventory agency and the EPA is also designated as the single national entity with overall responsibility for the annual greenhouse gas inventory. Within the OEA, the Emissions Statistics team in the Climate Change Programme (CCP), compiles the national greenhouse gas emission inventories for submission on behalf of the DECC under the Framework Convention on Climate Change and Regulation (EU) 2018/1999, the latter being the basis for EU Member States' reporting under the Convention and the Paris Agreement. All formal mechanisms together with the QA/QC procedures are fully operational since they were established in the 2007 reporting cycle.

Following establishment of the national system, institutional arrangements directed towards national inventory reporting that involve the EPA, DECC and other stakeholders were reorganised, extended and legally consolidated across all participating institutions to strengthen inventory capacity within the EPA. This ensured that more formal and comprehensive mechanisms of data collection and processing were established and maintained for long term implementation. In particular, the system puts in place formal procedures for the planning, preparation and management of the national atmospheric inventory and identifies the roles and responsibilities of all the organisations involved in its compilation. This was achieved through extensive discussions with all key data providers leading to the adoption of Memoranda of Understanding (MOU) between the key data providers and the inventory agency. These MOUs stipulate the scope, timing and quality of the inputs necessary for inventory compilation in accordance with the guidelines for national systems. Secondary MOUs are, in turn, used by some key data providers to formalise the receipt of data from their own particular sources. Table 1.1 lists the key data providers and indicates the range of data covered by MOU in the national system. A QA/QC plan is an integral part of the national system.

Figure 1.1 provides a schematic overview of the institutions, procedures and information flows involved in the national system. In addition to the primary data received from the key data providers, the inventory team draws on various other data streams available within the EPA, such as the National Waste Database, reports on wastewater treatment, Annual Environmental Reports from companies subject to Integrated Pollution Prevention Control (IPPC), Industrial Emissions Directive 2010/75/EU (IED) and submissions prepared under the European Pollutant Release and Transfer Register (E-PRTR) and also obtains information from other diverse sources to prepare the inventories for fluorinated gases and solvent use. The inventory team also draws on national research related to greenhouse gas emissions and special studies undertaken from time to time to acquire the information needed to improve the estimates for particular categories and gases.

The Emissions Trading Unit (ETU), within the EPA's Office of Environmental Sustainability (OES), is a key component of the national system. The ETU are responsible for administering the European Union Emissions Trading Scheme (ETS), under Directive 2003/87/EC (EP and CEU, 2003), in Ireland and, as such, provide annual verified emissions data to the inventory team.

The estimates of emissions and removals for forest lands under the Convention, are prepared by consultants contracted to the Department of Agriculture, Food and the Marine (DAFM). These are delivered to the inventory agency under a Memorandum of Understanding between DAFM and OEA.

The approval of the completed annual inventory involves sign-off by the QA/QC manager and the inventory manager before it is brought to the Board of the EPA via the Programme Manager of the Climate Change Programme in OEA. Any issues arising from the Board's examination of the estimates are communicated to the inventory experts for resolution before final adoption of the inventory. The results for the inventory year are normally released at national level in autumn of the following year. This is in advance of their official submission to the European Commission in accordance with Regulation (EU) 2018/1999 in January and March of the reporting year and subsequently to the UNFCCC secretariat in April. The national system is also exploited for the purpose of parallel inventory preparation and reporting of air pollutants under the LRTAP Convention ensuring efficiency and consistency in the compilation of emission inventories for a wide range of substances using common datasets and inputs.

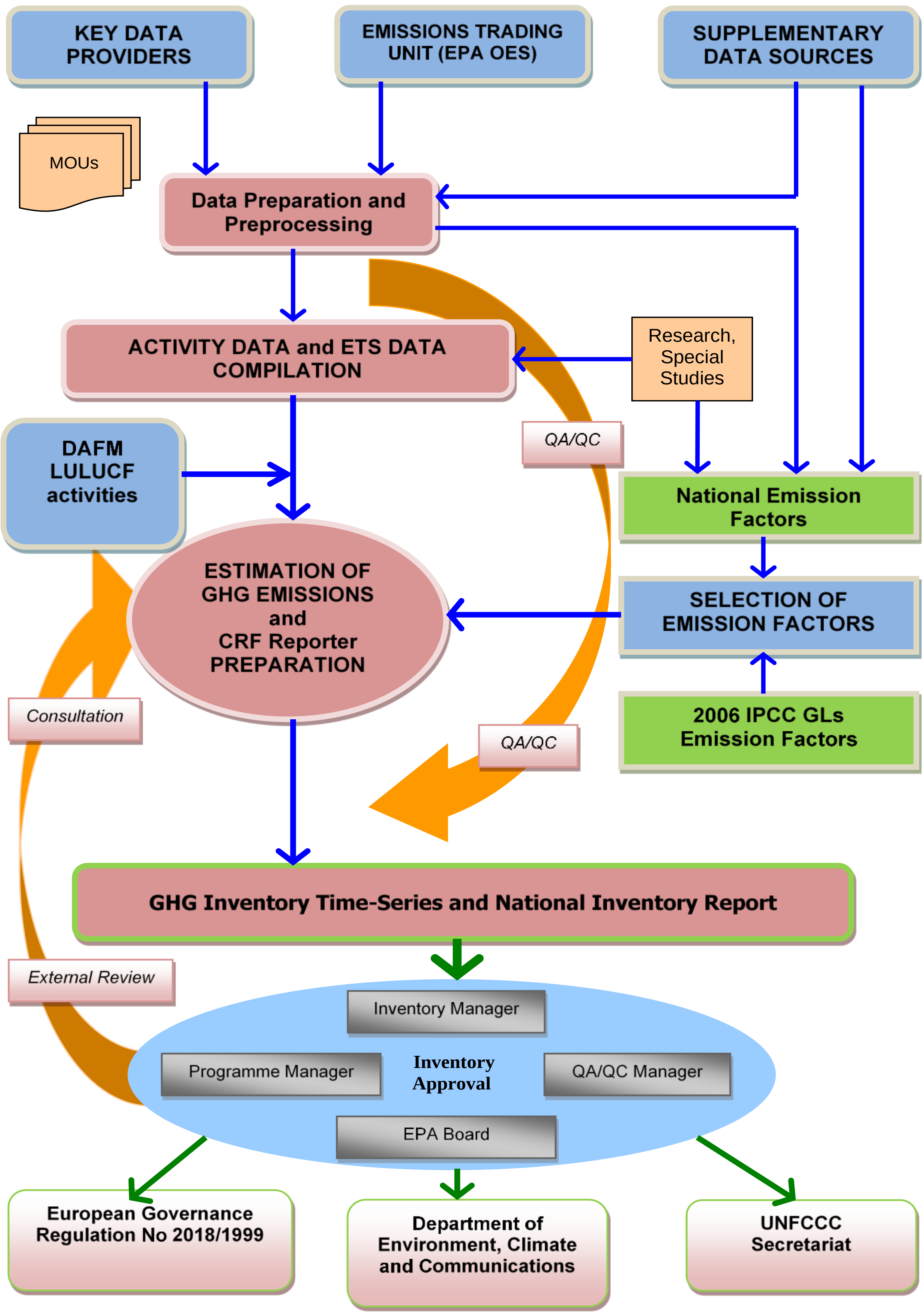


Figure 1.1 National Inventory System Overview

1.3.2 Overview of Inventory Planning, Preparation and Management

The inventory agency plans for preparation of the annual inventory as soon as possible after completion of the annual reporting cycle in April following submission to the UNFCCC secretariat. Planning largely involves the identification of improvements to be undertaken by way of revised methodologies and updated activity data or emission factors as well as addressing the issues and recommendations in the review of the previous inventory submission.

Planning also considers the further development of inventory reporting for the LULUCF sector as new data becomes available through national research and development of the national forest inventory.

In addition, any changes required by the outcome of review activities conducted among the Member States of the European Union, or by the need to report in a manner consistent with other Member States for the purposes of Regulation (EU) 2018/1999, are taken into account in inventory planning.

The first version of the latest annual inventory, produced in autumn of the following year, and a short National Inventory Report are used to comply with the subsequent 15th January deadline prescribed by Regulation (EU) 2018/1999, which governs the reporting of greenhouse gases by the European Union and its EU Member States.

After the 15th of January submission, the inventory is revised to take into account updated or outstanding information nationally. In addition, any observations or amendments following initial assessment at EU level of the 15th January submission by Member States to the European Commission are incorporated into the inventory between 15th January and 15th March.

The complete and final inventory submission, including the National Inventory Report, is submitted to the European Commission by 15th March as required under Regulation (EU) 2018/1999. This version of the latest inventory is fixed and retained for submission to the UNFCCC secretariat by 15th April to complete the reporting cycle. Ireland’s national system is functioning well, and the timeliness of inventory preparation has benefited from the implementation of more formal arrangements and enhanced engagement among the various institutions and contributors.

1.3.3 Quality Assurance, Quality Control and Verification Plan

In early 2005, the inventory agency in Ireland commissioned a project with UK consultants NETCEN to establish formal QA/QC procedures that would meet the needs of the UNFCCC reporting requirements. The project developed a QA/QC system including a documented QA/QC plan and procedures along with a QA/QC manual.

The manual provides a general overview of the QA/QC system. In addition, the manual provides guidance and templates for appropriate quality checking, documentation and traceability. The selection of source data, calculation methodologies, peer and expert review of inventory data and the annual requirements for continuous improvement for the inventory are also outlined in the manual.

The QA/QC plan identifies the specific data quality objectives related to the principles of transparency, consistency, completeness, comparability and accuracy required for Ireland's national inventory and provides specific guidance and documentation forms and templates for the practical implementation of QA/QC procedures. The QA/QC procedures cover such elements as data selection and acquisition, data processing and reporting.

The inventory agency initiated a new approach to QA/QC in the 2006 reporting cycle. Its application was completed and consolidated in delivering the submissions up to this present 2024 submission.

This involved the allocation of responsibilities linked to the national system mentioned in section 1.2.1 and the use of a template spread sheet system to record the establishment and maintenance of general inventory checking and management activities covering the overall compilation process, as well as the undertaking of specific annual activities and any necessary periodic activities in response to specific events or outcomes in inventory reporting and review. The system facilitates record keeping related to the chain of activities from data capture, through emissions calculations and checking, to archiving and the identification of improvements.

Ireland's calculation spread sheets in all sectors are structured and organised to facilitate the QA/QC process and more efficient time-series analysis and also to ensure ease of transfer of the outputs to the CRF Reporter [AR5] Tool. This facilitates rapid year-on-year extension of the time-series, rapid inter-annual comparisons and efficient updating and recalculation, where appropriate, in the annual reporting cycle. Internal aggregation to various levels corresponding to the CRF tables provides immediate and complete checks on the results.

External reviews of the agriculture sector and of the entire ETS results for 2005 were conducted as important new components of quality assurance at the beginning of 2007. The review for the agriculture sector was performed by a Technical Inspector in the Department of Agriculture, Food and the Marine. This review used the new calculation files to assess the consistency of the time series which had been subject to considerable improvement and recalculation in the 2006 reporting cycle. These improvements and recalculations were part of a move to higher tier methods for enteric fermentation in cattle as well as advice from the Department on various aspects of input data and calculation parameters. A detailed bilateral review with UK agricultural experts took place in the offices of the EPA in July 2014 to review, in particular, the changes to the agriculture inventory with respect to the use of the 2006 IPCC guidelines. The inventory agency also continues to work closely with the Department of Agriculture, Food and the Marine and seeks advice and guidance from experts in Teagasc, the Irish Agriculture and Food Development Authority on a regular basis.

The ETS returns to the ETU provide for the complete coverage of CO_2 estimates in a number of sub-categories under *1.A.1 Energy Industries* and *2.A. Mineral Products*. When the allocation to these categories from the ETS raw data is completed, the output is returned to the ETS administrator for final checking against the source data. This ensures the efficient and consistent transfer of the verified ETS emissions estimates into the national inventory. Inventory development continues to benefit from the internal review procedures that are on-going with regard to the EU and its Member States. In 2014, experts from the inventory team attended 2 workshops, in March and June, organised by UBA Germany and the European Commission to facilitate the implementation of the 2006 IPCC guidelines for inventory reporting for the first submission for the second commitment period in 2015.

1.3.4 Changes in the National Inventory Arrangements since Previous Annual GHG Inventory Submission

There were no changes to the national inventory arrangements in 2023.

1.4 Inventory Preparation, and Data Collection, Processing and Storage

1.4.1 GHG Inventory

An emissions inventory database normally contains information on measured emission quantities, activity statistics (populations, fuel consumption, vehicle/kilometres of travel, industrial production and land areas), emission factors and the associated emission estimates for a specified list of source categories. In practice, very few measured data are available for greenhouse gases and, consequently, the emissions from most activities are estimated by applying emission factors for each source/gas combination to appropriate activity data for the activity concerned. Virtually all emissions and removals estimates may be ultimately derived on the basis of such simple product of activity data and emission factor. However, a certain amount of data analysis and preparatory calculations are generally needed in order to make available suitable combinations of activity data and emission factors at the level of disaggregation that gives the best estimates of emissions and removals. In the case of some source/gas combinations, such as methane emissions from enteric fermentation, manure management, municipal solid waste disposed at solid waste disposal site and CO_2 sequestration by forest biomass, it may be necessary to apply sophisticated models to generate the activity data, the emission factors and or the emissions. The methods recommended by 2006 IPCC Guidelines for national greenhouse gas inventories use a tier system to take account of these issues and other factors, such as data availability, technical expertise, inventory capacity and other circumstances, which may vary considerably across sectors and Parties.

1.4.2 Data Collection, Processing and Storage

Preparation for the annual GHG inventory takes place in an Excel spread sheet system where activity data stored in Source Data files are linked to calculation sheets in Data Processing files that produce the emissions estimates at the lowest possible level of disaggregation. These are combined and allocated according to IPCC requirements for direct transmission into the CRF Reporter online application for the generation of the CRF tables and Party submissions. These results are stored in Outputs files while supporting QA/QC sheets, extracted from Data Processing files, are held in summary QA/QC record files. The Data Processing files hold the emission factors and they are structured on a time-series basis, which facilitates efficient recalculation and output to the CRF Reporter. This procedure applies to all IPCC sectors of the GHG inventory for which the calculations are made by the inventory team and the full set of files applicable to each year under the four headings is stored using appropriate version control on the EPA servers.

Table 1.1 lists the principal data suppliers and the information that they are required to deliver to the inventory agency annually under MOU for the preparation of the GHG inventory. In some cases, e.g. the national energy balance, the input file received from the data supplier may be linked directly to the Data Processing files, but generally some degree of preparation and pre-processing is needed before the activity data are used in inventory preparation. In collating and compiling the activity data, the inventory team collects data from the various data streams e.g. Annual Emissions Reports (AERs) under the European Pollutant Release and Transfer Register.

Table 1.1 Key Data Providers and Information covered by MOU

Key Data Provider	Data Supplied	Deadline	Sector in which data are used
Sustainable Energy Authority of Ireland	National Energy Balance; Detailed national energy consumption disaggregated by economic sector and fuel	30 September	Energy, Waste
Department of Agriculture, Food and Marine	**Table 1.1-1.4** Statistical data for cattle compiled under the Animal Identification and Movement (AIM) scheme Fertiliser and lime statistics Poultry statistics Sheep statistics	30 September	Agriculture
Department of Agriculture, Food and Marine (Forest Sector Development Division)	**Table 2.1** GHG emission/removal estimates from all pools for forest lands under the Convention Statistical data on Afforestation, Reforestation, Deforestation and harvesting for forest land lands under Article 3.3 of KP GHG emission/removal estimates from all biomass pools for KP Article 3.3 and elected activities under Article 3, paragraph 4, of the Kyoto Protocol (Cropland management and Grazing land management).	30 September	Land Use, Land-use Change and Forestry (LULUCF)
Central Statistics Office	Annual population, livestock populations, crop statistics, housing survey data	30 September	Agriculture, IPPU, Waste
Gas Networks Ireland	Analysis results for indigenous and imported natural gas	30 September	Energy
Marine Institute	Annual Report on Discharges, Spills and Emissions from Offshore Gas Production Installations	30 October	Energy
Emissions Trading Unit	Verified CO_2 estimates and related fuel and production data for installations covered by the EU ETS[1]	30 April	Energy, IPPU
*Department of Environment, Climate and Communications	National Oil Balance (as a component of the Energy Balance)	30 September	Energy
*Road Safety Authority	Road transport statistics from the National Car Test (NCT)	30 April	Energy
**Forest Service	(i) GIS data base on premiums and grants afforestation areas (iFORIS) with associated attributes (II) NFI database	30 September 2007, 2012, 2017	LULUCF
**Coillte	GIS data base of intersected of NFI permanent sample plot points (Coillte-NFI plots) with sub-compartment and management unit data.	30 September	LULUCF

[1]ETS – Emissions Trading Scheme

*These bodies have MOUs with SEAI rather than with OEA

**These bodies have MOUs with the Department of Agriculture, Food and Marine rather than with OEA

A Tier 3 model, CBM-CFS3 (Canadian Forest Service Carbon Budget Model) model is used to derive the estimates of emissions and removals for forest lands, which are incorporated in the overall scheme for LULUCF reporting under the Convention following the procedure outlined above. A variety of databases related to land cover, soil type and forest areas are applied for the *LULUCF* inventory under the Convention. These include the National Forest Inventory (NFI), the Forest Inventory and Planning System (FIPS), the Land Parcels Information System (LPIS), Co-ordinated Information on the Environment (CORINE) Land Cover Maps and the General Soil Map of Ireland. These are supported by statistical information from Bord na Móna, CSO and the Department of Housing, Planning and Local Government (DHPLG).

This work was undertaken by FERs Ltd, the consultants working to DAFM, who supply the estimates from these activities to OEA under an agreed MOU (Table 1.1). Secondary MOUs between DAFM and its data suppliers formalise annual data collection for this area of the inventory. The model contains a multitude of component modules needed to produce estimates of the carbon stock changes for the various carbon pools under afforestation and deforestation areas and for reporting any relevant emissions of CH_4 and N_2O. The model processes detailed spatially explicit data on forest species and soil type obtained from the NFI, FIPS, soils maps, supported by the Grants and Premiums Administration System (GPAS) of DAFM, and felling license records. The model uses complex pre-processing functions, growth models, allometric equations and pool allocation and transfers to produce the results required for Article 3, paragraph 3 and paragraph 4, selected activities.

The annual ETS compilation serves as an important source of activity-specific and company-specific data on CO_2 emissions, fuel use and emission factors for major combustion sources and industrial processes. The emissions trading scheme covers 106 stationary installations in Ireland with combined CO_2 emissions of 14,686.1 kt in 2022, accounting for 24.2 per cent of total greenhouse gas emissions (60,604.9 kt CO_2 eq). Guidance provided under the associated Decision 2004/156/EC (EP and CEU, 2004) on methodologies for estimating and reporting greenhouse gas emissions to support Directive 2003/87/EC, together with monitoring and verification mechanisms administered by the ETU, consolidates and improves the information in relation to a substantial proportion of CO_2 emissions for the purposes of reporting national GHG inventories under the Convention and the Paris Agreement.

All of the data used in the compilation of the national GHG inventory submission is stored on an EPA data server located in the Monaghan Regional Inspectorate of the EPA where key staff involved in the compilation of the national inventory are located. All background data for recent years are available in electronic format, with a transparent file structure. All data (emission estimates, activity data, inventory submissions, references, QA/QC) on the data server are backed up daily.

1.5 Methodologies and Emission Factors

Table 1.4 and Table 1.5 present summaries of the methodologies and emission factors used by Ireland to estimate GHG emissions reported for the years 1990-2022. More than 80 per cent of the total emissions (excluding LULUCF) are covered by Tier 2 methods or higher in Ireland’s GHG inventory under the.

1.5.1 Carbon dioxide (CO_2)

Tier 2 or Tier 3 methods are used for the majority of CO_2 combustion source categories and country-specific emission factors are used for all fuels. Even for those combustion categories where data limitations dictate the use of Tier 1 methods, such as *1.A.2 Manufacturing Industries and Construction* and *1.A.4 Other Sectors*, the CO_2 emissions obtained using the energy balance fuel data and country-specific emission factors are reliable. Tier 2 methods also apply to important process sources of CO_2 emissions, such as cement and lime production, where country and plant specific circumstances are again taken fully into account.

The national model used to estimate carbon stock change in the various carbon pools for forest lands in respect of Convention is a Tier 3 methodology. The methods for CO_2 in other LULUCF categories and for relevant CH_4 and N_2O emissions in this sector are invariably Tier 1.

1.5.2 Methane (CH_4)

Ireland's national circumstances are well captured in the Tier 2 methods applied for the major sources of CH_4 in the inventory, which are enteric fermentation and manure management associated with cattle and the CH_4 emissions from solid waste disposal sites.

Tier 2 and Tier 3 methods are used for CH_4 emissions from *1.A.1 Energy Industries, 1.A.3.a domestic aviation* and 1.*A.3.b Road Transport*, respectively, while Tier 1 methods and IPCC default emission factors are used for other CH_4 emissions.

1.5.3 Nitrous oxide (N_2O)

Ireland relies on the simplified IPCC Tier 1 methodologies and country specific and default emission factors to estimate all N_2O emissions in agriculture, which is the main source of N_2O in the inventory.

Tier 2 and Tier 3 methods are used for N_2O emissions from *1.A.1 Energy Industries, 1.A.3.a Domestic aviation* and *1.A.3.b Road Transport*, respectively, while Tier 1 methods and IPCC default emission factors are used for other N_2O emissions.

1.6 Overview of Key Categories

The 2006 IPCC guidelines defines a key category as one that is prioritised within the national inventory system because its estimate has a significant influence on the Party's total inventory of greenhouse gases in terms of the absolute level of emissions and removals, the trend in emissions and removals or uncertainty in emissions or removals. Information about key categories is considered to be crucial to the choice of methodology for individual sources and to the management and reduction of overall inventory uncertainty. The identification of such categories is recommended in order that inventory agencies can give them priority in the preparation of annual inventories, especially in cases where resources may be limited. Information on key categories is clearly also vital for the development of policies and measures for emissions reduction. The 2006 IPCC guidelines provide two approaches for undertaking the analysis of key categories that can be applied at any appropriate level of source aggregation, depending on the information available. The simplest approach, approach 1, is again used for 2022 data to further highlight which sources of emissions are the most important in Ireland. This approach identifies key categories using a pre-determined cumulative emissions threshold. Key categories are those that, when summed together in descending order of magnitude, add up to 95 percent of the total level.

1.6.1 Key Categories at IPCC Level 2

As inventories of CO_2, CH_4 and N_2O were developed in Ireland during the 1990s, it was quickly established that CO_2 emissions from fuel combustion was by far the largest contributor to the combined national total for these three primary greenhouse gases. It was also evident that CH_4 emissions produced by Ireland's large cattle herd and the N_2O emissions from agricultural soils, associated with farming practices and large inputs of nitrogen to agricultural soils, were also major sources, even if the estimates were more uncertain than those for CO_2. A preliminary estimate of key categories is therefore provided by considering the emissions aggregated at the IPCC Level 2 source category classification, which clearly indicates the importance of CO_2 emissions from fuel combustion and CH_4 and N_2O emissions from agriculture.

The results at the IPCC Level 2 source category classification may be readily drawn from the CRF table Summary 2. Those for 1990 and 2022 are shown in Table 1.2 and Table 1.3, respectively. It can be seen that there are 9 highly significant key categories of emissions in Ireland in the 1990 and 2022 including; CO_2 combustion sources in *1.A.1 Energy Industries*, *1.A.2 Manufacturing Industries and Construction*, *1.A.3 Transport* and *1.A.4 Other Sectors*, CO_2 process emissions from *2.A.1 Cement Production* along with the CH_4 emissions from categories *3.A Enteric Fermentation*, *3.B Manure Management* and *5.A Solid Waste Disposal* and N_2O emissions from *3.D Agricultural Soils*. These nine categories accounted for 92.0 per cent and 94.6 per cent of total emissions in 1990 and 2022, respectively. In the case of 2022 emissions, one additional Level 2 source category is needed to reach the cumulative 95 per cent threshold that defines key categories: N_2O emissions from *3.B Manure Management. 3.B* is key in 2022 for N_2O level analysis and not in 1990, whereas categories *2.B.1* and *2.B.2* are key in 1990 level analysis and not in 2022.

The increase in the contribution of CO_2 emissions from category *1.A.3 Transport* from 9.1 per cent in 1990 to 19.2 per cent in 2022 is notable, along with the reduction in the contribution from *1.A.1* in *Energy Industries* from 20.2 per cent in 1990 to 16.3 per cent in 2022. This simple analysis of key categories continues to prove useful to the formulation of mitigation strategies and for prioritising work on inventories in Ireland.

When LULUCF is accounted for in the Level 2 analysis, CO_2 emissions in three LULUCF categories (*4.A Forest land, 4.C. Grassland, 4.D Wetlands*) become key categories in 1990, and the same three categories and associated gas along with CO_2 emissions from *4.G Harvested Wood Products*, are also key categories in 2022. CH_4 emissions from LULUCF categories, *4.C Grassland* and *4.D Wetlands* are also key categories at this level of analysis in 1990 and 2022.

Table 1.2 Key Categories at IPCC Level 2 in 1990

IPCC Category code	IPCC Category (level 2)	GHG	1990 Estimate (kt CO_2 eq)	Level Assessment (%)	Cumulative Total of Level (%)
3.A	Enteric Fermentation	CH4	12,319.46	22.31	22.31
1.A.1.	Energy Industries	CO2	11,145.01	20.18	42.48
1.A.4	Other Sectors (Comm/Resid/Agric)	CO2	9,918.12	17.96	60.44
1.A.3	Transport	CO2	5,029.63	9.11	69.55
3.D.	Agricultural Soils	N2O	4,312.07	7.81	77.35
1.A.2.	Manufacturing Industries and Construction	CO2	4,055.45	7.34	84.70
3.B	Manure Management	CH4	1,666.64	3.02	87.72
5.A	Solid Waste Disposal	CH4	1,476.24	2.67	90.39
2.B.1	Ammonia Production	CO2	990.23	1.79	92.18
2.B.2	Nitric Acid Production	N2O	885.10	1.60	93.78
2.A.1	Cement Production	CO2	884.00	1.60	95.38

Table 1.3 Key Categories at IPCC Level 2 in 2022

IPCC Category code	IPCC Category (level 2)	GHG	2022 Estimate (kt CO_2 eq)	Level Assessment (%)	Cumulative Total of Level (%)
3.A	Enteric Fermentation	CH4	14,584.03	24.06	24.06
1.A.3	Transport	CO2	11,616.18	19.17	43.23
1.A.1.	Energy Industries	CO2	9,874.15	16.29	59.52
1.A.4	Other Sectors (Comm/Resid/Agric)	CO2	7,903.11	13.04	72.56
3.D.	Agricultural Soils	N2O	4,378.46	7.22	79.79
1.A.2.	Manufacturing Industries and Construction	CO2	4,283.52	7.07	86.86
3.B	Manure Management	CH4	2,090.78	3.45	90.31
2.A.1	Cement Production	CO2	1,956.53	3.23	93.53
5.A	Solid Waste Disposal	CH4	634.15	1.05	94.58
3.B	Manure Management	N2O	632.69	1.04	95.63

Table 1.4 Summary of Methods

IPCC SOURCE AND SINK CATEGORIES	CO_2	CH_4	N_2O	HFC	PFC	SF_6	NF_3
1. Energy	**CS, M, T1, T2, T3**	**CS, M, T1, T2, T3**	**CS, M, T1, T2, T3**				
A. Fuel Combustion (Sectoral Approach)	M, T1, T2, T3	M, T1, T2, T3	M, T1, T2, T3				
1. Energy Industries	T1, T3	T1, T2	T1, T2				
2. Manufacturing Industries and Construction	T1, T2, T3	T1	T1				
3. Transport	M, T2, T3	M, T1, T3	M, T1, T3				
4. Other Sectors	T1, T2	T1	T1				
5. Other							
B. Fugitive Emissions from Fuels	CS, T3	CS, T1, T3	CS, T3				
1. Solid Fuels		T1					
2. Oil and Natural Gas	CS, T3	CS, T1, T3	CS, T3				
C. Carbon Dioxide Transport and Storage	NA						
2. Industrial Processes and Product Use	**CR, T1, T2, T3**		**T1**	**T1, T2, T3**	**T2**	**T1, T2**	**T2**
A. Mineral Industry	T3						
B. Chemical Industry	T1		T1				
C. Metal Production							
D. Non-Energy Products from Fuels and Solvent Use	T1, T2						
E. Electronic Industry				T2	T2	T2	T2
F. Product Uses as Substitutes for ODS				T1, T2, T3			
G. Other Product Manufacture and Use	CR		T1			T1, T2	
H. Other	CR						
3. Agriculture	**T1**	**CS, T1, T2**	**T1, T2**				
A. Enteric Fermentation		CS, T1, T2					
B. Manure Management		T1, T2	T2				
C. Rice Cultivation							
D. Agricultural Soils			T1				
E. Prescribed Burning of Savannas							
F. Field Burning of Agricultural Residues							
G. Liming	T1						
H. Urea Application	T1						
I. Other							
4. Land-Use, Land-Use Change and Forestry	**CS, D, T1, T2, T3**	**D, T1, T2**	**D, T1, T2**				
A. Forest Land	CS, T1, T2, T3	D, T1	D, T1				
B. Cropland	CS, D	D, T1	D, T1				
C. Grassland	D, T1, T2, T3	D, T1, T2	D, T1				
D. Wetlands	D, T1, T2, T3	D, T1, T2	D, T2				
E. Settlements	D, T1, T3		T1				
F. Other Land	T1, T3		T1				
G. Harvested wood products	T2						
H. Other							
5. Waste	**T1**	**T1, T2**	**T1**				
A. Solid Waste Disposal		T2					
B. Biological treatment of solid waste		T1	T1				
C. Incineration and open burning of waste	T1	T1	T1				
D. Wastewater treatment and discharge		T1, T2	T1				
E. Other							
6. Other							
International Bunkers							
Aviation	T1	M, T3	M, T3				
Navigation	T1	T1	T1				
Multilateral Operations							
CO_2 Emissions from Biomass	T1, T2, T3	T1	T1				
CO_2 captured							
Long-term storage of C in waste disposal sites							
Indirect N_2O							
Indirect CO_2	T1						

T1: IPCC Tier 1 or equivalent

T2: IPCC Tier 2 or equivalent

T3: IPCC Tier 3 or equivalent

Table 1.5 Summary of Emission Factors

IPCC SOURCE AND SINK CATEGORIES	CO_2	CH_4	N_2O	HFC	PFC	SF_6	NF_3
1. Energy	**CS, D, M, PS**	**CS, D, M, PS**	**CS, D, M, PS**				
A. Fuel Combustion (Sectoral Approach)	CS, D, M, PS	**D, M**	D, M				
1. Energy Industries	CS, D, PS	D	D				
2. Manufacturing Industries and Construction	CS, D, PS	D	D				
3. Transport	CS, M	D, M	D, M				
4. Other Sectors	CS, D	D	D				
5. Other							
B. Fugitive Emissions from Fuels	CS, PS	CS, D, PS	CS, PS				
1. Solid Fuels		D					
2. Oil and Natural Gas	CS, PS	CS, D, PS	CS, PS				
C. Carbon Dioxide Transport and Storage							
2. Industrial Processes and Product Use	**CR, D, PS**		**D**	**CS**	**CS**	**CS**	**CS**
A. Mineral Industry	PS						
B. Chemical Industry	CS		PS				
C. Metal Production	D						
D. Non-Energy Products from Fuels and Solvent Use	D						
E. Electronic Industry				CS	CS	CS	CS
F. Product Uses as Substitutes for ODS				CS			
G. Other Product Manufacture and Use	CR		D			CS	
H. Other	CR						
3. Agriculture	**D**	**CS, D**	**CS, D**				
A. Enteric Fermentation		CS, D					
B. Manure Management		CS, D	CS, D				
C. Rice Cultivation							
D. Agricultural Soils			CS, D				
E. Prescribed Burning of Savannas							
F. Field Burning of Agricultural Residues							
G. Liming	D						
H. Urea Application	D						
I. Other							
4. Land-Use, Land-Use Change and Forestry	**CS, D, OTH**	**CS, D**	**CS, D**				
A. Forest Land	CS	CS, D	CS, D				
B. Cropland	D	D	D				
C. Grassland	CS, D	CS, D	D				
D. Wetlands	CS, D	CS, D	CS, D				
E. Settlements	CS, D, OTH		D				
F. Other Land	CS		D				
G. Harvested wood products	D						
H. Other							
5. Waste	**D**	**CS, D**	**D**				
A. Solid Waste Disposal		CS, D					
B. Biological treatment of solid waste		D	D				
C. Incineration and open burning of waste	D	D	D				
D. Wastewater treatment and discharge		CS, D	D				
E. Other							
6. Other							
International Bunkers							
Aviation	CS	M	M				
Marine	CS	D	D				
Multilateral Operations							
CO_2 Emissions from Biomass	CS, D	D, M, CR	D, M, CR				
CO_2 captured							
Long-term storage of C in waste disposal sites							
Indirect N_2O							
Indirect CO_2	CS, CR, D						

PS: Plant specific
D: Default
CS: Country specific
M: Model
CR: CORINAIR

1.6.2 Disaggregated Key Categories

Ireland uses the approach 1 from the 2006 IPCC guidelines to extend the analysis above to identify key categories that may be treated separately at a more disaggregated level, level 3. This gives more information about the individual sources or combination of sources and gases that are of most importance within a Level 2 category. The disaggregation corresponds generally to that at which the emissions are calculated and to that used for estimating uncertainty. The results of the analysis for the approach 1 level 3 assessment in relation to emissions excluding LULUCF in both 1990 and 2022 are presented in Table 1.6 and Table 1.7, respectively. Tables 1.8 and 1.9 present the approach 1 level 3 assessment including LULUCF. Ranking in this way identifies those categories that should be prioritised in the inventory process itself and also the individual components of emissions that could be targeted by specific abatement measures. Results for approach 1 trend assessment for 1990-2022 excluding LULUCF are shown in Table 1.10 and the trend assessment including LULUCF is presented in Table 1.11. The complete tables of ranked sources for 2022 key category analysis are provided in Tables 1.A-D in Annex 1.

The results of the level and trend assessments for 2022 **excluding LULUCF** categories may be summarised as follows:

(i) The **level assessment** identifies 29 key categories, 23 of which are also key categories by trend assessment. CH_4 emissions in *3.B.1.1 Manure Management-Non-Dairy Cattle;* CO_2 emissions in *1.A.4.c Agriculture/Fishing-Liquid fuels*; N_2O emissions in *3.D.2 Indirect Soils;* CH_4 emissions in *3.B1.1 Manure Management-Dairy Cattle*; CH_4 emissions in 3.B.1.3 *Manure Management-Swine* and N_2O emissions in *3.B.2.5 Manure Management-indirect* are key categories by level assessment only.

(ii) There are 18 key categories of CO_2 in level assessment, accounting for 58.5 per cent of total emissions;

(iii) There are 7 key categories of CH_4, 3 key categories of N_2O and one category of HFC in level assessment, which account for 28.1 per cent, 7.7 per cent and 1.0 per cent, respectively, of total emissions;

(iv) Energy accounts for 16 key categories, Agriculture for 10, while Industrial Processes and Product Use contributes two and Waste contributes one;

(v) The **trend assessment** identifies 26 key categories, three of which (CO_2 emissions in *1.A.2 Manufacturing Industries-Solid Fuels*; CO_2 emissions in *1.A.4.b Residential-Peat Fuel* and CO_2 emissions in *1.A.2 Manufacturing Industries-NR wastes)* are not key categories for 2022 level assessment;

(vi) There are 19 key categories of CO_2 in trend assessment, accounting for 82.8 per cent of the total trend;

(vii) There are 5 key categories of CH_4, one key category of N_2O and one key categories of HFC in trend assessment, which account for 10.0 per cent, 0.8 per cent and 1.5 per cent, respectively, of the total trend.

The results of the level and trend assessment for 2022 **including LULUCF** categories may be summarised as follows:

(i) The **level assessment** identifies 37 key categories, 24 of these are sources of CO_2 emissions, accounting for 59.1 per cent of total emissions;

(ii) There are 8 additional categories that are not present in the assessment excluding LULUCF, all 8 of which are LULUCF categories.

(iii) The 8 additional categories are: CO_2 emissions from*, 4.A.2 Land Converted to Forest Land, 4.A.1 Forest Land Remaining Forest Land, 4.D. Wetlands, 4.G Harvested Wood Products, 4.C. Grassland, 4.C Drained Organic Soils* and CH_4 emissions from, *4.D Wetlands*, *4.C Drained Organic Soils.*

(iv) There are 9 key categories from sources of CH_4 and 3 key categories of N_2O which account for 28.7 per cent and 6.4 per cent, respectively, of total emissions;

(v) Energy accounts for 16 key categories, Agriculture for 10, LULUCF for 8, while Industrial Processes contributes 2 and Waste contributes 1;

(vi) The **trend assessment** identifies 33 key categories, 7 of which were not present in the trend assessment excluding LULUCF: CO_2 emissions from LULUCF categories: 4*.A.2 Land converted to Forest Land, 4.C. Grassland, 4.A.1 Forest land Remaining Forest Land, 4.D. Wetlands, 4.G Harvested Wood Products* and CH_4 emissions from *4.C Drained Organic Soils* and CH_4 Emissions from *1.A.4.b Residential Solid Fuels.*

(vii) There are 24 key categories of CO_2 in the trend assessment, accounting for 83.3 per cent of the total trend;

(viii) There are 7 key categories of CH_4, 1 key categories of N_2O and 1 key category of HFC in the trend assessment, which account for 9.7 per cent, 0.6 per cent and 1.2 per cent, respectively, of the total trend.

The list of key categories given by level assessment in 2022 is very similar to that for 1990. However, the higher ranking of the main CO_2 emissions from road transport is notable in 2022. Six out of the top ten key categories in 1990 (excluding LULUCF) were in the top ten in 2022 but in a different order. The remaining 4 key categories in 2022 are: CO_2 emissions from *1.A.1 Energy Industries* Solid Fuels, *1.A.4.b. Residential* - Liquid Fuels, *1.A.2 Manufacturing Industries* – Gaseous Fuels and *2.A.1 Cement Production*. These sectors replaced 4 key sectors in 1990: CO_2 emissions from *1.A.1 Energy Industries* – Peat Fuels, *1.A.2 Manufacturing Industries* – Liquid Fuels, *1.A.4.b. Residential* – Peat Fuel and *1.A.4.b. Residential* - Solid Fuels.

Those six key categories contributed 45.9 and 51.7 per cent, of total emissions in 1990 and 2022, respectively. The emissions of CO_2 from the use of liquid fuels by road transport (*1.A.3.b*) and CH_4 emissions from *3.A.1. Enteric Fermentation* - Non-Dairy Cattle were the largest source categories of greenhouse gas emissions in Ireland in 2022, accounting for 18.2 and 12.7 per cent of the total, respectively.

1.7 Use of Key Category Analysis

The approach 1 used to the determine key categories is based on the principle that the cumulative uncertainty in their emissions represents 90 per cent of the total inventory uncertainty and that 95 per cent of total emissions account for this cumulative fraction of uncertainty. This quantitative approach may therefore result in a much larger number of key categories than might be expected using simpler qualitative criteria. In effect, an inventory with only a small number of major emission sources will require the inclusion of many source categories in order to reach the 95 per cent emissions threshold.

This is well shown by the results of key category determination for Ireland, based on approach 1 level assessment, in Table 1.9. The results including LULUCF indicate that 27 of the 37 key categories in 2022 each accounted for less than 3 per cent of the total emissions and that only 5 key categories contributed more than 5 per cent each to the total. The approach 1 analysis adequately identifies the specific sources of emissions that are significant in terms of the overall uncertainty of the inventory, but it provides little direction on where to focus priority when the number is large. In these circumstances, information on the uncertainty in the individual source categories and other factors must be taken into account in making decisions regarding the most cost-effective use of inventory capacity related to key categories.

The results of the approach 1 key category analysis in Table 1.7 and 1.10 (excluding LULUCF) clearly show the impact of CO_2 emissions from energy consumption on total emissions in Ireland. These emissions account for 16 of the key categories listed in Table 1.7 (level, excluding LULUCF) and for 54.3 per cent of total emissions in 2022. While key categories determined by CO_2 emissions from energy consumption have a major bearing on total emissions in Ireland, the remaining potential for significant reduction in the uncertainties associated with these sources is rather limited. The activity data and CO_2 emission factors for Energy source categories in general are among the most reliable items of input data in the inventory and there is consequently little scope for improving the accuracy of the emission estimates. The application of a robust Tier 2 methodology for emissions of CH_4 from enteric fermentation in cattle (non-dairy and dairy) and the use of verified estimates for CO_2 emissions from cement production means that the contributions from these 3 additional key categories (ranked 2, 4 and 9 in Table 1.7, respectively), making up a further 24.7 per cent of the total, are also known with probably the highest certainty now achievable.

The HFC emissions from *2.F.1 Refrigeration and air-conditioning*, N_2O emissions from *3.D.1 Agricultural Soils* – direct soil emissions and CH_4 emissions *3.A.2 Enteric fermentation in sheep* and *3.B.1 Manure management - Dairy and non-dairy Cattle* and *5.A Solid Waste Disposal* account for most of the remaining important key categories in Table 1.7. The uncertainties in the estimates for these complex sources (section 1.7) will remain high due to the large number of factors that influence their emissions and the relatively simple methods that continue to be used.

1.8 Uncertainty Evaluation

The approach 1, propagation of error, method provided by the 2006 IPCC guidelines has been used to make an assessment of uncertainty in the emissions inventory data for 2022 in the same way as for previous years. This method estimates uncertainties for the entire inventory in a particular year and the uncertainty in the trend over time by combining the uncertainties in activity data and emission factors for each source category. The analysis for 2022 data is presented in Table 1.12 (excluding LULUCF) and Table 1.13 (including LULUCF), using emissions on a GWP basis and a level of source category disaggregation that corresponds in general to the level used for emissions calculation and for key category analysis. This disaggregation level limits the likely dependency and correlation between source categories.

The input values of uncertainty for activity data and emission factors in the GHG inventory have been assigned largely on the basis of general information related to the methodological descriptions in the 2006 IPCC guidelines, supported by opinions elicited from the principal data suppliers, such as the CSO, SEAI, Government Departments and individual experts who contributed to certain parts of the inventory.

Where higher tier methods are used for combustion sources, such as those covered by ETS and road transport, the activity data uncertainty estimates are those indicated for the tier concerned. Accordingly, low estimates of uncertainty apply to the activity data for categories such as *1.A.1 Energy Industries* and *1.A.3 Transport*, as shown on Table 1.12. Slightly higher uncertainty levels are used for energy activity data in sub-categories under *1.A.2 Manufacturing Industries and Construction* and *1.A.4 Other Sectors*, where the end use of fuels is not as well quantified in the top-down methods used. Low activity data uncertainties are justified in respect of CO_2 emissions sources in *2.A Industrial Processes*, for which bottom-up data are applied in most cases and the major sources of emissions are covered by ETS. Country-specific CO_2 emission factors are used for all combustion sources, which gives a basis for assigning the uncertainties for emission factors while again taking into account the applicable tiers. Uncertainties in the emission factors for CH_4 and N_2O released from combustion sources are high and not well established quantitatively. For CH_4 and N_2O emission factors for combustion categories, the most up-to-date IPCC publications are used and an indicative uncertainty of 50 per cent is used for both gases.

The Agriculture sector is the second most important sector in Ireland's GHG inventory and has a major influence on overall uncertainty due to its large contribution in terms of CH_4 and N_2O emissions. Ireland has long-established and robust statistical data collection procedures in place for agriculture in general, which guides the selection of 1 per cent as the activity data uncertainty for all agriculture sub-categories. The 2006 IPCC guidelines indicate that the emission factor estimates for the Tier 2 method to determine CH_4 emissions from enteric fermentation in cattle are likely to have an uncertainty of 20 per cent. Following the opinion of national agriculture experts, a value of 15 per cent has been adopted for these emissions to take into account Ireland's detailed Tier 2 method and use of reliable data. In some of the other important emissions sources in Agriculture (such as manure management and agricultural soils) the activity data or emission factors ultimately used are determined by several specific component inputs, which are individually subject to varying degrees of uncertainty. Uncertainties in Agriculture have been estimated at the level of livestock for both enteric fermentation (3.A) and manure management (3.B), and according to the six direct nitrogen inputs for agricultural soils (3.D.1.1 - 3.D.1.6). This finer level of disaggregation is the principal reason for the overall level of the inventory uncertainty reducing in submission 2018 and continues in this submission in order to include the revised EF uncertainty associated with cattle dung and urine deposited by grazing cattle in category 3.D.1.3 to account for new country specific EFs in this submission.

The uncertainty estimates used for emission factors for these sources have been derived by assigning uncertainties to the key component parameters and combining them at the level of activity data or emission factors, as appropriate, using equations 3.1 and 3.2 in chapter 3 of the 2006 IPCC guidelines Volume 1 for each activity to obtain the input to the Tier 1 uncertainty assessment. The footnotes to Table 1.12 show how some of these uncertainty inputs are obtained.

Category 5.A Solid Waste is the principal source of CH_4 emissions outside Agriculture. Under the methodology used, the component uncertainties for both activity data and emission factor for CH_4

generation are derived using equations 3.1 and 3.2 in chapter 3 of the 2006 IPCC guidelines Volume 1 as shown in the footnotes to Table 1.12. These are combined with uncertainties of 30 per cent and 10 per cent for flaring and utilisation respectively to obtain the overall uncertainty using equation 3.2.

Equations 3.1 and 3.2 are both applied as appropriate in a hierarchical approach to derive uncertainty for LULUCF under the Convention. This is achieved by developing uncertainties for carbon pools, which are combined to give the values for the individual land-use categories, which are then combined with uncertainties for other reported activities to give the totals for LULUCF. Additional information on uncertainties for LULUCF is provided in chapter 6.

The F-gas inventory has been substantially revised following work by consultants in 2013, and new data sources were established. The uncertainties associated with the F-gas emission estimates were reviewed and are still considered to be appropriate for this submission.

The approach 1 uncertainty analysis (excluding LULUCF) for Ireland's 2022 inventory under the Convention gives an overall uncertainty of 3.50 per cent in total emissions and a trend uncertainty of 2.28 per cent for the period 1990 to 2022. This equates to a decrease on level uncertainty as compared to the values reported in the 2023 submission (for 1990 to 2021) of 4.02 and 2.32 per cent, respectively.

The reason for the overall decrease from 2021 to 2022 is primarily due to lower emissions share of nitrous oxide from Agriculture in the overall level of emissions in 2022 as these gases have higher associated level uncertainty.

Relatively low estimates are determined largely by the low uncertainties in the estimate of CO_2 emissions, which account for 60.6 per cent of total national emissions in 2022 and which are estimated to contribute to 13.1 per cent of the level uncertainty (excluding LULUCF). When CH_4 is included, bringing the proportion of total emissions up to 89.7 per cent, the contribution to the level of uncertainty is 64.4 per cent (excluding LULUCF), with 51.3 per cent due to CH_4. The influence of N_2O contributes 35.0 per cent of the total level of uncertainty, whereas it accounts for only 9.1 per cent of national total emissions. The impact of HFCs, PFCs, SF_6 and NF_3 on inventory uncertainty remains negligible (0.6 per cent contribution) because these gases account for only 1.2 per cent of total emissions in Ireland.

The approach 1 uncertainty analysis (including LULUCF) for Ireland's 2022 inventory under the Convention (Table 1.13) gives an overall level uncertainty of 9.28 per cent in total emissions and a trend uncertainty of 11.81 per cent for the period 1990 to 2022.

1.9 Completeness and Time-Series Consistency

Table 1.14 gives an overview of the level of completeness of the 2021 GHG inventory submission with respect to the greenhouse gases covered by the revised UNFCCC reporting guidelines, the IPCC Level 2 source-category split in operation since 2005 for reporting under the Convention. Further detail on source/gas coverage at IPCC Level 3 is provided in the individual chapters describing the inventory methods and data for each Level 1 source-category.

Table 1.6 Key Category Analysis Level Assessment 1990 (excluding LULUCF)

Ranking	IPCC Category code	IPCC Category	Greenhouse Gas	1990 Estimate (kt CO_2 eq)	Level assessment (%)	Cumulative Total (%)
1	3.A.1	Enteric Fermentation - Non-Dairy Cattle	CH4	6,381.33	11.55	11.55
2	1.A.1	Energy Industries - Solid Fuels	CO2	4,844.66	8.77	20.33
3	1.A.3.b	Road Transport - Liquid Fuels	CO2	4,690.42	8.49	28.82
4	3.A.1	Enteric Fermentation - Dairy Cattle	CH4	3,803.81	6.89	35.70
5	3.D.1	Agricultural Soils - Direct Soil Emissions	N2O	3,587.35	6.50	42.20
6	1.A.1	Energy Industries - Peat Fuel	CO2	3,164.78	5.73	47.93
7	1.A.4.b	Residential - Peat Fuel	CO2	3,123.37	5.66	53.58
8	1.A.4.b	Residential - Solid Fuels	CO2	2,483.42	4.50	58.08
9	1.A.2	Manufacturing Industries & Construction - Liquid Fuels	CO2	2,311.20	4.18	62.27
10	3.A.2	Enteric Fermentation - Sheep	CH4	2,047.96	3.71	65.97
11	1.A.1	Energy Industries - Gaseous Fuels	CO2	1,880.66	3.41	69.38
12	1.A.4.a	Commercial/Institutional - Liquid Fuels	CO2	1,759.49	3.19	72.56
13	5.A	Solid Waste Disposal	CH4	1,476.24	2.67	75.24
14	1.A.1	Energy Industries - Liquid Fuels	CO2	1,254.90	2.27	77.51
15	1.A.4.b	Residential - Liquid Fuels	CO2	1,173.10	2.12	79.63
16	2.B.1	Chemical Industry - Ammonia Production	CO2	990.23	1.79	81.43
17	2.B.2	Chemical Industry - Nitric Acid Production	N2O	885.10	1.60	83.03
18	2.A.1	Cement Production	CO2	884.00	1.60	84.63
19	1.A.2	Manufacturing Industries & Construction - Gaseous Fuels	CO2	873.02	1.58	86.21
20	1.A.2	Manufacturing Industries & Construction - Solid Fuels	CO2	871.24	1.58	87.79
21	1.A.4.c	Agriculture/Fishing - Liquid Fuels	CO2	747.23	1.35	89.14
22	3.D.2	Agricultural Soils - Indirect Soil Emissions	N2O	724.72	1.31	90.45
23	3.B.1.1	Manure Management - Non-Dairy Cattle	CH4	716.64	1.30	91.75
24	3.B.1.1	Manure Management - Dairy Cattle	CH4	487.25	0.88	92.63
25	3.G.1	Liming - Limestone CaCO3	CO2	355.04	0.64	93.27
26	3.B.1.3	Manure Management - Swine	CH4	285.69	0.52	93.79
27	1.A.4.b	Residential - Gaseous Fuels	CO2	269.73	0.49	94.28
28	1.A.4.b	Residential - Peat Fuel	CH4	254.97	0.46	94.74
29	3.B.2.5	Manure Management - Indirect N2O emissions	N2O	232.98	0.42	95.16

Table 1.7 Key Category Analysis Level Assessment 2022 (excluding LULUCF)

Ranking	IPCC Category code	IPCC Category	Greenhouse Gas	2022 Estimate (kt CO_2 eq)	Level assessment (%)	Cumulative Total (%)
1	1.A.3.b	Road Transport - Liquid Fuels	CO2	11,019.55	18.18	18.18
2	3.A.1	Enteric Fermentation - Non-Dairy Cattle	CH4	7,689.18	12.69	30.87
3	1.A.1	Energy Industries - Gaseous Fuels	CO2	5,616.78	9.27	40.14
4	3.A.1	Enteric Fermentation - Dairy Cattle	CH4	5,334.08	8.80	48.94
5	3.D.1	Agricultural Soils - Direct Soil Emissions	N2O	3,642.80	6.01	54.95
6	1.A.4.b	Residential - Liquid Fuels	CO2	3,171.65	5.23	60.18
7	1.A.2	Manufacturing Industries & Construction - Gaseous Fuels	CO2	2,697.88	4.45	64.63
8	1.A.1	Energy Industries - Solid Fuels	CO2	2,196.43	3.62	68.26
9	2.A.1	Cement Production	CO2	1,956.53	3.23	71.49
10	3.A.2	Enteric Fermentation - Sheep	CH4	1,460.15	2.41	73.90
11	1.A.4.b	Residential - Gaseous Fuels	CO2	1,279.22	2.11	76.01
12	1.A.1	Energy Industries - Liquid Fuels	CO2	1,130.51	1.87	77.87
13	1.A.2	Manufacturing Industries & Construction - Liquid Fuels	CO2	1,087.55	1.79	79.67
14	3.B.1.1	Manure Management - Non-Dairy Cattle	CH4	963.38	1.59	81.26
15	1.A.4.a	Commercial/Institutional - Gaseous Fuels	CO2	845.50	1.40	82.65
16	1.A.4.c	Agriculture/Fishing - Liquid Fuels	CO2	844.29	1.39	84.05
17	3.D.2	Agricultural Soils - Indirect Soil Emissions	N2O	735.66	1.21	85.26
18	1.A.4.b	Residential - Peat Fuel	CO2	692.08	1.14	86.40
19	5.A	Solid Waste Disposal	CH4	634.15	1.05	87.45
20	3.G.1	Liming - Limestone CaCO3	CO2	623.98	1.03	88.48
21	1.A.1	Energy Industries - Other Fuels	CO2	594.13	0.98	89.46
22	3.B.1.1	Manure Management - Dairy Cattle	CH4	578.50	0.95	90.41
23	2.F.1	Product Uses as Substitutes for ODS -Refrigeration and air-con	HFC	576.28	0.95	91.36
24	1.A.4.a	Commercial/Institutional - Liquid Fuels	CO2	562.04	0.93	92.29
25	1.A.4.b	Residential - Solid Fuels	CO2	507.54	0.84	93.13
26	3.B.1.3	Manure Management - Swine	CH4	357.37	0.59	93.72
27	1.A.1	Energy Industries - Peat Fuel	CO2	336.31	0.55	94.27
28	1.A.3.d	Navigation - Liquid Fuels	CO2	302.59	0.50	94.77
29	3.B.2.5	Manure Management - Indirect N2O emissions	N2O	294.70	0.49	95.26

Table 1.8 Key Category Analysis Level Assessment 1990 (including LULUCF)

Ranking	IPCC Category code	IPCC Category	Greenhouse Gas	1990 Estimate (kt CO_2 eq)	1990 Estimate for LULUCF (kt CO_2 eq)	Absolute Values (kt CO_2 eq)	Level assessment (%)	Cumulative Total (%)
1	3.A.1	Enteric Fermentation - Non-Dairy Cattle	CH4	6,381.33	0.00	6,381.33	9.52	9.52
2	1.A.1	Energy Industries - Solid Fuels	CO2	4,844.66	0.00	4,844.66	7.23	16.75
3	1.A.3.b	Road Transport - Liquid Fuels	CO2	4,690.42	0.00	4,690.42	7.00	23.75
4	3.A.1	Enteric Fermentation - Dairy Cattle	CH4	3,803.81	0.00	3,803.81	5.68	29.43
5	3.D.1	Agricultural Soils - Direct Soil Emissions	N2O	3,587.35	0.00	3,587.35	5.35	34.78
6	1.A.1	Energy Industries - Peat Fuel	CO2	3,164.78	0.00	3,164.78	4.72	39.50
7	1.A.4.b	Residential - Peat Fuel	CO2	3,123.37	0.00	3,123.37	4.66	44.16
8	1.A.4.b	Residential - Solid Fuels	CO2	2,483.42	0.00	2,483.42	3.71	47.87
9	4.A.1	LULUCF - Forest land Remaining Forest Land	CO2	0.00	-2,402.54	2,402.54	3.59	51.45
10	4.D	LULUCF - Wetlands	CH4	0.00	2,383.51	2,383.51	3.56	55.01
11	1.A.2	Manufacturing Industries & Construction - Liquid Fuels	CO2	2,311.20	0.00	2,311.20	3.45	58.46
12	3.A.2	Enteric Fermentation - Sheep	CH4	2,047.96	0.00	2,047.96	3.06	61.52
13	4.C	LULUCF - Grassland	CO2	0.00	1,909.78	1,909.78	2.85	64.37
14	1.A.1	Energy Industries - Gaseous Fuels	CO2	1,880.66	0.00	1,880.66	2.81	67.17
15	4.D	LULUCF - Wetlands	CO2	0.00	1,780.24	1,780.24	2.66	69.83
16	1.A.4.a	Commercial/Institutional - Liquid Fuels	CO2	1,759.49	0.00	1,759.49	2.63	72.45
17	4.C	LULUCF - Drained organic soils from forest to grasslands	CH4	0.00	1,646.29	1,646.29	2.46	74.91
18	5.A	Solid Waste Disposal	CH4	1,476.24	0.00	1,476.24	2.20	77.11
19	1.A.1	Energy Industries - Liquid Fuels	CO2	1,254.90	0.00	1,254.90	1.87	78.99
20	1.A.4.b	Residential - Liquid Fuels	CO2	1,173.10	0.00	1,173.10	1.75	80.74
21	2.B.1	Chemical Industry - Ammonia Production	CO2	990.23	0.00	990.23	1.48	82.21
22	2.B.2	Chemical Industry - Nitric Acid Production	N2O	885.10	0.00	885.10	1.32	83.53
23	2.A.1	Cement Production	CO2	884.00	0.00	884.00	1.32	84.85
24	1.A.2	Manufacturing Industries & Construction - Gaseous Fuels	CO2	873.02	0.00	873.02	1.30	86.16
25	1.A.2	Manufacturing Industries & Construction - Solid Fuels	CO2	871.24	0.00	871.24	1.30	87.46
26	1.A.4.c	Agriculture/Fishing - Liquid Fuels	CO2	747.23	0.00	747.23	1.12	88.57
27	3.D.2	Agricultural Soils - Indirect Soil Emissions	N2O	724.72	0.00	724.72	1.08	89.65
28	3.B.1.1	Manure Management - Non-Dairy Cattle	CH4	716.64	0.00	716.64	1.07	90.72
29	4.A.2	LULUCF - Land Converted to Forest Land	CO2	0.00	-522.34	522.34	0.78	91.50
30	3.B.1.1	Manure Management - Dairy Cattle	CH4	487.25	0.00	487.25	0.73	92.23
31	4.G	LULUCF - Harvested wood products	CO2	0.00	-413.04	413.04	0.62	92.85
32	3.G.1	Liming - Limestone CaCO3	CO2	355.04	0.00	355.04	0.53	93.38
33	4.C	LULUCF - Drained organic soils from rewetted organic soils	CO2	0.00	348.29	348.29	0.52	93.89
34	3.B.1.3	Manure Management - Swine	CH4	285.69	0.00	285.69	0.43	94.32
35	1.A.4.b	Residential - Gaseous Fuels	CO2	269.73	0.00	269.73	0.40	94.72
36	1.A.4.b	Residential - Peat Fuel	CH4	254.97	0.00	254.97	0.38	95.10

Table 1.9 Key Category Analysis Level Assessment 2022 (including LULUCF)

Ranking	IPCC Category code	IPCC Category	Greenhouse Gas	2022 Estimate (kt CO_2 eq)	2022 Estimate for LULUCF (kt CO_2 eq)	Absolute Values (kt CO_2 eq)	Level assessment (%)	Cumulative Total (%)
1	1.A.3.b	Road Transport - Liquid Fuels	CO2	11,019.55	0.00	11,019.55	15.14	15.14
2	3.A.1	Enteric Fermentation - Non-Dairy Cattle	CH4	7,689.18	0.00	7,689.18	10.57	25.71
3	1.A.1	Energy Industries - Gaseous Fuels	CO2	5,616.78	0.00	5,616.78	7.72	33.43
4	3.A.1	Enteric Fermentation - Dairy Cattle	CH4	5,334.08	0.00	5,334.08	7.33	40.76
5	3.D.1	Agricultural Soils - Direct Soil Emissions	N2O	3,642.80	0.00	3,642.80	5.01	45.77
6	1.A.4.b	Residential - Liquid Fuels	CO2	3,171.65	0.00	3,171.65	4.36	50.13
7	4.A.2	LULUCF - Land Converted to Forest Land	CO2	0.00	-3,137.88	3,137.88	4.31	54.44
8	1.A.2	Manufacturing Industries & Construction - Gaseous Fuels	CO2	2,697.88	0.00	2,697.88	3.71	58.15
9	4.D	LULUCF - Wetlands	CH4	0.00	2,590.97	2,590.97	3.56	61.71
10	1.A.1	Energy Industries - Solid Fuels	CO2	2,196.43	0.00	2,196.43	3.02	64.73
11	2.A.1	Cement Production	CO2	1,956.53	0.00	1,956.53	2.69	67.42
12	3.A.2	Enteric Fermentation - Sheep	CH4	1,460.15	0.00	1,460.15	2.01	69.42
13	1.A.4.b	Residential - Gaseous Fuels	CO2	1,279.22	0.00	1,279.22	1.76	71.18
14	4.C	LULUCF - Drained organic soils from forest to grasslands	CH4	0.00	1,276.77	1,276.77	1.75	72.94
15	4.A.1	LULUCF - Forest land Remaining Forest Land	CO2	0.00	1,259.31	1,259.31	1.73	74.67
16	4.D	LULUCF - Wetlands	CO2	0.00	1,153.19	1,153.19	1.58	76.25
17	1.A.1	Energy Industries - Liquid Fuels	CO2	1,130.51	0.00	1,130.51	1.55	77.81
18	1.A.2	Manufacturing Industries & Construction - Liquid Fuels	CO2	1,087.55	0.00	1,087.55	1.49	79.30
19	3.B.1.1	Manure Management - Non-Dairy Cattle	CH4	963.38	0.00	963.38	1.32	80.62
20	4.G	LULUCF - Harvested wood products	CO2	0.00	-865.73	865.73	1.19	81.81
21	1.A.4.a	Commercial/Institutional - Gaseous Fuels	CO2	845.50	0.00	845.50	1.16	82.98
22	1.A.4.c	Agriculture/Fishing - Liquid Fuels	CO2	844.29	0.00	844.29	1.16	84.14
23	4.C	LULUCF - Grassland	CO2	0.00	820.49	820.49	1.13	85.26
24	3.D.2	Agricultural Soils - Indirect Soil Emissions	N2O	735.66	0.00	735.66	1.01	86.27
25	1.A.4.b	Residential - Peat Fuel	CO2	692.08	0.00	692.08	0.95	87.23
26	5.A	Solid Waste Disposal	CH4	634.15	0.00	634.15	0.87	88.10
27	3.G.1	Liming - Limestone CaCO3	CO2	623.98	0.00	623.98	0.86	88.96
28	1.A.1	Energy Industries - Other Fuels	CO2	594.13	0.00	594.13	0.82	89.77
29	3.B.1.1	Manure Management - Dairy Cattle	CH4	578.50	0.00	578.50	0.80	90.57
30	2.F.1	Product Uses as Substitutes for ODS -Refrigeration and air-con	HFC	576.28	0.00	576.28	0.79	91.36
31	1.A.4.a	Commercial/Institutional - Liquid Fuels	CO2	562.04	0.00	562.04	0.77	92.13
32	1.A.4.b	Residential - Solid Fuels	CO2	507.54	0.00	507.54	0.70	92.83
33	3.B.1.3	Manure Management - Swine	CH4	357.37	0.00	357.37	0.49	93.32
34	1.A.1	Energy Industries - Peat Fuel	CO2	336.31	0.00	336.31	0.46	93.78
35	4.C	LULUCF - Drained organic soils from rewetted organic soils	CO2	0.00	330.69	330.69	0.45	94.24
36	1.A.3.d	Navigation - Liquid Fuels	CO2	302.59	0.00	302.59	0.42	94.65
37	3.B.2.5	Manure Management - Indirect N2O emissions	N2O	294.70	0.00	294.70	0.41	95.06

Table 1.10 Key Category Analysis Trend Assessment 1990-2022 (excluding LULUCF)

Ranking	IPCC Category code	IPCC Category	Greenhouse Gas	1990 Estimate (kt CO_2 eq)	2022 Estimate (kt CO_2 eq)	Trend Assessment (%)	Contribution to Trend (%)	Cumulative total (%)
1	1.A.3.b	Road Transport - Liquid Fuels	CO2	4,690.42	11,019.55	8.83	15.29	15.29
2	1.A.1	Energy Industries - Gaseous Fuels	CO2	1,880.66	5,616.78	5.34	9.25	24.54
3	1.A.1	Energy Industries - Peat Fuel	CO2	3,164.78	336.31	4.72	8.17	32.70
4	1.A.1	Energy Industries - Solid Fuels	CO2	4,844.66	2,196.43	4.69	8.12	40.83
5	1.A.4.b	Residential - Peat Fuel	CO2	3,123.37	692.08	4.11	7.12	47.95
6	1.A.4.b	Residential - Solid Fuels	CO2	2,483.42	507.54	3.33	5.77	53.72
7	1.A.4.b	Residential - Liquid Fuels	CO2	1,173.10	3,171.65	2.83	4.91	58.63
8	1.A.2	Manufacturing Industries & Construction - Gaseous Fuels	CO2	873.02	2,697.88	2.62	4.53	63.15
9	1.A.2	Manufacturing Industries & Construction - Liquid Fuels	CO2	2,311.20	1,087.55	2.18	3.77	66.93
10	1.A.4.a	Commercial/Institutional - Liquid Fuels	CO2	1,759.49	562.04	2.06	3.56	70.49
11	3.A.1	Enteric Fermentation - Dairy Cattle	CH4	3,803.81	5,334.08	1.74	3.02	73.51
12	2.A.1	Cement Production	CO2	884.00	1,956.53	1.48	2.57	76.08
13	5.A	Solid Waste Disposal	CH4	1,476.24	634.15	1.48	2.57	78.64
14	1.A.4.b	Residential - Gaseous Fuels	CO2	269.73	1,279.22	1.48	2.56	81.20
15	3.A.2	Enteric Fermentation - Sheep	CH4	2,047.96	1,460.15	1.18	2.05	83.25
16	3.A.1	Enteric Fermentation - Non-Dairy Cattle	CH4	6,381.33	7,689.18	1.03	1.79	85.04
17	1.A.2	Manufacturing Industries & Construction - Solid Fuels	CO2	871.24	280.53	1.02	1.76	86.80
18	1.A.4.a	Commercial/Institutional - Gaseous Fuels	CO2	223.49	845.50	0.90	1.56	88.36
19	1.A.1	Energy Industries - Other Fuels	CO2	-	594.13	0.89	1.55	89.91
20	2.F.1	Product Uses as Substitutes for ODS -Refrigeration and air-con	HFC	-	576.28	0.87	1.50	91.41
21	3.D.1	Agricultural Soils - Direct Soil Emissions	N2O	3,587.35	3,642.80	0.44	0.76	92.17
22	1.A.1	Energy Industries - Liquid Fuels	CO2	1,254.90	1,130.51	0.37	0.64	92.82
23	3.G.1	Liming - Limestone CaCO3	CO2	355.04	623.98	0.35	0.61	93.43
24	1.A.4.b	Residential - Peat Fuel	CH4	254.97	56.47	0.34	0.58	94.01
25	1.A.2	Manufacturing Industries & Construction - Non-Renewable waste	CO2	-	217.57	0.33	0.57	94.57
26	1.A.3.d	Navigation - Liquid Fuels	CO2	84.90	302.59	0.31	0.55	95.12

Table 1.11 Key Category Analysis Trend Assessment 2022 (including LULUCF)

Ranking	IPCC Category code	IPCC Category	Greenhouse Gas	1990 Estimate (kt CO_2 eq)	2022 Estimate (kt CO_2 eq)	Trend Assessment (%)	Contribution to Trend (%)	Cumulative total (%)
1	1.A.3.b	Road Transport - Liquid Fuels	CO2	4,690.42	11,019.55	7.50	12.97	12.97
2	1.A.1	Energy Industries - Gaseous Fuels	CO2	1,880.66	5,616.78	4.52	7.82	20.79
3	1.A.1	Energy Industries - Peat Fuel	CO2	3,164.78	336.31	3.92	6.78	27.57
4	1.A.1	Energy Industries - Solid Fuels	CO2	4,844.66	2,196.43	3.88	6.70	34.27
5	1.A.4.b	Residential - Peat Fuel	CO2	3,123.37	692.08	3.42	5.90	40.17
6	4.A.2	LULUCF - Land Converted to Forest Land	CO2	522.34	3,137.88	3.25	5.62	45.80
7	1.A.4.b	Residential - Solid Fuels	CO2	2,483.42	507.54	2.77	4.79	50.59
8	1.A.4.b	Residential - Liquid Fuels	CO2	1,173.10	3,171.65	2.40	4.15	54.74
9	1.A.2	Manufacturing Industries & Construction - Gaseous Fuels	CO2	873.02	2,697.88	2.22	3.83	58.57
10	1.A.2	Manufacturing Industries & Construction - Liquid Fuels	CO2	2,311.20	1,087.55	1.80	3.11	61.68
11	4.A.1	LULUCF - Forest land Remaining Forest Land	CO2	2,402.54	1,259.31	1.71	2.95	64.63
12	1.A.4.a	Commercial/Institutional - Liquid Fuels	CO2	1,759.49	562.04	1.71	2.95	67.58
13	4.C	LULUCF - Grassland	CO2	1,909.78	820.49	1.59	2.74	70.32
14	3.A.1	Enteric Fermentation - Dairy Cattle	CH4	3,803.81	5,334.08	1.52	2.63	72.95
15	2.A.1	Cement Production	CO2	884.00	1,956.53	1.26	2.18	75.14
16	1.A.4.b	Residential - Gaseous Fuels	CO2	269.73	1,279.22	1.25	2.16	77.29
17	5.A	Solid Waste Disposal	CH4	1,476.24	634.15	1.23	2.12	79.41
18	4.D	LULUCF - Wetlands	CO2	1,780.24	1,153.19	0.99	1.71	81.12
19	3.A.2	Enteric Fermentation - Sheep	CH4	2,047.96	1,460.15	0.97	1.67	82.79
20	3.A.1	Enteric Fermentation - Non-Dairy Cattle	CH4	6,381.33	7,689.18	0.96	1.66	84.45
21	1.A.2	Manufacturing Industries & Construction - Solid Fuels	CO2	871.24	280.53	0.84	1.46	85.91
22	1.A.4.a	Commercial/Institutional - Gaseous Fuels	CO2	223.49	845.50	0.76	1.32	87.23
23	1.A.1	Energy Industries - Other Fuels	CO2	-	594.13	0.75	1.30	88.53
24	2.F.1	Product Uses as Substitutes for ODS -Refrigeration and air-con	HFC	-	576.28	0.73	1.26	89.79
25	4.C	LULUCF - Drained organic soils from forest to grasslands	CH4	1,646.29	1,276.77	0.65	1.12	90.90
26	4.G	LULUCF - Harvested wood products	CO2	413.04	865.73	0.53	0.91	91.82
27	3.D.1	Agricultural Soils - Direct Soil Emissions	N2O	3,587.35	3,642.80	0.32	0.55	92.37
28	3.G.1	Liming - Limestone CaCO3	CO2	355.04	623.98	0.30	0.52	92.89
29	1.A.1	Energy Industries - Liquid Fuels	CO2	1,254.90	1,130.51	0.29	0.51	93.40
30	1.A.4.b	Residential - Peat Fuel	CH4	254.97	56.47	0.28	0.48	93.88
31	1.A.2	Manufacturing Industries & Construction - Non-Renewable waste	CO2	-	217.57	0.28	0.48	94.36
32	1.A.3.d	Navigation - Liquid Fuels	CO2	84.90	302.59	0.27	0.46	94.82
33	1.A.4.b	Residential - Solid Fuels	CH4	220.09	43.65	0.25	0.43	95.24

Table 1.12 Tier 1 Uncertainty Estimates 2022 excluding LULUCF (continued on following pages)

	CATEGORIES OF EMISSIONS AND REMOVALS	Gas	Emissions in 1990 (kt CO2eq)	Emissions in 2022 (kt CO2eq)	Activity Data (AD) Uncertainty (%)	Emission Factor (EF) Uncertainty (%)	Combined Uncertainty (%)	Contribution to Variance by Category in Base Year	Contribution to Variance by Category in Year 2022	Uncertainty in Trend in Total Emissions due to AD (%)	Uncertainty in Trend in Total Emissions due to EF (%)	Uncertainty into the Trend in Total Emissions (%)
1	1.A.1 Fuel combustion - Energy Industries - Gaseous Fuels	CO2	1880.66	5616.78	1.00	2.50	2.69	0.01	0.06	0.14	0.16	0.05
2	1.A.1 Fuel combustion - Energy Industries - Liquid Fuels	CO2	1254.90	1130.51	1.00	2.50	2.69	0.00	0.00	0.03	0.01	0.00
3	1.A.1 Fuel combustion - Energy Industries - Other Fossil Fuels	CO2	0.00	594.13	1.00	5.00	5.10	0.00	0.00	0.02	0.05	0.00
4	1.A.1 Fuel combustion - Energy Industries - Peat	CO2	3164.78	336.31	1.00	5.00	5.10	0.09	0.00	0.01	0.28	0.08
5	1.A.1 Fuel combustion - Energy Industries - Solid Fuels	CO2	4844.66	2196.43	1.00	5.00	5.10	0.20	0.03	0.06	0.28	0.08
6	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Gaseous Fuels	CO2	873.02	2697.88	2.50	2.50	3.54	0.00	0.02	0.17	0.08	0.04
7	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	CO2	2311.20	1087.55	10.00	2.50	10.31	0.19	0.03	0.28	0.07	0.08
8	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Other Fossil Fuels	CO2	0.00	217.57	1.00	5.00	5.10	0.00	0.00	0.01	0.02	0.00
9	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Peat	CO2	0.00	0.00	2.00	5.00	5.39	0.00	0.00	0.00	0.00	0.00
10	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Solid Fuels	CO2	871.24	280.53	2.00	5.00	5.39	0.01	0.00	0.01	0.06	0.00
11	1.A.3.a Domestic Aviation	CO2	47.98	21.38	1.00	2.50	2.69	0.00	0.00	0.00	0.00	0.00
12	1.A.3.b Road Transportation	CO2	4690.42	11019.55	1.25	3.00	3.25	0.08	0.35	0.35	0.32	0.23
13	1.A.3.c Railways	CO2	133.19	117.69	1.00	1.00	1.41	0.00	0.00	0.00	0.00	0.00
14	1.A.3.d Domestic Navigation - Liquid Fuels	CO2	84.90	302.59	1.00	2.00	2.24	0.00	0.00	0.01	0.01	0.00
15	1.A.3.e Other Transportation	CO2	73.14	154.97	1.00	2.50	2.69	0.00	0.00	0.00	0.00	0.00
16	1.A.4 Other Sectors - Gaseous Fuels	CO2	493.22	2124.72	2.50	2.50	3.54	0.00	0.02	0.14	0.07	0.02
17	1.A.4 Other Sectors - Liquid Fuels	CO2	3679.82	4577.98	10.00	5.00	11.18	0.55	0.71	1.17	0.05	1.38
18	1.A.4 Other Sectors - Peat	CO2	3259.11	692.08	10.00	20.00	22.36	1.74	0.07	0.18	1.04	1.12
19	1.A.4 Other Sectors - Solid Fuels	CO2	2485.97	508.32	5.00	10.00	11.18	0.25	0.01	0.07	0.40	0.17
20	1.B.2.b Fugitive Emissions from Fuels - Oil and Natural Gas - Natural Gas	CO2	0.01	0.20	1.00	100.00	100.00	0.00	0.00	0.00	0.00	0.00
21	2.A.1 Cement Production	CO2	884.00	1956.53	1.50	1.50	2.12	0.00	0.00	0.08	0.03	0.01
22	2.A.2 Lime Production	CO2	214.08	107.50	1.50	1.50	2.12	0.00	0.00	0.00	0.00	0.00
23	2.A.3 Glass Production	CO2	13.33	0.00	5.00	2.50	5.59	0.00	0.00	0.00	0.00	0.00
24	2.A.4 Other Process Uses of Carbonates	CO2	5.32	4.34	5.00	2.50	5.59	0.00	0.00	0.00	0.00	0.00
25	2.B.1 Ammonia Production	CO2	990.23	0.00	1.00	5.00	5.10	0.01	0.00	0.00	0.10	0.01
26	2.C Metal Production	CO2	26.08	0.00	5.00	2.50	5.59	0.00	0.00	0.00	0.00	0.00
27	2.D Non-energy Products from Fuels and Solvent Use	CO2	116.75	179.06	30.00	5.00	30.41	0.00	0.01	0.14	0.00	0.02
28	3.G Liming	CO2	355.04	623.98	5.00	50.00	50.25	0.10	0.27	0.08	0.21	0.05
29	3.H Urea Application	CO2	96.68	126.82	5.00	50.00	50.25	0.01	0.01	0.02	0.02	0.00
30	5.C Incineration and Open Burning of Waste	CO2	95.59	35.98	10.00	5.00	11.18	0.00	0.00	0.01	0.01	0.00
	Total CO2		**32945.30**	**36711.39**				**3.246**	**1.606**			**3.336**
						Level uncertainty, CO2	**1.802**	**1.267**	**Trend uncertainty, CO2**			**1.826**

	CATEGORIES OF EMISSIONS AND REMOVALS	Gas	Emissions in 1990 (kt CO2eq)	Emissions in 2022 (kt CO2eq)	Activity Data (AD) Uncertainty (%)	Emission Factor (EF) Uncertainty (%)	Combined Uncertainty (%)	Contribution to Variance by Category in Base Year	Contribution to Variance by Category in Year 2022	Uncertainty in Trend in Total Emissions due to AD (%)	Uncertainty in Trend in Total Emissions due to EF (%)	Uncertainty into the Trend in Total Emissions (%)
1	1.A.1 Fuel combustion - Energy Industries - Biomass	CH4	0.00	4.80	1.00	66.00	66.01	0.00	0.00	0.00	0.01	0.00
2	1.A.1 Fuel combustion - Energy Industries - Gaseous Fuels	CH4	3.84	2.83	1.00	70.00	70.01	0.00	0.00	0.00	0.00	0.00
3	1.A.1 Fuel combustion - Energy Industries - Liquid Fuels	CH4	0.44	0.38	1.00	66.00	66.01	0.00	0.00	0.00	0.00	0.00
4	1.A.1 Fuel combustion - Energy Industries - Other Fossil Fuels	CH4	0.00	3.17	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00
5	1.A.1 Fuel combustion - Energy Industries - Peat	CH4	2.13	0.21	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00
6	1.A.1 Fuel combustion - Energy Industries - Solid Fuels	CH4	1.02	0.46	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00
7	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Biomass	CH4	2.14	4.63	10.00	50.00	50.99	0.00	0.00	0.00	0.00	0.00
8	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Gaseous Fuels	CH4	0.44	1.33	2.50	50.00	50.06	0.00	0.00	0.00	0.00	0.00
9	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	CH4	2.43	0.97	10.00	50.00	50.99	0.00	0.00	0.00	0.00	0.00
10	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Other Fossil Fuels	CH4	0.00	0.21	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00
11	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Peat	CH4	0.00	0.00	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00
12	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Solid Fuels	CH4	2.58	0.83	2.00	50.00	50.04	0.00	0.00	0.00	0.00	0.00
13	1.A.3.a Domestic Aviation	CH4	0.04	0.01	1.00	66.00	66.01	0.00	0.00	0.00	0.00	0.00
14	1.A.3.b Road Transportation	CH4	54.51	8.71	1.25	71.00	71.01	0.00	0.00	0.00	0.07	0.00
15	1.A.3.c Railways	CH4	0.21	0.19	1.00	60.00	60.01	0.00	0.00	0.00	0.00	0.00
16	1.A.3.d Domestic Navigation - Liquid Fuels	CH4	0.22	0.81	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00
17	1.A.3.e Other Transportation	CH4	0.04	0.08	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00
18	1.A.4 Other Sectors - Biomass	CH4	15.77	15.96	10.00	50.00	50.99	0.00	0.00	0.00	0.00	0.00
19	1.A.4 Other Sectors - Gaseous Fuels	CH4	1.26	5.26	2.50	50.00	50.06	0.00	0.00	0.00	0.00	0.00
20	1.A.4 Other Sectors - Liquid Fuels	CH4	12.19	15.58	10.00	66.00	66.75	0.00	0.00	0.00	0.00	0.00
21	1.A.4 Other Sectors - Peat	CH4	255.34	56.47	10.00	50.00	50.99	0.06	0.00	0.01	0.20	0.04
22	1.A.4 Other Sectors - Solid Fuels	CH4	220.09	43.65	5.00	50.00	50.25	0.04	0.00	0.01	0.18	0.03
23	1.B.1 Fugitive emissions from Solid Fuels	CH4	62.22	19.34	10.00	50.00	50.99	0.00	0.00	0.00	0.04	0.00
24	1.B.2.a Fugitive Emissions from Fuels - Oil and Natural Gas - Oil	CH4	0.24	0.39	10.00	50.00	50.99	0.00	0.00	0.00	0.00	0.00
25	1.B.2.b Fugitive Emissions from Fuels - Oil and Natural Gas - Natural Gas	CH4	56.07	69.66	10.00	50.00	50.99	0.00	0.00	0.02	0.01	0.00
26	3.A.1 Enteric Fermentation-Dairy Cattle	CH4	3803.81	5334.08	1.00	15.00	15.03	1.07	1.75	0.14	0.31	0.12
27	3.A.1 Enteric Fermentation-Non-Dairy Cattle	CH4	6381.33	7689.18	1.00	15.00	15.03	3.02	3.64	0.20	0.19	0.07
28	3.A.2 Enteric Fermentation-Sheep	CH4	2047.96	1460.15	1.00	30.00	30.02	1.24	0.52	0.04	0.43	0.18
29	3.A.3 Enteric Fermentation-Swine	CH4	43.95	54.07	1.00	30.00	30.02	0.00	0.00	0.00	0.00	0.00
30	3.A.4 Enteric Fermentation-Other Animals	CH4	42.41	46.55	1.00	30.00	30.02	0.00	0.00	0.00	0.00	0.00
31	3.B.1.1 Manure Management-Dairy Cattle	CH4	487.25	578.50	1.00	15.00	15.03	0.02	0.02	0.01	0.01	0.00
32	3.B.1.1 Manure Management-Non-Dairy Cattle	CH4	716.64	963.38	1.00	15.00	15.03	0.04	0.06	0.02	0.05	0.00
33	3.B.1.2 Manure Management-Sheep	CH4	105.40	72.81	1.00	30.00	30.02	0.00	0.00	0.00	0.02	0.00
34	3.B.1.3 Manure Management-Swine	CH4	285.69	357.37	1.00	30.00	30.02	0.02	0.03	0.01	0.02	0.00
35	3.B.1.4 Manure Management-Other Animals	CH4	71.66	118.73	1.00	30.00	30.02	0.00	0.00	0.00	0.02	0.00
36	5.A Solid Waste Disposal	CH4	1476.24	634.15	34.64	34.64	48.99	1.71	0.26	0.56	0.62	0.70
37	5.B Biological treatment of solid waste: Composting and AD	CH4	0.00	34.57	10.00	30.00	31.62	0.00	0.00	0.01	0.02	0.00
38	5.C Incineration and Open Burning of Waste	CH4	1.18	0.06	10.00	30.00	31.62	0.00	0.00	0.00	0.00	0.00
39	5.D Wastewater Treatment and Discharge	CH4	68.43	58.69	10.00	30.00	31.62	0.00	0.00	0.02	0.01	0.00
	Total CH4		**16225.18**	**17658.22**				**7.236**	**6.299**			**1.160**
						Level uncertainty, CH4		**2.690**	**2.510**	**Trend uncertainty, CH4**		**1.077**
	Combined CO2 and CH4		**49170.48**	**54369.60**				**10.483**	**7.904**			**4.496**
					Level uncertainty, CO2 and CH4			**3.238**	**2.811**	**Trend uncertainty, CO2 & CH4**		**2.120**

	CATEGORIES OF EMISSIONS AND REMOVALS	Gas	Emissions in 1990 (kt CO2eq)	Emissions in 2022 (kt CO2eq)	Activity Data (AD) Uncertainty (%)	Emission Factor (EF) Uncertainty (%)	Combined Uncertainty (%)	Contribution to Variance by Category in Base Year	Contribution to Variance by Category in Year 2022	Uncertainty in Trend in Total Emissions due to AD (%)	Uncertainty in Trend in Total Emissions due to EF (%)	Uncertainty into the Trend in Total Emissions (%)
1	1.A.1 Fuel combustion - Energy Industries - Biomass	N2O	0.00	12.41	1.00	63.00	63.01	0.00	0.00	0.00	0.01	0.00
2	1.A.1 Fuel combustion - Energy Industries - Gaseous Fuels	N2O	9.08	77.91	1.00	50.00	50.01	0.00	0.00	0.00	0.06	0.00
3	1.A.1 Fuel combustion - Energy Industries - Liquid Fuels	N2O	1.31	1.02	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00
4	1.A.1 Fuel combustion - Energy Industries - Other Fossil Fuels	N2O	0.00	3.99	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00
5	1.A.1 Fuel combustion - Energy Industries - Peat	N2O	46.30	4.10	1.00	50.00	50.01	0.00	0.00	0.00	0.04	0.00
6	1.A.1 Fuel combustion - Energy Industries - Solid Fuels	N2O	6.89	3.13	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00
7	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Biomass	N2O	2.70	5.96	10.00	50.00	50.99	0.00	0.00	0.00	0.00	0.00
8	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Gaseous Fuels	N2O	0.42	1.26	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00
9	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	N2O	4.54	1.77	10.00	50.00	50.99	0.00	0.00	0.00	0.00	0.00
10	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Other Fossil Fuels	N2O	0.00	0.39	1.00	20.00	20.02	0.00	0.00	0.00	0.00	0.00
11	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Peat	N2O	0.00	0.00	2.00	50.00	50.04	0.00	0.00	0.00	0.00	0.00
12	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Solid Fuels	N2O	3.66	1.18	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00
13	1.A.3.a Domestic Aviation	N2O	0.35	0.15	1.00	66.00	66.01	0.00	0.00	0.00	0.00	0.00
14	1.A.3.b Road Transportation	N2O	43.86	110.73	1.25	68.00	68.01	0.00	0.02	0.00	0.08	0.01
15	1.A.3.c Railways	N2O	13.77	12.17	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00
16	1.A.3.d Domestic Navigation - Liquid Fuels	N2O	0.60	2.19	1.00	90.00	90.01	0.00	0.00	0.00	0.00	0.00
17	1.A.3.e Other Transportation	N2O	0.04	0.07	1.00	25.00	25.02	0.00	0.00	0.00	0.00	0.00
18	1.A.4 Other Sectors - Biomass	N2O	1.99	2.00	10.00	50.00	50.99	0.00	0.00	0.00	0.00	0.00
19	1.A.4 Other Sectors - Gaseous Fuels	N2O	0.24	0.99	2.50	50.00	50.06	0.00	0.00	0.00	0.00	0.00
20	1.A.4 Other Sectors - Liquid Fuels	N2O	68.16	81.90	10.00	50.00	50.99	0.00	0.00	0.02	0.01	0.00
21	1.A.4 Other Sectors - Peat	N2O	11.76	2.49	5.00	50.00	50.25	0.00	0.00	0.00	0.01	0.00
22	1.A.4 Other Sectors - Solid Fuels	N2O	10.43	2.07	5.00	50.00	50.25	0.00	0.00	0.00	0.01	0.00
23	1.B.2.b Fugitive Emissions from Fuels - Oil and Natural Gas - Natural Gas	N2O	0.00	0.00	1.00	150.00	150.00	0.00	0.00	0.00	0.00	0.00
24	2.B.2 Nitric Acid Production	N2O	885.10	0.00	1.00	10.00	10.05	0.03	0.00	0.00	0.18	0.03
25	2.G Other Product Manufacture and Use	N2O	27.87	40.55	5.00	5.00	7.07	0.00	0.00	0.01	0.00	0.00
26	3.B.2.1 Manure Management -Dairy Cattle	N2O	49.80	52.87	11.22	50.00	51.24	0.00	0.00	0.02	0.00	0.00
27	3.B.2.1 Manure Management -Non-Dairy Cattle	N2O	179.20	243.33	11.22	50.00	51.24	0.03	0.04	0.07	0.04	0.01
28	3.B.2.2 Manure Management -Sheep	N2O	19.92	15.31	11.22	50.00	51.24	0.00	0.00	0.00	0.01	0.00
29	3.B.2.3 Manure Management -Swine	N2O	8.96	11.20	11.22	50.00	51.24	0.00	0.00	0.00	0.00	0.00
30	3.B.2.4 Manure Management -Deer	N2O	0.21	0.02	11.22	50.00	51.24	0.00	0.00	0.00	0.00	0.00
31	3.B.2.4 Manure Management -Goats	N2O	0.58	0.31	11.22	50.00	51.24	0.00	0.00	0.00	0.00	0.00
32	3.B.2.4 Manure Management -Horses	N2O	6.12	8.24	11.22	50.00	51.24	0.00	0.00	0.00	0.00	0.00
33	3.B.2.4 Manure Management -Mules & Asses	N2O	0.56	0.68	11.22	50.00	51.24	0.00	0.00	0.00	0.00	0.00
34	3.B.2.4 Manure Management -Poultry	N2O	3.39	5.26	11.22	50.00	51.24	0.00	0.00	0.00	0.00	0.00
35	3.B.2.4 Manure Management -Fur Animals	N2O	4.85	0.79	50.00	50.00	70.71	0.00	0.00	0.00	0.00	0.00
36	3.B.2.5 Indirect N2O emissions	N2O	232.98	294.70	11.22	100.00	100.63	0.18	0.24	0.08	0.07	0.01
37	3.D.1.1 Inorganic N Fertilizer	N2O	1919.38	1616.29	1.00	50.00	50.01	3.02	1.78	0.04	0.44	0.20
38	3.D.1.2 Organic N Fertilizers	N2O	350.24	466.09	11.22	100.00	100.63	0.41	0.60	0.13	0.15	0.04
39	3.D.1.3 Urine and Dung Deposited by Grazing Animals	N2O	995.93	1090.22	11.18	50.00	51.23	0.85	0.85	0.31	0.00	0.10
40	3.D.1.4 Crop Residues	N2O	132.64	106.11	10.00	100.00	100.50	0.06	0.03	0.03	0.07	0.01
41	3.D.1.5 Mineralization/Immobilization Associated with Loss/Gain of Soil Organic Matter	N2O	1.21	8.73	22.57	100.00	102.52	0.00	0.00	0.01	0.01	0.00
42	3.D.1.6 Cultivation of Organic Soils	N2O	187.95	355.37	12.22	100.00	100.74	0.12	0.35	0.11	0.27	0.09
43	3.D.2 Indirect N2O Emissions From Managed Soils	N2O	724.72	735.66	11.18	50.00	51.23	0.45	0.39	0.21	0.05	0.05
44	5.B Biological treatment of solid waste: Composting	N2O	0.00	16.54	10.00	10.00	14.14	0.00	0.00	0.00	0.00	0.00
45	5.C Incineration and Open Burning of Waste	N2O	0.98	0.33	10.00	10.00	14.14	0.00	0.00	0.00	0.00	0.00
46	5.D Wastewater Treatment and Discharge	N2O	66.82	97.55	10.00	10.00	14.14	0.00	0.00	0.02	0.00	0.00
	Total N2O		**6025.48**	**5494.01**				**5.155**	**4.303**			**0.537**
						Level uncertainty, N2O		**2.270**	**2.074**			**0.733**
	Combined CO2, CH4 and N2O		**55195.96**	**59863.61**				**15.637**	**12.208**			**5.033**
					Level uncertainty, CO2, CH4 & N2O			**3.954**	**3.494**	**Trend uncertainty, CO2, CH4 & N2O**		**2.243**

	CATEGORIES OF EMISSIONS AND REMOVALS	Gas	Emissions in 1990 (kt CO2eq)	Emissions in 2022 (kt CO2eq)	Activity Data (AD) Uncertainty (%)	Emission Factor (EF) Uncertainty (%)	Combined Uncertainty (%)	Contribution to Variance by Category in Base Year	Contribution to Variance by Category in Year 2022	Uncertainty in Trend in Total Emissions due to AD (%)	Uncertainty in Trend in Total Emissions due to EF (%)	Uncertainty into the Trend in Total Emissions (%)
1	2.E Electronics Industry & 2.F Product Uses and Substitutes for ODS	Aggregate F-gases	1.07	734.45	20.00	10.00	22.36	0.00	0.07	0.38	0.13	0.16
2	2.G Other Product Manufacture and Use	Aggregate F-gases	34.45	6.82	10.00	0.00	10.00	0.00	0.00	0.00	0.00	0.00
	Total F-gases		**35.52**	**741.27**				**0.000**	**0.073**			**0.159**
						Level uncertainty, F-gases		**0.006**	**0.271**			**0.399**
	TOTAL for all gases		**55231.48**	**60604.89**				**15.637**	**12.281**			**5.192**
					Total level uncertainty for all GHGs			**3.954**	**3.504**	**Total trend uncertainty for all GHGs**		**2.279**

Equation 3.1 (chapter 3 of the 2006 IPCC guidelines Volume 1):

$$U_{total} = \sqrt{U_1^2 + U_2^2 + \cdots + U_n^2}$$

Where:

U_{total} = the percentage uncertainty in the product of the quantities (half the 95 per cent confidence interval divided by the total and expressed as a percentage);

U_n = the percentage uncertainties associated with each of the quantities.

Equation 3.2 (chapter 3 of the 2006 IPCC guidelines Volume 1):

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

Where:

U_{total} = the percentage uncertainty in the sum of the quantities (half the 95 per cent confidence interval divided by the total (i.e., mean) and expressed as a percentage). This term ‘uncertainty’ is thus based upon the 95 per cent confidence interval;

x_n and U_n = the uncertain quantities and the percentage uncertainties associated with them, respectively.

Table 1.13 Tier 1 Uncertainty Estimates 2022 including LULUCF (continued on following pages)

	CATEGORIES OF EMISSIONS AND REMOVALS	Gas	Emissions in 1990 (kt CO2eq)	Emissions in 2022 (kt CO2eq)	Activity Data (AD) Uncertainty (%)	Emission Factor (EF) Uncertainty (%)	Combined Uncertainty (%)	Contribution to Variance by Category in Base Year	Contribution to Variance by Category in Year 2022	Type A Sensitivity (%)	Type B Sensitivity (%)	Uncertainty in Trend in Total Emissions due to AD (%)	Uncertainty in Trend in Total Emissions due to EF (%)	Uncertainty into the Trend in Total Emissions (%)
1	1.A.1 Fuel combustion - Energy Industries - Gaseous Fuels	CO2	1880.66	5616.78	1.00	2.50	2.69	0.01	0.05	0.06	0.09	0.13	0.15	0.04
2	1.A.1 Fuel combustion - Energy Industries - Liquid Fuels	CO2	1254.90	1130.51	1.00	2.50	2.69	0.00	0.00	0.00	0.02	0.03	0.01	0.00
3	1.A.1 Fuel combustion - Energy Industries - Other Fossil Fuels	CO2	0.00	594.13	1.00	5.00	5.10	0.00	0.00	0.01	0.01	0.01	0.05	0.00
4	1.A.1 Fuel combustion - Energy Industries - Peat	CO2	3164.78	336.31	1.00	5.00	5.10	0.07	0.00	0.05	0.01	0.01	0.25	0.06
5	1.A.1 Fuel combustion - Energy Industries - Solid Fuels	CO2	4844.66	2196.43	1.00	5.00	5.10	0.17	0.03	0.05	0.04	0.05	0.25	0.06
6	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Gaseous Fuels	CO2	873.02	2697.88	2.50	2.50	3.54	0.00	0.02	0.03	0.04	0.16	0.07	0.03
7	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	CO2	2311.20	1087.55	10.00	2.50	10.31	0.16	0.03	0.02	0.02	0.26	0.06	0.07
8	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Other Fossil Fuels	CO2	0.00	217.57	1.00	5.00	5.10	0.00	0.00	0.00	0.00	0.01	0.02	0.00
9	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Peat	CO2	0.00	0.00	2.00	5.00	5.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Solid Fuels	CO2	871.24	280.53	2.00	5.00	5.39	0.01	0.00	0.01	0.00	0.01	0.05	0.00
11	1.A.3.a Domestic Aviation	CO2	47.98	21.38	1.00	2.50	2.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	1.A.3.b Road Transportation	CO2	4690.42	11019.55	1.25	3.00	3.25	0.06	0.31	0.10	0.18	0.32	0.30	0.19
13	1.A.3.c Railways	CO2	133.19	117.69	1.00	1.00	1.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	1.A.3.d Domestic Navigation - Liquid Fuels	CO2	84.90	302.59	1.00	2.00	2.24	0.00	0.00	0.00	0.01	0.01	0.01	0.00
15	1.A.3.e Other Transportation	CO2	73.14	154.97	1.00	2.50	2.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	1.A.4 Other Sectors - Gaseous Fuels	CO2	493.22	2124.72	2.50	2.50	3.54	0.00	0.01	0.03	0.04	0.12	0.07	0.02
17	1.A.4 Other Sectors - Liquid Fuels	CO2	3679.82	4577.98	10.00	5.00	11.18	0.47	0.63	0.01	0.08	1.07	0.05	1.16
18	1.A.4 Other Sectors - Peat	CO2	3259.11	692.08	10.00	20.00	22.36	1.46	0.06	0.05	0.01	0.16	0.93	0.89
19	1.A.4 Other Sectors - Solid Fuels	CO2	2485.97	508.32	5.00	10.00	11.18	0.21	0.01	0.04	0.01	0.06	0.36	0.13
20	1.B.2.b Fugitive Emissions from Fuels - Oil and Natural Gas - Natural Gas	CO2	0.01	0.20	1.00	100.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	2.A.1 Cement Production	CO2	884.00	1956.53	1.50	1.50	2.12	0.00	0.00	0.02	0.03	0.07	0.03	0.01
22	2.A.2 Lime Production	CO2	214.08	107.50	1.50	1.50	2.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	2.A.3 Glass Production	CO2	13.33	0.00	5.00	2.50	5.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	2.A.4 Other Process Uses of Carbonates	CO2	5.32	4.34	5.00	2.50	5.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	2.B.1 Ammonia Production	CO2	990.23	0.00	1.00	5.00	5.10	0.01	0.00	0.02	0.00	0.00	0.09	0.01
26	2.C Metal Production	CO2	26.08	0.00	5.00	2.50	5.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00
27	2.D Non-energy Products from Fuels and Solvent Use	CO2	116.75	179.06	30.00	5.00	30.41	0.00	0.01	0.00	0.00	0.13	0.00	0.02
28	3.G Liming	CO2	355.04	623.98	5.00	50.00	50.25	0.09	0.24	0.00	0.01	0.07	0.20	0.05
29	3.H Urea Application	CO2	96.68	126.82	5.00	50.00	50.25	0.01	0.01	0.00	0.00	0.01	0.02	0.00
30	4.A.1 Forest Land Remaining Forest Land	CO2	-2402.54	1259.31	51.00	114.00	124.89	24.81	5.93	0.06	0.02	1.51	7.26	54.99
31	4.A.2 Land Converted to Forest Land	CO2	-522.34	-3137.88	51.00	114.00	124.89	1.17	36.81	0.04	0.05	3.76	4.88	37.91
32	4.B.1 Cropland Remaining Cropland	CO2	-48.15	-83.41	20.59	69.15	72.15	0.00	0.01	0.00	0.00	0.04	0.04	0.00
33	4.C. Grassland	CO2	2260.94	1160.62	12.22	90.00	90.83	11.62	2.66	0.02	0.02	0.33	1.89	3.67
34	4.D. Wetlands	CO2	1780.24	1153.19	21.49	101.45	103.70	9.39	3.43	0.01	0.02	0.58	1.27	1.96
35	4.E.2 Land Converted to Settlements	CO2	60.03	143.62	39.97	81.83	91.07	0.01	0.04	0.00	0.00	0.13	0.11	0.03
36	4.F.2 Land Converted to Other Land	CO2	0.83	13.93	51.93	75.00	91.23	0.00	0.00	0.00	0.00	0.02	0.02	0.00
37	4.G Harvested Wood Products	CO2	-413.04	-865.73	25.00	26.92	36.74	0.06	0.24	0.01	0.01	0.51	0.19	0.29
38	5.C Incineration and Open Burning of Waste	CO2	95.59	35.98	10.00	5.00	11.18	0.00	0.00	0.00	0.00	0.01	0.01	0.00
	Total CO2		**33661.26**	**36355.05**				**49.79**	**50.54**					**101.60**
						Level uncertainty, CO2		**7.06**	**7.11**				**Trend uncertainty, CO2**	**10.08**

	CATEGORIES OF EMISSIONS AND REMOVALS	Gas	Emissions in 1990 (kt CO2eq)	Emissions in 2022 (kt CO2eq)	Activity Data (AD) Uncertainty (%)	Emission Factor (EF) Uncertainty (%)	Combined Uncertainty (%)	Contribution to Variance by Category in Base Year	Contribution to Variance by Category in Year 2022	Type A Sensitivity (%)	Type B Sensitivity (%)	Uncertainty in Trend in Total Emissions due to AD (%)	Uncertainty in Trend in Total Emissions due to EF (%)	Uncertainty into the Trend in Total Emissions (%)
1	1.A.1 Fuel combustion - Energy Industries - Biomass	CH4	0.00	4.80	1.00	66.00	66.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00
2	1.A.1 Fuel combustion - Energy Industries - Gaseous Fuels	CH4	3.84	2.83	1.00	70.00	70.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	1.A.1 Fuel combustion - Energy Industries - Liquid Fuels	CH4	0.44	0.38	1.00	66.00	66.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	1.A.1 Fuel combustion - Energy Industries - Other Fossil Fuels	CH4	0.00	3.17	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	1.A.1 Fuel combustion - Energy Industries - Peat	CH4	2.13	0.21	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	1.A.1 Fuel combustion - Energy Industries - Solid Fuels	CH4	1.02	0.46	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Biomass	CH4	2.14	4.63	10.00	50.00	50.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Gaseous Fuels	CH4	0.44	1.33	2.50	50.00	50.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	CH4	2.43	0.97	10.00	50.00	50.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Other Fossil Fuels	CH4	0.00	0.21	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Peat	CH4	0.00	0.00	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Solid Fuels	CH4	2.58	0.83	2.00	50.00	50.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	1.A.3.a Domestic Aviation	CH4	0.04	0.01	1.00	66.00	66.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	1.A.3.b Road Transportation	CH4	54.51	8.71	1.25	71.00	71.01	0.00	0.00	0.00	0.00	0.00	0.06	0.00
15	1.A.3.c Railways	CH4	0.21	0.19	1.00	60.00	60.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	1.A.3.d Domestic Navigation - Liquid Fuels	CH4	0.22	0.81	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	1.A.3.e Other Transportation	CH4	0.04	0.08	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	1.A.4 Other Sectors - Biomass	CH4	15.77	15.96	10.00	50.00	50.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	1.A.4 Other Sectors - Gaseous Fuels	CH4	1.26	5.26	2.50	50.00	50.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	1.A.4 Other Sectors - Liquid Fuels	CH4	12.19	15.58	10.00	66.00	66.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	1.A.4 Other Sectors - Peat	CH4	255.34	56.47	10.00	50.00	50.99	0.05	0.00	0.00	0.00	0.01	0.18	0.03
22	1.A.4 Other Sectors - Solid Fuels	CH4	220.09	43.65	5.00	50.00	50.25	0.03	0.00	0.00	0.00	0.01	0.16	0.03
23	1.B.1 Fugitive emissions from Solid Fuels	CH4	62.22	19.34	10.00	50.00	50.99	0.00	0.00	0.00	0.00	0.00	0.04	0.00
24	1.B.2.a Fugitive Emissions from Fuels - Oil and Natural Gas - Oil	CH4	0.24	0.39	10.00	50.00	50.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	1.B.2.b Fugitive Emissions from Fuels - Oil and Natural Gas - Natural Gas	CH4	56.07	69.66	10.00	50.00	50.99	0.00	0.00	0.00	0.00	0.02	0.01	0.00
26	3A1 Enteric Fermentation-Dairy Cattle	CH4	3803.81	5334.08	1.00	15.00	15.03	0.90	1.54	0.02	0.09	0.13	0.31	0.11
27	3A1 Enteric Fermentation-Non-Dairy Cattle	CH4	6381.33	7689.18	1.00	15.00	15.03	2.54	3.20	0.01	0.13	0.18	0.21	0.08
28	3A2 Enteric Fermentation-Sheep	CH4	2047.96	1460.15	1.00	30.00	30.02	1.04	0.46	0.01	0.02	0.03	0.37	0.14
29	3A3 Enteric Fermentation-Swine	CH4	43.95	54.07	1.00	30.00	30.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30	3A4 Enteric Fermentation-Other Animals	CH4	42.41	46.55	1.00	30.00	30.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
31	3B1.1 Manure Management-Dairy Cattle	CH4	487.25	578.50	1.00	15.00	15.03	0.01	0.02	0.00	0.01	0.01	0.01	0.00
32	3B1.1 Manure Management-Non-Dairy Cattle	CH4	716.64	963.38	1.00	15.00	15.03	0.03	0.05	0.00	0.02	0.02	0.05	0.00
33	3B1.2 Manure Management-Sheep	CH4	105.40	72.81	1.00	30.00	30.02	0.00	0.00	0.00	0.00	0.00	0.02	0.00
34	3B1.3 Manure Management-Swine	CH4	285.69	357.37	1.00	30.00	30.02	0.02	0.03	0.00	0.01	0.01	0.03	0.00
35	3B1.4 Manure Management-Other Animals	CH4	71.66	118.73	1.00	30.00	30.02	0.00	0.00	0.00	0.00	0.00	0.02	0.00
36	4.A LULUCF - Forest Land	CH4	57.24	73.87	30.00	100.00	104.40	0.01	0.01	0.00	0.00	0.05	0.02	0.00
37	4.B LULUCF - Cropland	CH4	0.05	0.02	100.00	39.10	107.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00
38	4.C LULUCF - Grassland	CH4	1659.29	1278.87	96.40	91.20	132.70	13.36	6.90	0.01	0.02	2.89	0.76	8.95
39	4.D LULUCF - Wetlands	CH4	2383.51	2590.97	86.00	66.50	108.71	18.50	19.02	0.00	0.04	5.23	0.04	27.36
40	5.A Solid Waste Disposal	CH4	1476.24	634.15	34.64	34.64	48.99	1.44	0.23	0.02	0.01	0.52	0.55	0.56
41	5.B Biological treatment of solid waste: Composting and AD	CH4	0.00	34.57	10.00	30.00	31.62	0.00	0.00	0.00	0.00	0.01	0.02	0.00
42	5.C Incineration and Open Burning of Waste	CH4	1.18	0.06	10.00	30.00	31.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00
43	5.D Wastewater Treatment and Discharge	CH4	68.43	58.69	10.00	30.00	31.62	0.00	0.00	0.00	0.00	0.01	0.01	0.00
	Total CH4		**20325.27**	**21601.95**				**37.95**	**31.48**					**37.27**
							Level uncertainty, CH4	**6.16**	**5.61**				**Trend uncertainty, CH4**	**6.11**
	Combined CO2 and CH4		**53986.53**	**57957.00**				**87.75**	**82.02**					**138.87**
					Level uncertainty, CO2 and CH4			**9.37**	**9.06**				**Trend uncertainty, CO2 & CH4**	**11.78**

	CATEGORIES OF EMISSIONS AND REMOVALS	Gas	Emissions in 1990 (kt CO2eq)	Emissions in 2022 (kt CO2eq)	Activity Data (AD) Uncertainty (%)	Emission Factor (EF) Uncertainty (%)	Combined Uncertainty (%)	Contribution to Variance by Category in Base Year	Contribution to Variance by Category in Year 2022	Type A Sensitivity (%)	Type B Sensitivity (%)	Uncertainty in Trend in Total Emissions due to AD (%)	Uncertainty in Trend in Total Emissions due to EF (%)	Uncertainty into the Trend in Total Emissions (%)
1	1.A.1 Fuel combustion - Energy Industries - Biomass	N2O	0.00	12.41	1.00	63.00	63.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00
2	1.A.1 Fuel combustion - Energy Industries - Gaseous Fuels	N2O	9.08	77.91	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.06	0.00
3	1.A.1 Fuel combustion - Energy Industries - Liquid Fuels	N2O	1.31	1.02	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	1.A.1 Fuel combustion - Energy Industries - Other Fossil Fuels	N2O	0.00	3.99	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	1.A.1 Fuel combustion - Energy Industries - Peat	N2O	46.30	4.10	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.04	0.00
6	1.A.1 Fuel combustion - Energy Industries - Solid Fuels	N2O	6.89	3.13	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Biomass	N2O	2.70	5.96	10.00	50.00	50.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Gaseous Fuels	N2O	0.42	1.26	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	N2O	4.54	1.77	10.00	50.00	50.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Other Fossil Fuels	N2O	0.00	0.39	1.00	20.00	20.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Peat	N2O	0.00	0.00	2.00	50.00	50.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Solid Fuels	N2O	3.66	1.18	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	1.A.3.a Domestic Aviation	N2O	0.35	0.15	1.00	66.00	66.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	1.A.3.b Road Transportation	N2O	43.86	110.73	1.25	68.00	68.01	0.00	0.01	0.00	0.00	0.00	0.07	0.01
15	1.A.3.c Railways	N2O	13.77	12.17	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	1.A.3.d Domestic Navigation - Liquid Fuels	N2O	0.60	2.19	1.00	90.00	90.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	1.A.3.e Other Transportation	N2O	0.04	0.07	1.00	25.00	25.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	1.A.4 Other Sectors - Biomass	N2O	1.99	2.00	10.00	50.00	50.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	1.A.4 Other Sectors - Gaseous Fuels	N2O	0.24	0.99	2.50	50.00	50.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	1.A.4 Other Sectors - Liquid Fuels	N2O	68.16	81.90	10.00	50.00	50.99	0.00	0.00	0.00	0.00	0.02	0.01	0.00
21	1.A.4 Other Sectors - Peat	N2O	11.76	2.49	5.00	50.00	50.25	0.00	0.00	0.00	0.00	0.00	0.01	0.00
22	1.A.4 Other Sectors - Solid Fuels	N2O	10.43	2.07	5.00	50.00	50.25	0.00	0.00	0.00	0.00	0.00	0.01	0.00
23	1.B.2.b Fugitive Emissions from Fuels - Oil and Natural Gas - Natural Gas	N2O	0.00	0.00	1.00	150.00	150.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	2.B.2 Nitric Acid Production	N2O	885.10	0.00	1.00	10.00	10.05	0.02	0.00	0.02	0.00	0.00	0.16	0.02
25	2.G Other Product Manufacture and Use	N2O	27.87	40.55	5.00	5.00	7.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00
26	3.B.2.1 Manure Management -Dairy Cattle	N2O	49.80	52.87	11.22	50.00	51.24	0.00	0.00	0.00	0.00	0.01	0.00	0.00
27	3.B.2.1 Manure Management -Non-Dairy Cattle	N2O	179.20	243.33	11.22	50.00	51.24	0.02	0.04	0.00	0.00	0.06	0.04	0.01
28	3.B.2.2 Manure Management -Sheep	N2O	19.92	15.31	11.22	50.00	51.24	0.00	0.00	0.00	0.00	0.00	0.01	0.00
29	3.B.2.3 Manure Management -Swine	N2O	8.96	11.20	11.22	50.00	51.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30	3.B.2.4 Manure Management -Deer	N2O	0.21	0.02	11.22	50.00	51.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00
31	3.B.2.4 Manure Management -Goats	N2O	0.58	0.31	11.22	50.00	51.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00
32	3.B.2.4 Manure Management -Horses	N2O	6.12	8.24	11.22	50.00	51.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00
33	3.B.2.4 Manure Management -Mules & Asses	N2O	0.56	0.68	11.22	50.00	51.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00
34	3.B.2.4 Manure Management -Poultry	N2O	3.39	5.26	11.22	50.00	51.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00
35	3.B.2.4 Manure Management -Fur Animals	N2O	4.85	0.79	50.00	50.00	70.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00
36	3.B.2.5 Indirect N2O emissions	N2O	232.98	294.70	11.22	100.00	100.63	0.15	0.21	0.00	0.00	0.08	0.07	0.01
37	3.D.1.1 Inorganic N Fertilizer	N2O	1919.38	1616.29	1.00	50.00	50.01	2.54	1.57	0.01	0.03	0.04	0.37	0.14
38	3.D.1.2 Organic N Fertilizers	N2O	350.24	466.09	11.22	100.00	100.63	0.34	0.53	0.00	0.01	0.12	0.15	0.04
39	3.D.1.3 Urine and Dung Deposited by Grazing Animals	N2O	995.93	1090.22	11.18	50.00	51.23	0.72	0.75	0.00	0.02	0.29	0.02	0.08
40	3.D.1.4 Crop Residues	N2O	132.64	106.11	10.00	100.00	100.50	0.05	0.03	0.00	0.00	0.02	0.06	0.00
41	3.D.1.5 Mineralization/Immobilization Associated with Loss/Gain of Soil Organic Matter	N2O	1.21	8.73	22.57	100.00	102.52	0.00	0.00	0.00	0.00	0.00	0.01	0.00
42	3.D.1.6 Cultivation of Organic Soils	N2O	187.95	355.37	12.22	100.00	100.74	0.10	0.31	0.00	0.01	0.10	0.26	0.08
43	3.D.2 Indirect N2O Emissions From Managed Soils	N2O	724.72	735.66	11.18	50.00	51.23	0.38	0.34	0.00	0.01	0.19	0.03	0.04
44	4.A LULUCF - Forest Land	N2O	144.43	229.70	30.00	100.00	104.40	0.06	0.14	0.00	0.00	0.16	0.12	0.04
45	4.B.1 LULUCF - Cropland remaining Cropland	N2O	0.01	0.00	100.00	100.00	141.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00
46	4.C.1 LULUCF - Grassland Remaining Grassland	N2O	8.06	45.39	91.02	100.00	135.22	0.00	0.01	0.00	0.00	0.10	0.06	0.01
47	4.D LULUCF - Wetlands	N2O	39.57	13.48	86.00	100.00	131.89	0.01	0.00	0.00	0.00	0.03	0.05	0.00
48	4.E.1. LULUCF-Settlements remaining settlements	N2O	2.63	72.75	45.24	54.69	70.98	0.00	0.01	0.00	0.00	0.08	0.06	0.01
49	4.E.2 LULUCF - Land Converted to Settlements	N2O	2.63	72.75	45.24	54.69	70.98	0.00	0.01	0.00	0.00	0.08	0.06	0.01
50	4.F LULUCF -Other Land	N2O	0.07	29.69	30.00	100.00	104.40	0.00	0.00	0.00	0.00	0.02	0.05	0.00
51	5.B Biological treatment of solid waste: Composting	N2O	0.00	16.54	10.00	10.00	14.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00
52	5.C Incineration and Open Burning of Waste	N2O	0.98	0.33	10.00	10.00	14.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00
53	5.D Wastewater Treatment and Discharge	N2O	66.82	97.55	10.00	10.00	14.14	0.00	0.00	0.00	0.00	0.02	0.00	0.00

	Total N2O		**6220.25**	**5889.999**				**4.403**	**3.945**					**0.498**
							Level uncertainty, N2O	**2.098**	**1.986**				**Trend uncertainty, N2O**	**0.706**
	Combined CO2, CH4 and N2O		**60206.78**	**63846.95**				**92.151**	**85.969**					**139.372**
							Level uncertainty, CO2, CH4 & N2O	**9.600**	**9.272**				**Trend uncertainty, CO2, CH4 & N2O**	**11.806**

	CATEGORIES OF EMISSIONS AND REMOVALS	Gas	Emissions in 1990 (kt CO2eq)	Emissions in 2022 (kt CO2eq)	Activity Data (AD) Uncertainty (%)	Emission Factor (EF) Uncertainty (%)	Combined Uncertainty (%)	Contribution to Variance by Category in Base Year	Contribution to Variance by Category in Year 2022	Type A Sensitivity (%)	Type B Sensitivity (%)	Uncertainty in Trend in Total Emissions due to AD (%)	Uncertainty in Trend in Total Emissions due to EF (%)	Uncertainty into the Trend in Total Emissions (%)
1	2.E Electronics Industry & 2.F Product Uses and Substitutes for ODS	Aggregate F-gases	1.07	734.45	20.00	10.00	22.36	0.00	0.06	0.01	0.01	0.34	0.12	0.13
2	2.G Other Product Manufacture and Use	Aggregate F-gases	34.45	6.82	10.00	0.00	10.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Total F-gases		**35.52**	**741.27**				**0.000**	**0.065**					**0.134**
						Level uncertainty, F-gases		**0.006**	**0.254**				**Trend uncertainty, F-gases**	**0.366**
	TOTAL for all gases		**60242.30**	**64588.23**				**92.151**	**86.033**					**139.506**
					Total level uncertainty for all GHGs			**9.600**	**9.275**			**Total trend uncertainty for all GHGs**		**11.811**

Equation 3.1 (chapter 3 of the 2006 IPCC guidelines Volume 1):

$$U_{total} = \sqrt{U_1^2 + U_2^2 + \cdots + U_n^2}$$

Where:

U_{total} = the percentage uncertainty in the product of the quantities (half the 95 per cent confidence interval divided by the total and expressed as a percentage);
U_n = the percentage uncertainties associated with each of the quantities.

Equation 3.2 (chapter 3 of the 2006 IPCC guidelines Volume 1):

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

Where:

U_{total} = the percentage uncertainty in the sum of the quantities (half the 95 per cent confidence interval divided by the total (i.e., mean) and expressed as a percentage). This term ‘uncertainty’ is thus based upon the 95 per cent confidence interval;

x_n and U_n = the uncertain quantities and the percentage uncertainties associated with them, respectively.

Table 1.14 Summary of Completeness

IPCC SOURCE AND SINK CATEGORIES	CO_2	CH_4	N_2O	HFC	PFC	SF_6	NF_3
1. Energy							
A. Fuel Combustion (Sectoral Approach)	All	All	All	NA	NA	NA	NA
1. Energy Industries	All	All	All	NA	NA	NA	NA
2. Manufacturing Industries and Construction	All	All	All	NA	NA	NA	NA
3. Transport	All	All	All	NA	NA	NA	NA
4. Other Sectors	All	All	All	NA	NA	NA	NA
5. Other	NO	NO	NO	NA	NA	NA	NA
B. Fugitive Emissions from Fuels							
1. Solid Fuels	NO	All	NO	NA	NA	NA	NA
2. Oil and Natural Gas	All	All	Part	NA	NA	NA	NA
C. Carbon Dioxide Transport and Storage	NO	NO	NO	NA	NA	NA	NA
2. Industrial Processes and Product Use							
A. Mineral Industry	All	NA	NA	NA	NA	NA	NA
B. Chemical Industry	All	NO	All	NO	NO	NO	NO
C. Metal Production	NO	NO	NO	NO	NO	NO	NO
D. Non-Energy Products from Fuels and Solvent Use	All	NA	NA	NA	NA	NA	NA
E. Electronic Industry	NA	NA	NA	All	All	All	All
F. Product Uses as Substitutes for ODS	NA	NA	NA	All	NO	NO	NO
G. Other Product Manufacture and Use	NO	NO	Part	NO	NO	All	NO
H. Other	NO	NO	NO	NA	NA	NA	NA
3. Agriculture							
A. Enteric Fermentation	NA	All	NA	NA	NA	NA	NA
B. Manure Management	NA	All	All	NA	NA	NA	NA
C. Rice Cultivation	NA	NO	NA	NA	NA	NA	NA
D. Agricultural Soils	NA	NE	All	NA	NA	NA	NA
E. Prescribed Burning of Savannas	NO	NO	NO	NA	NA	NA	NA
F. Field Burning of Agricultural Residues	NO	NO	NO	NA	NA	NA	NA
G. Liming	NO	NO	NO	NA	NA	NA	NA
H. Urea Application	All	NO	NO	NA	NA	NA	NA
I. Other	All	NO	NO	NA	NA	NA	NA
4. Land-Use, Land-Use Change and Forestry							
A. Forest Land	All	All	All	NA	NA	NA	NA
B. Cropland	All	NO	All	NA	NA	NA	NA
C. Grassland	All	NO	IE	NA	NA	NA	NA
D. Wetlands	All	NE	All	NA	NA	NA	NA
E. Settlements	Part	NO	NO	NA	NA	NA	NA
F. Other Land	All	NE	NE	NA	NA	NA	NA
G. Harvested Wood Products	All	NO	NO	NA	NA	NA	NA
H. Other	NO	NO	NO	NA	NA	NA	NA
5. Waste							
A. Solid Waste Disposal	NO	All	NA	NA	NA	NA	NA
B. Biological Treatment of Solid Waste	NA	All	All	NA	NA	NA	NA
C. Waste Incineration and Open Burning of Waste	All	All	All	NA	NA	NA	NA
D. Wastewater Treatment and Discharge	NO	All	All	NA	NA	NA	NA
E. Other	NO	NO	NO	NA	NA	NA	NA
6. Other	NO	NO	NO	NA	NA	NA	NA
Memo Items:							
International Bunkers							
Aviation	All	All	All	NA	NA	NA	NA
Navigation	All	All	All	NA	NA	NA	NA
Multilateral Operations	NO	NO	NO	NA	NA	NA	NA
CO_2 Emissions from Biomass	All	NA	NA	NA	NA	NA	NA
CO_2 captured	NO	NO	NO	NA	NA	NA	NA
Long-term storage of C in waste disposal sites	NE	NO	NO	NA	NA	NA	NA
Indirect N_2O	NO	NO	NE	NA	NA	NA	NA
Indirect CO_2	Part	NO	NO	NA	NA	NA	NA

All: Emissions of the gas are covered for all sources under the source category/memo item
NA: Emissions of the gas not applicable to the source category/memo item
NO: Emissions of the gas does not occur in Ireland for the source category/memo item
NE: Emissions on the gas not estimated for the source category/memo item
Part: Emissions of the gas estimated for some activities in the source category

Chapter 2 Trends in greenhouse gas emissions

2.1 Description and interpretation of emission trends for aggregated GHG emissions

The trends in emissions of the greenhouse gases in Ireland over the period 1990-2022 are shown in Figure 2.1 and Table 2.1. The estimates reported here show some changes on those reported in the previous submission, which reflect recalculations that are fully described in subsequent chapters. The trends in the principal emission components, shown as CO_2 equivalents, within the five IPCC sectors are shown on Figure 2.4 through Figure 2.11.

Total emissions of the seven greenhouse gases in Ireland (including indirect CO_2 emissions without land use, land use change and forestry) increased steadily from 55,231.5 kt CO_2 eq in 1990 to 71,476.9 kt CO_2 eq in 2001, which is the highest level of GHG emissions ever reported in Ireland. Emissions then plateaued until 2008 with estimates ranging from 69,032.5 kt CO_2 eq to 71,213.8 kt CO_2 eq. There was then a sharp decrease from 69,032.5 kt CO_2 eq in 2008 to 58,582.4 kt CO_2 eq in 2011. Emissions in 2022 at 60,604.9 kt CO_2 eq are 1.9 per cent lower than 2021.

The largest annual change occurred from 2008 to 2009 when emissions decreased by 5,776.4 kt CO_2 eq from 69,032.5 kt CO_2 eq to 63,256.2 kt CO_2 eq a reduction of 8.4 per cent. Total emissions in 2022 were 9.7 per cent higher than in 1990 and 15.2 per cent lower than the peak level in 2001. Inter annual changes to national total emission estimates are shown in Figure 2.2.

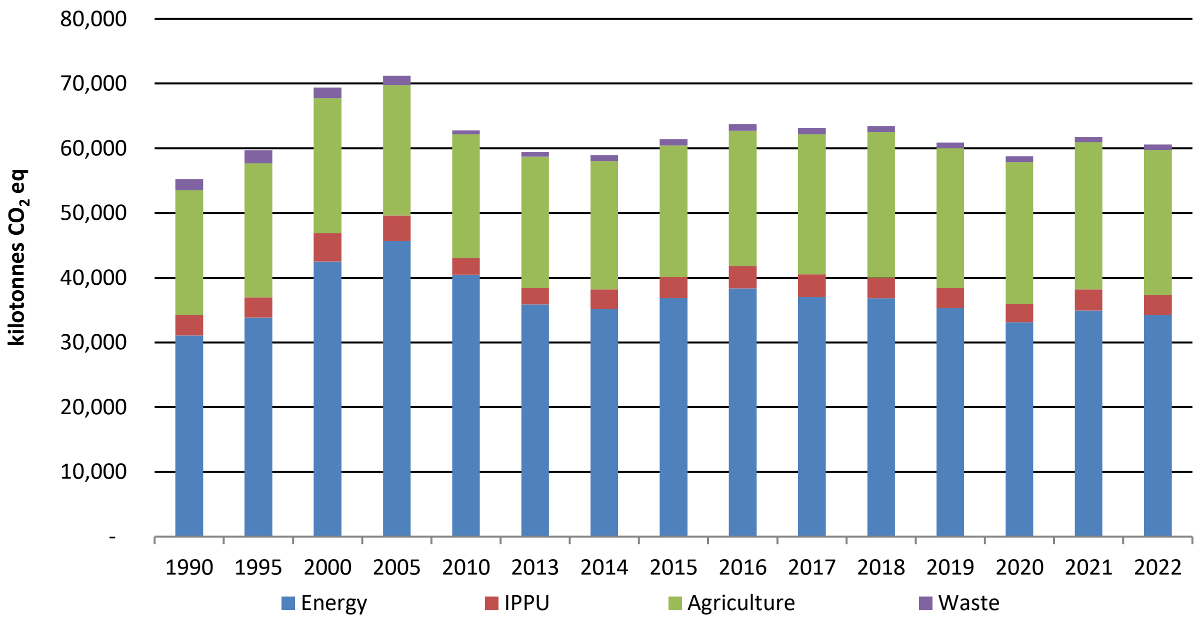


Figure 2.1 National total Greenhouse Gas emissions (excluding LULUCF) 1990-2022

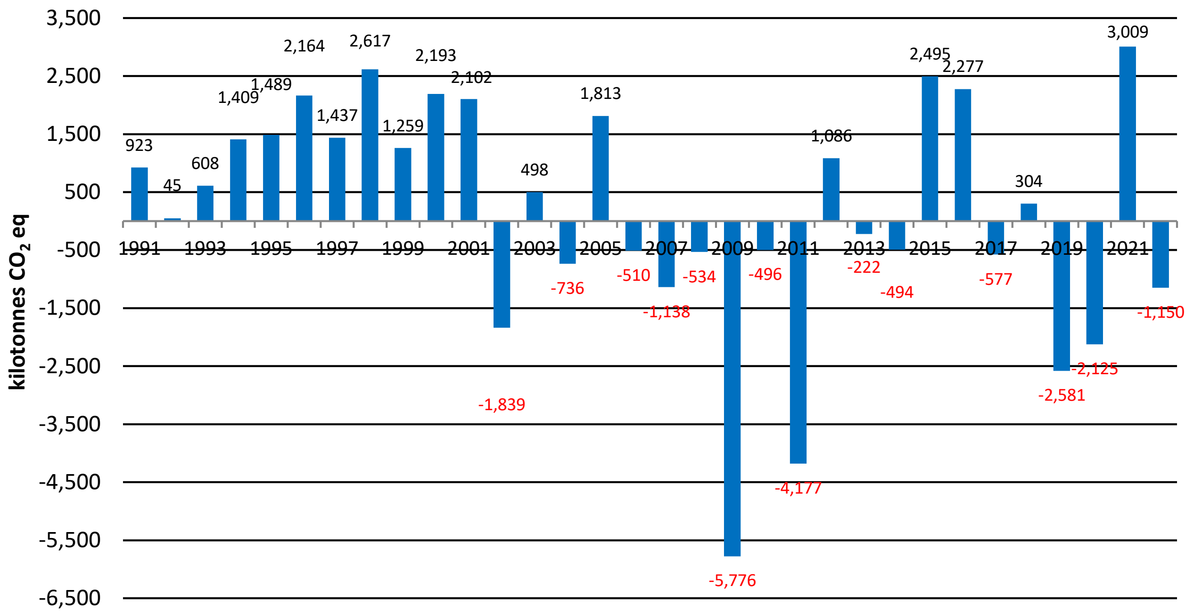


Figure 2.2 Inter annual changes

In 2022, the total Energy sector accounted for 56.5 per cent of total emissions, Agriculture contributed 37.0 per cent while a further 5.0 per cent emanated from Industrial Processes and Product Use and 1.4 per cent was due to Waste.

The Energy sector accounted for the bulk of the CO_2 emissions in 2022 (91.7 per cent), IPPU and Agriculture sectors contributed further 6.1 per cent and 2.0 per cent, respectively and Waste contributed the remainder 0.1 per cent. CH_4 emissions are produced mainly in the Agriculture sector (94.4 per cent) and Waste sector (4.1 per cent), the Energy sector contributed the remainder 1.4 per cent. Most of the N_2O emissions are generated in Agriculture (91.2 per cent) and Energy (6.0 per cent) with Waste and IPPU contributing a further 2.1 per cent and 0.7 per cent, respectively. IPPU sector is responsible for 100 per cent of F-gas emissions.

The large increase in emissions during the period 1990-2001 was clearly driven by the growth in CO_2 emissions from energy use. CO_2 from the Energy sector increased its share of national total emissions from 54.6 per cent in 1990 to 61.2 per cent share in 2001. The bulk of this increase occurred in the years between 1994 and 2001, during which Ireland experienced a period of unprecedented economic growth with energy CO_2 emissions increasing by an average of 4.4 per cent annually.

The rate of economic growth slowed down from 2002 to 2004, which together with the closure of ammonia and nitric acid production plants and the continued decline in cattle populations and fertiliser use resulted in a reduction in the emission levels in the period 2002 to 2004.

The increase in 2005 was largely due to increased emissions from road transport and from electricity generation from two new peat-fired stations.

The declining trend between 2005 and 2008 is largely attributable to decreases in the agriculture and waste sectors and in 2008 to reduced emissions from mineral products in the industrial processes sector. In addition, the sustained increase in transport emissions, the major contributor to the trend, came to an end in 2008 and together with the economic downturn caused a major decrease in emissions in 2009 to 2011, before rising in 2012 and decreasing in 2013 and 2014.

The increase seen in 2015, continued in 2016, and was due to increased emissions from almost all IPCC sectors. The most significant contributors were energy use categories, including road transport, and emissions from enteric fermentation. In 2019 emissions decreased by 4.1 per cent mainly due to reduced coal consumption in electricity generation and by a further 3.5 per cent in 2020 mainly due to reduced transport emissions during COVID restrictions and less peat used for electricity generation. Emissions have rebounded post COVID by 5.1 per cent in 2021 and decrease by 1.9 per cent in 2022.

Table 2.1. Greenhouse Gas Emissions 1990-2022 (kt CO_2 equivalent)

(a) Emissions by Gas

Greenhouse Gas Emissions	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Percentage change (1990-2022)
CO_2 emissions without net CO_2 from LULUCF	32,945.3	35,853.4	45,249.5	48,152.7	41,791.6	37,278.9	36,850.2	38,716.0	40,366.9	39,075.6	39,009.4	37,323.4	35,124.5	37,544.3	36,711.4	11.4
CO_2 emissions with net CO_2 from LULUCF	33,661.3	37,777.1	47,010.0	50,172.8	42,501.4	37,261.1	36,385.1	38,714.7	39,545.9	39,865.3	39,024.2	37,434.9	36,123.2	37,936.1	36,355.1	8.0
CH_4 emissions without CH_4 from LULUCF	16,225.2	17,192.2	16,973.0	16,413.8	14,603.9	15,604.4	15,690.1	16,261.4	16,698.8	17,182.9	17,533.9	17,016.6	17,246.0	17,572.6	17,658.2	8.8
CH_4 emissions with CH_4 from LULUCF	20,325.3	21,184.4	20,826.4	20,281.8	18,659.6	19,348.6	19,454.2	19,922.0	20,303.0	21,088.9	21,259.1	20,750.7	20,976.6	21,403.0	21,601.9	6.3
N_2O emissions without N_2O from LULUCF	6,025.5	6,454.7	6,446.2	5,506.0	5,243.2	5,428.7	5,212.8	5,274.0	5,386.4	5,687.1	6,021.1	5,658.2	5,669.8	5,893.5	5,494.0	-8.8
N_2O emissions with N_2O from LULUCF	6,220.2	6,690.2	6,700.4	5,829.9	5,725.9	5,864.3	5,651.7	5,697.2	5,801.5	6,156.8	6,467.6	6,094.6	6,093.0	6,299.0	5,889.9	-5.3
HFCs	0.5	31.4	245.7	818.2	1,016.7	1,060.9	1,139.0	1,116.0	1,183.6	1,093.5	782.9	770.6	621.4	661.1	666.4	134258.5
PFCs	0.1	88.6	361.3	196.5	42.3	7.6	3.2	18.5	33.5	42.4	44.8	56.6	57.7	59.7	50.4	46244.5
SF_6	34.9	81.5	53.4	100.1	34.1	44.5	38.2	45.5	40.1	40.0	41.8	34.2	17.0	15.3	16.2	-53.5
NF_3	NO	4.1	46.0	26.6	27.8	21.3	18.8	16.4	15.8	26.5	18.4	11.2	9.5	8.7	8.2	
Total (without LULUCF)	**55,231.5**	**59,706.0**	**69,375.2**	**71,213.8**	**62,759.7**	**59,446.2**	**58,952.4**	**61,447.7**	**63,725.1**	**63,148.0**	**63,452.2**	**60,870.9**	**58,746.0**	**61,755.1**	**60,604.9**	**9.7**
Total (with LULUCF)	**60,242.3**	**65,857.4**	**75,243.3**	**77,425.8**	**68,007.9**	**63,608.2**	**62,690.3**	**65,530.1**	**66,923.4**	**68,313.4**	**67,638.7**	**65,152.9**	**63,898.5**	**66,382.9**	**64,588.2**	**7.2**
Total (without LULUCF, with indirect)	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	
Total (with LULUCF, with indirect)	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	

(b) Emissions by IPCC Source Category (kt CO_2 equivalent)

Greenhouse Gas Source and Sink Categories	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Percentage change (1990-2022)
1. Energy	31,067.5	33,835.4	42,483.6	45,702.3	40,460.3	35,853.9	35,193.7	36,859.5	38,369.9	37,060.0	36,837.2	35,260.1	33,125.6	34,961.1	34,261.0	10.3
2. Industrial Processes	3,198.3	3,108.1	4,407.2	3,900.1	2,582.8	2,608.1	3,017.5	3,202.0	3,420.7	3,438.5	3,180.1	3,136.5	2,812.7	3,216.6	3,029.3	-5.3
3. Agriculture	19,256.5	20,742.7	20,841.0	20,157.0	19,127.8	20,229.1	19,791.9	20,365.7	20,918.6	21,670.5	22,501.7	21,576.4	21,929.8	22,754.0	22,436.8	16.5
4. LULUCF	5,010.8	6,151.4	5,868.1	6,212.0	5,248.2	4,162.1	3,737.9	4,082.4	3,198.3	5,165.4	4,186.5	4,282.0	5,152.4	4,627.8	3,983.3	-20.5
5. Waste	1,709.2	2,019.8	1,643.4	1,454.4	588.9	755.1	949.2	1,020.4	1,015.9	979.0	933.3	897.9	877.8	823.4	877.9	-48.6
6. Other	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	
Total (including LULUCF)	**60,242.3**	**65,857.4**	**75,243.3**	**77,425.8**	**68,007.9**	**63,608.2**	**62,690.3**	**65,530.1**	**66,923.4**	**68,313.4**	**67,638.7**	**65,152.9**	**63,898.5**	**66,382.9**	**64,588.2**	**7.2**

2.2 Trends by Gas

Emissions of CO_2 accounted for 60.6 per cent of the total (excluding LULUCF) of 60,604.9 kt CO_2 eq in 2022, with CH_4 and N_2O contributing 29.1 per cent and 9.1 per cent, respectively. The combined emissions of HFC, PFC, SF_6 and NF_3 accounted for 1.2 per cent of total emissions in 2022. In 1990 emissions of CO_2, CH_4, N_2O and the combined emissions of HFCs, PFCs, SF_6 and NF_3 accounted for 59.6, 29.4, 10.9 and less than 0.1 per cent, respectively of total emissions of 55,231.5 kt CO_2 eq as presented in Figure 2.3.

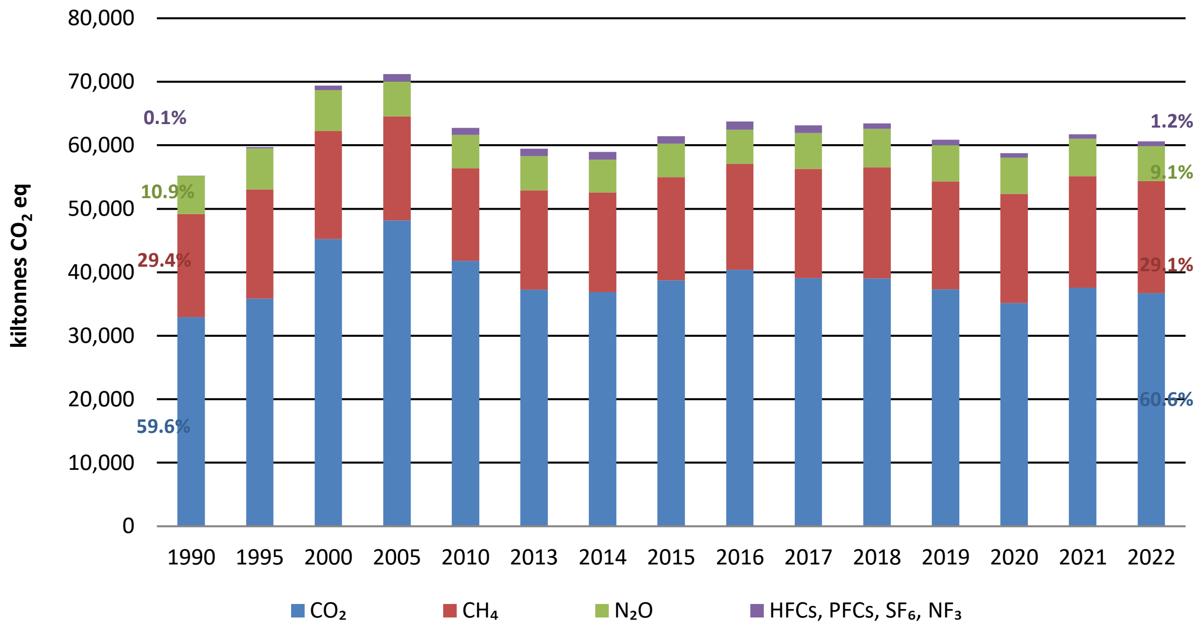


Figure 2.3 Greenhouse Gas emissions-by Gas (excluding LULUCF) 1990-2022

2.2.1 Trends in Carbon Dioxide

CO_2 is the most significant contributor to the greenhouse gas emissions with 1.A.1 Energy Industries and 1.A.3 Transport sectors responsible for 26.9 per cent and 31.6 per cent of total CO_2 emissions (excluding LULUCF) in 2022, respectively. 1.A.4 Other Sectors represents a share of 21.5 per cent, 1.A.2 Manufacturing Industries and Construction has a 11.7 per cent share and the remainder of CO_2 emissions (8.3 per cent share) fall into other categories.

Emissions of CO_2 increased from 32,945.3 kt in 1990 to 36,711.4 kt in 2022, which equates to an increase of 11.4 per cent. The main driver behind this increase in emissions is primarily fuel combustion in Transport followed by Energy Industries. Over the period 1990-2022, emissions of CO_2 from Transport, predominantly road traffic in Ireland, increased by 130.9 per cent. This trend is exaggerated somewhat in later years by so-called fuel-tourism. In 2022, it is estimated that 6.5 per cent of diesel sold in Ireland was used in vehicles in the UK and other countries.

Over the time-series, emissions of CO_2 from 1.A.1 Energy Industries increased in the first decade by 54.7 per cent until they peaked in 2001 and decreased by 42.7 per cent to 2022, showing an overall decrease of 11.4 per cent CO_2 over the 1990-2022 period. In addition, even though Ireland has only a small number of energy intensive industries, CO_2 emissions from combustion in the industrial sector 1.A.2 Manufacturing Industries and Construction increased by 5.6 per cent between 1990 and 2022.

2.2.2 Trends in Methane

Methane is the second most significant contributor to greenhouse gas emissions in Ireland which is due to the large population of cattle. In 2022 emissions of CH_4 were 17,658.2 kt CO_2 eq, indicating a increase of 8.8 per cent on the 1990 level of 16,225.2 kt CO_2 eq. Emissions of CH_4 increased progressively from 1990, reaching a peak in 1998 of 18,030.7 kt CO_2 eq, which reflects an increase in livestock numbers and therefore increased emissions from source categories 3.A Enteric Fermentation and 3.B Manure Management.

Between 1998 and 2011, CH_4 emissions decreased because of falling livestock numbers due to reform of the Common Agricultural Policy (CAP). However, total CH_4 emissions in the period 2001-2014 fluctuated to some extent on a yearly basis. This trend is a direct result of fluctuating CH_4 emissions from 1.A.4 Other Sectors and 1.B Fugitive Emissions from Fuels. The main contributor to the CH_4 trend has been Agriculture and in 2022 the sector accounted for 94.4 per cent of the total methane emissions (compared to 86.2 per cent share in 1990 when emissions from Waste had a larger share in the methane trend). The sectoral methane emissions from Agriculture increased by 19.2 per cent between 1990 (13,986.1 kt CO_2 eq) and 2022 (16,674.8 kt CO_2 eq).

Another significant source of methane emissions is Waste sector, especially from landfill gas in category 5.A Solid Waste Disposal on Land. CH_4 emissions from Waste decreased from 9.1 per cent share of total methane emissions (1,476.2 kt CO_2 eq) in 1990 to 3.6 per cent share (634.1 kt CO_2 eq) in 2022. This decrease is a result of improved management of landfill facilities, including increased recovery of landfill gas utilised for electricity generation and flaring.

2.2.3 Trends in Nitrous Oxide

Nitrous oxide emissions decreased by 8.8 per cent from their 1990 level of 6,025.5 kt CO_2 eq in 1990 to 5,494.0 kt CO_2 eq in 2022. Similar to CH_4, emissions of N_2O increased during the 1990s to reach peak level of 6,875.8 kt CO_2 eq in 1998 reflecting increased use of synthetic fertilisers and increased amounts of animal manures associated with increasing animal numbers over that period. Emissions of N_2O subsequently show a clear downward trend following reductions in synthetic fertiliser use and organic nitrogen applications on land as a result of the effect of the CAP reform on animal numbers as well the closure of Ireland’s only nitric acid plant in 2002.

The largest contributor to the trend is the Agriculture sector with 91.2 per cent share of the total N_2O emissions (5,011.2 kt CO_2 eq) in 2022. This reflects an increase from 86.2 per cent share (4,818.6 kt CO_2 eq) in 1990. Emissions from IPPU in chemical industry used to be the second largest contributor to the trend contributing 15.2 per cent to total N_2O emissions in 1990 and an average of 11.3 per cent share to the trend between 1990 and 2000, before falling to 4.3 per cent share in 2002 – the year of nitric acid plant closure.

Energy and Waste sectors contribute 6.0 per cent and 2.1 per cent, respectively to total N_2O emissions in 2022.

2.2.4 Trends in Fluorinated Gases (HFCs, PFCs, SF_6, NF_3)

Emissions of F-gases (HFCs, PFCs, SF_6 and NF_3) were 741.3 kt CO_2 eq in 2022 compared to 35.5 kt CO_2 eq in 1990, a 21-fold increase over the time series. However, F-gas emissions only account for 1.2 per cent of the national total in 2022. F-gases include a wide range of substances that are used in a diverse range of products and manufacturing processes. Therefore, it can be difficult to identify the factors contributing to actual trends in emissions over time. However, it is possible to establish the main contributory sub-categories underlying these trends.

The main causative factor of the increase in F-gas emissions has been the growth in HFC emissions from 2.F.1 Refrigeration and Air Conditioning through their use as replacement refrigerants across virtually all refrigeration sub-categories since 1996. Increased use of HFCs in 2.F.4 categories: Metered Dose Inhalers (MDIs) and Aerosols is also an important component of the trend. On the other hand, following a 2013 study on F-gases, emissions from 2.F.2 Foams were proven to be not occurring in manufacturing process and consequently were removed from the whole time series. Similar was the finding in 2.F.3 Fire extinguishers between 1990-1996 (incl.) and significant emission reductions for the following years in the trend have been applied. Sector 2.E.1 Semiconductor Manufacture was the only source in 1990 until 2.F.4 Aerosols entered the market in 1990, followed by 2.F.1 MAC in 1993, 2.F.1 Refrigeration and Air Conditioning in 1995 and both 2.F.3 Fire extinguishers and 2.F.4 MDIs in 1996. Emissions from HFCs increased steadily from 0.5 kt CO_2 eq in 1990 to 666.4 kt CO_2 eq in 2022.

Emissions of PFCs increased from 0.1 kt CO_2 eq in 1990 up to their peak of 361.3 kt CO_2 eq in 2000 through their use in the semiconductor manufacturing process in 2.E.1 Semiconductor Manufacture. Semiconductor manufacturers continue to investigate various reduction initiatives through gas substitution and new process technologies which is reflected in the downward trend in PFC emissions between 2000 and 2022 (50.4 kt CO_2 eq in 2022).

SF_6 is used in a diverse number or products and processes and is therefore included in several IPCC source sub-categories including 2.E.1 Semiconductor Manufacture, 2.G.1 Electrical Equipment and four subcategories under 2.G.2 Other. Emissions of SF_6 were 34.9 kt CO_2 eq and 16.2 kt CO_2 eq in 1990 and 2022, respectively. However, total emissions of SF_6 across the time series vary considerably, primarily because the two largest sources (Semiconductor Manufacture and Electrical Equipment) vary from year to year. Emissions of SF_6 grew steadily from 1990, peaking at 130.0 kt CO_2 eq in 1997. The increase over the period 1990-1997 was largely due to increased use of SF_6 in Semiconductor Manufacture. Emissions from both Semiconductor Manufacture and Electrical Equipment then show a steady decline across the time series (although there are peaks in 2003 and 2005 due to elevated emissions from Semiconductor Manufacture). Similar to PFCs, semiconductor manufacturers have undertaken to reduce the use of SF_6 through gas substitution and new process technologies. In 2.E.1 Electrical Equipment, where SF_6 is used for electrical insulation, arc quenching and current interruption, a leak reduction programme has been in place since 1997, when peak emissions are observed.

NF_3 are solely released from 2.E.1 Semiconductor Manufacture. Emissions of NF_3 were reported since 1995 (4.1 kt CO_2 eq.) when use of this gas commenced in the industry and peaked in 2000 (46.0 kt CO_2 eq.). Emissions in 2022 are 8.2 kt CO_2 eq.

2.3 Description and interpretation of emission trends by sector

Greenhouse gas emissions broken down by IPCC sector are presented in Table 2.1 (b). The largest contribution is from the Energy sector, which in 2022 contributes 56.5 per cent of total greenhouse gas emissions (excluding LULUCF). The second largest sector is Agriculture, which accounted for 37.0 per cent of total greenhouse gas emissions in 2022. Emissions from Industrial Processes and Product Use accounted for 5.0 per cent and Waste accounted for 1.4 per cent of total emissions in 2022. The following sub-sections discuss the main contributors to trends within each IPCC source sector including LULUCF sector. Emissions of indirect gases are discussed in section 2.4.

2.3.1 Trends in Energy (IPCC Sector 1)

Emissions from the Energy sector increased by 10.3 per cent from 31,067.5 kt CO_2 eq in 1990 to 34,261.0 kt CO_2 eq in 2022. The most significant increases occurred between 1994 and 2001, driven by major increases in emissions from 1.A.1 Energy Industries and 1.A.3 Transport. Emissions were comparatively stable between 2001 and 2008, reaching a peak in 2005 of 45,702.3 kt CO_2 eq. A major decrease occurred between 2008 and 2009 when the sectoral emissions fell by 9.9 per cent. A further reduction of 16.0 per cent has occurred between 2009 and 2022.

Energy Industries (1.A.1) accounted for 20.3 per cent and 16.5 per cent of total national greenhouse gas emissions excluding LULUCF in 1990 and 2022, respectively. Total greenhouse gas emissions from this sub-sector increased by 54.5 per cent from 11,216.0 kt CO_2 eq in 1990 to 17,326.3 kt CO_2 eq in 2001. Some reductions were achieved in 2002, 2003 and 2004 from improvements in energy efficiency and fuel switching as new electricity producers entered the market with the result that emissions decreased to 15,326.1 kt CO_2 eq in 2004. Emissions subsequently increased in 2005 to 15,818.5 kt CO_2 eq as levels of peat use returned to former levels with the entry into service of two new peat fired power plants. Emissions in 2006 decreased to 15,065.6 kt CO_2 eq due to a reduction in the use of Moneypoint coal-fired station during the installation of pollutant control measures, while further reductions in 2007 (14,571.3 kt CO_2 eq) are largely a result of the displacement of oil by natural gas. In 2008, emissions increased by 0.8 per cent or 120.1 kt CO_2 eq to 14,691.4 kt CO_2 eq, then decreased in 2009 by 10.8 per cent to 13,103.0 kt CO_2 eq reflecting the impact of the economic recession in Ireland. There was a slight increase in emissions (2.0 per cent) in 2010 to reach 13,363.8 kt CO_2 eq which reflects a reduction in the share of renewables in gross electricity consumption from 14.3 per cent in 2009 to 13.0 per cent in 2010. Wind and hydro resources were less in 2010 which resulted in more electricity generation from coal and gas-fired power stations. By 2012, wind and hydro energy generation had grown substantially, resulting in a renewables contribution to gross electricity consumption of 19.1 per cent. However, these changes combined with increased consumption of coal and reduction of natural gas resulted in an increase in emissions from the Energy Industries sector of 7.0 per cent between 2011 and 2012, from 11,968.0 kt CO_2 eq to 12,810.5 kt CO_2 eq, respectively. In 2013 emissions from this sector decreased by 10.6 per cent on 2012 levels to reach 11,449.2 kt CO_2 eq, which reflects further increase in the share of renewables in gross electricity consumption with 20.2 per cent contribution in 2013. Emissions in 2014 were 11,244.3 kt CO_2 eq (1.8 per cent decrease on 2013 levels) reflecting a decrease in the consumption of coal and a further increase in the share of renewables in gross electricity consumption to 22.9 per cent. In 2015, emissions were 5.4 per cent above those in 2014 at 11,853.5 kt CO_2 eq, the main driver of which was an 18.8 per cent increase in the combustion of coal in Ireland's only coal fired electricity generation plant. Emissions in 2016 were 12,575.0 kt CO_2 eq, a 6.1 per cent increase on 2015 levels. This reflects a decrease in the share of renewables in gross electricity consumption from 27.3 per cent in 2015 to 25.5 per cent in 2016 and a 24.1 per cent increase in natural gas consumption for power generation in 2016. Emissions in 2020 were 8,635.0 kt CO_2 eq, a decrease of 7.5 per cent on 2019 mainly due to a decrease in peat combustion and an increase in renewable electricity generation. Emissions in 2021 were 10,171.0 kt CO_2 eq, an increase of 17.8 per cent on 2020 per cent mainly due to an increase in coal combustion and a decrease in natural gas and renewable electricity generation. In 2022, 1.A.1 emissions decreased by 1.8 per cent to 9,988.6 kt CO_2 eq reflecting a 16.1 per cent decrease in coal use and a corresponding 12.6 per cent increase in natural gas use in electricity generation.

Overall drivers and trends in emissions from the Energy sector are presented in Figure 2.4 and Figure 2.5.

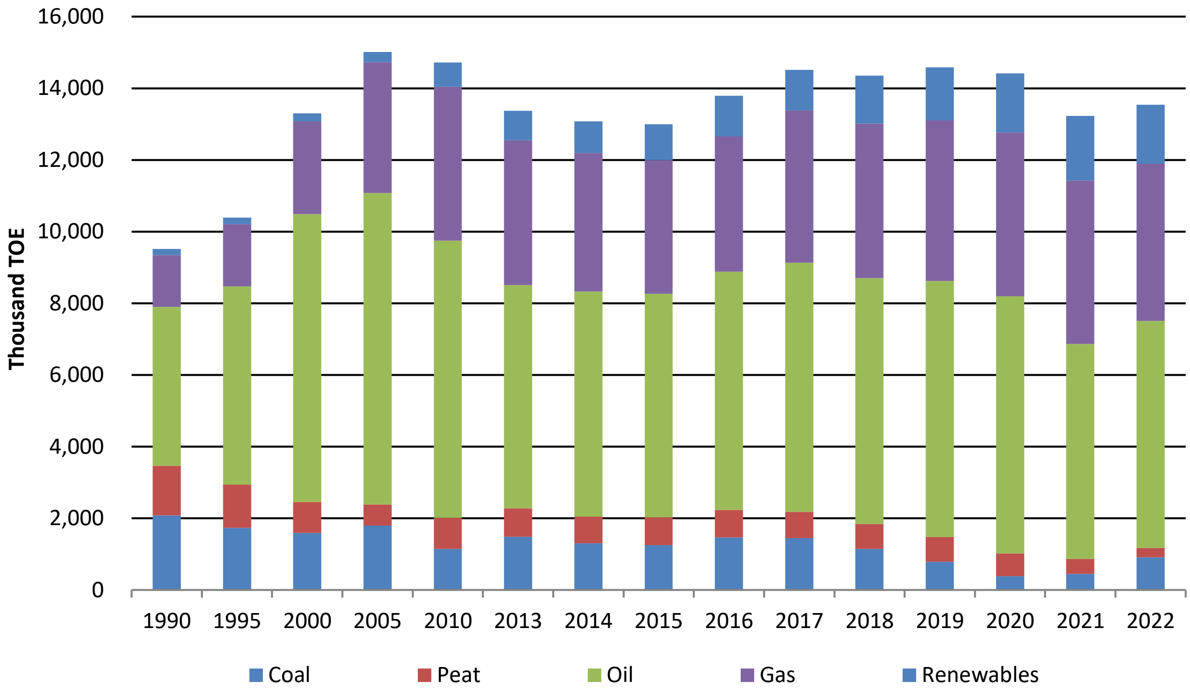


Figure 2.4 Total Primary Energy Requirement (TPER) 1990-2022

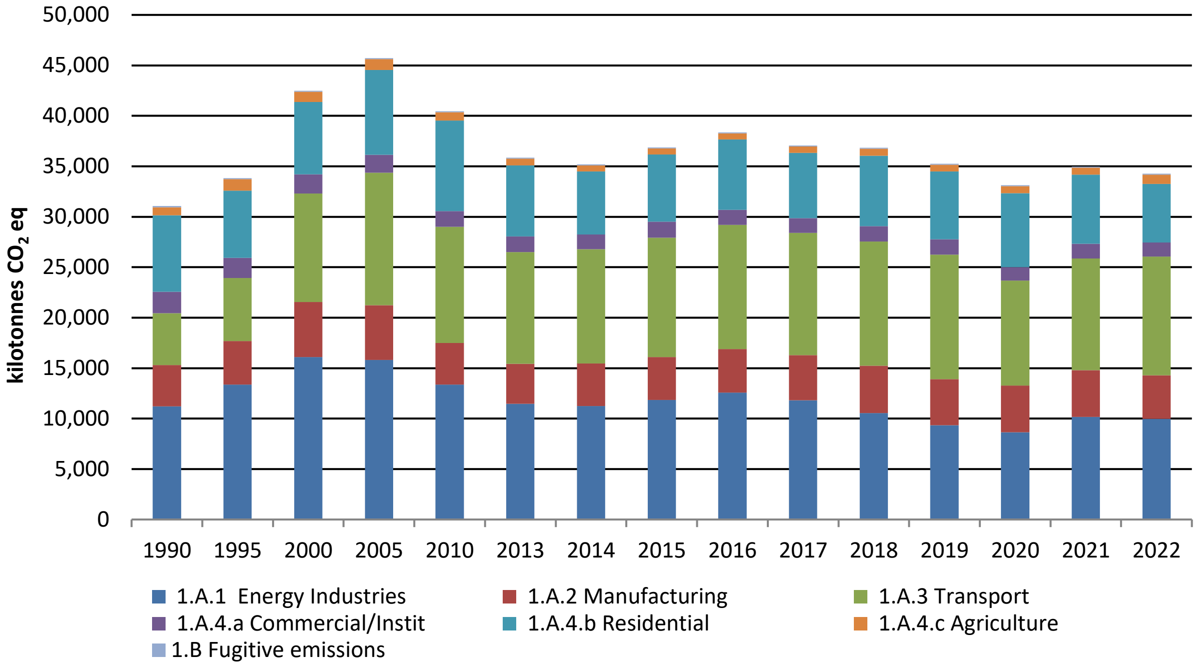


Figure 2.5 Trend in Emissions from Energy 1990-2022

There are only a small number of energy intensive industries in Ireland under sub-category 1.A.2 Manufacturing Industries and Construction. This sub-category accounted for 7.4 per cent (4,074.4 kt CO_2 eq) and 7.1 per cent (4,302.1 kt CO_2 eq) of total national greenhouse gas emissions in 1990 and 2022, respectively. The trend shows an increase of 5.6 per cent over the same period as a result of large increases in use of petroleum coke in 1.A.2.f Non-metallic minerals and natural gas in 1.A.2.b Non-ferrous metals, 1.A.2.e Food Processing, Beverages and Tobacco and 1.A.2.g Other Industries. Emissions from the sector were increasing in the trend and remained at their highest between the years 2000 and 2008 with their peak at 5,427.1 kt CO_2 eq in 2005. Following an economic downturn, emissions sharply declined by 19.7 per cent between 2008 and 2009, from 5,127.8 kt CO_2 eq to 4,116.5 kt CO_2 eq, respectively and continued to decline until 2012 (3,805.0 kt CO_2 eq), followed by increases in 2013 and 2014, by 4.9 per cent, and 10.8 per cent as compared to 2012 levels when manufacturing industry started to recover from recession. Emissions in 2022 were 13.1 per cent above those in 2012 and 6.8 per cent below last year's emissions.

Fuel combustion emissions in 1.A.3 Transport accounted for 9.3 per cent and 19.4 per cent of total national greenhouse gas emissions in 1990 and 2022, respectively. The overall sector's emissions increased by 128.4 per cent from 5,143.3 kt CO_2 eq in 1990 to 11,751.3 kt CO_2 eq in 2022. This is largely accounted for by a 132.6 per cent increase in road transport emissions over the same period, due to sustained growth in the use of passenger cars and goods vehicles. The trend is however, somewhat exaggerated by so-called fuel tourism whereby a proportion of the automotive fuel sold in the Republic of Ireland is used in vehicles in the UK and other countries. Fuel tourism is estimated to have accounted for 1.1 per cent of petrol and 6.5 per cent of diesel sales in 2022. It is worth noting that in the years 1990-1995 inclusive there was cross border movement of automotive fuels into the Republic of Ireland.

The principal drivers in road transport emission trends are shown in Figures 2.6 and 2.7. Transport emissions were 2,635.1 kt CO_2 eq lower in 2022 than in 2007. This represents a decrease of 18.3 per cent, following sustained increases in this sector since 1990. The decrease primarily reflects the impact of the economic downturn plus the changes in vehicle registration tax and road tax introduced in mid-2008 and the Biofuels Obligation Scheme and a 15.7 per cent decrease in transport emissions in 2020 due to COVID restrictions. Road transport emissions have rebounded since the lifting of COVID restrictions, with emissions increasing by 6.6 per cent in 2021 and a further 6.7 per cent in 2022.

Emissions from domestic aviation decreased by 55.5 per cent between 1990 (48.4 kt CO_2 eq) and 2022 (21.5 kt CO_2 eq), having peaked in 2006 at 92.0 kt CO_2 eq. However, their overall effect on transport emission trends is negligible.

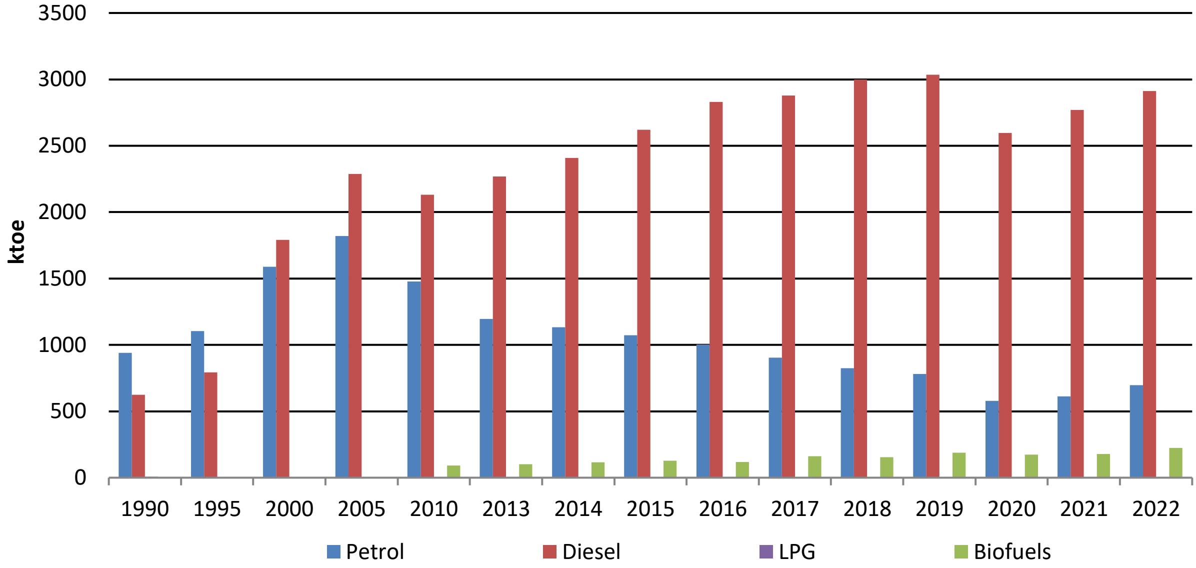


Figure 2.6 Fuel use in Road Transport 1990-2022

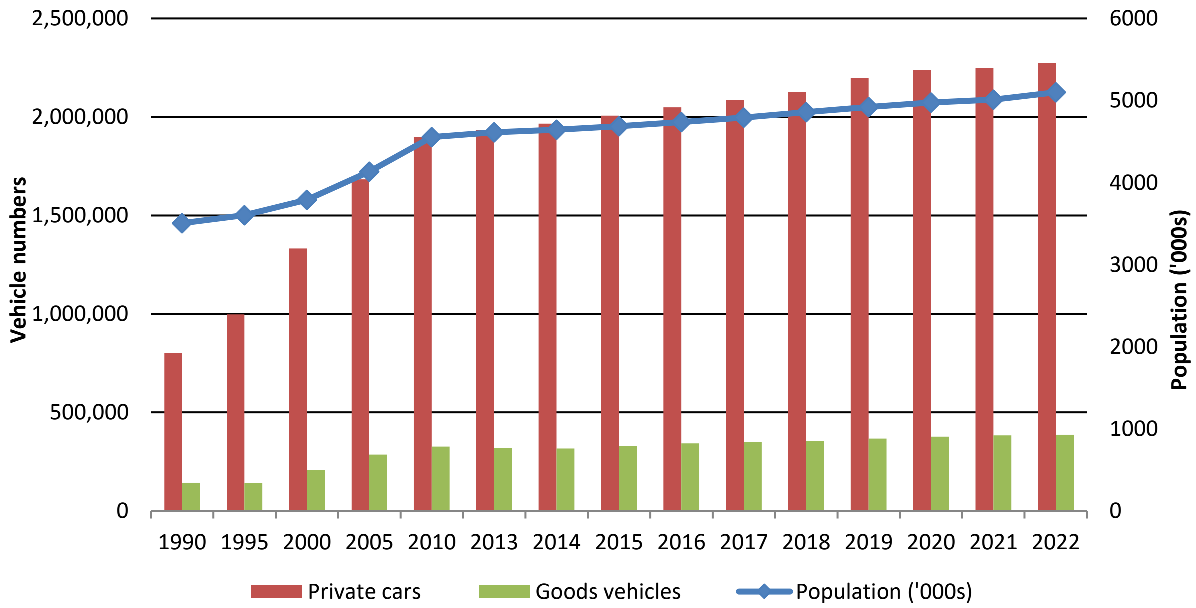


Figure 2.7 Vehicle numbers and Census of Population 1990-2022

Emissions from category 1.A.4 Other Sectors decreased by 22.7 per cent from 10,515.3 kt CO_2 eq in 1990 to 8,129.5 kt CO_2 eq in 2022. Emissions from the Commercial (1.A.4.a), Residential (1.A.4.b) sub-categories decreased by 33.3, 23.6 per cent whilst Agriculture/Fishing (1.A.4.c) increased by 13.5 per cent, respectively between 1990 and 2022. Fuel-switching is evident as the emissions of CO_2 from coal and peat use in the residential sector decreased by 79.6 per cent and 77.8 per cent, respectively between 1990 and 2022 while those from oil and natural gas increased by 208.5 per cent over this period.

2.3.2 Trends in Industrial Processes and Product Use (IPCC Sector 2)

The contribution from Industrial Processes and Product Use (IPPU) is relatively small, accounting for 5.8 per cent of total greenhouse gases in 1990 and 5.0 per cent in 2022. Total emissions from the sector were 3,198.3 kt CO_2 eq in 1990 and 3,029.4 kt CO_2 eq in 2022. This is a decrease of 5.3 per cent in emissions over the time series. Overall trends in emissions from IPPU are presented in Figure 2.8.

In the early 1990's (1990 to 1994) the contribution of 2.B Chemical Industry to overall sectoral emissions was on average 58.2 per cent. By the late 1990's (1995 to 1999) this proportion had fallen to 49.1 per cent on average of total emissions from the sector. In 1990 emissions from 2.B. Chemical Industry were 1,875.3 kt CO_2 eq, however by 2000 they had reduced by 15.9 per cent to 1,576.8 kt CO_2 eq and by further 32.7 per cent in 2002 that was the last year of the chemical plant being operational for a full year before being closed in 2003. Over the same period Ireland was experiencing increased levels of economic growth, the knock-on effect of which was an increase in construction and therefore an increased need for building products such as cement. In the period 1990-2000 emissions from cement production (2.A.1), which are reported under 2.A Mineral Products, increased by 92.4 per cent; from 884.0 kt CO_2 to 1,700.9 kt CO_2. Economic growth was sustained into the early years of the new millennium with associated increases in emissions from the sector, during which two new cement production plants were commissioned, with one opening in 2000 and the other in 2003. This resulted in further growth in emissions from the cement sector to reach peak of 2,374.1 kt CO_2 in 2007 (an increase of 168.6 per cent from 1990). Due to the economic recession, emissions from sector 2.A.1 decreased by 59.3 per cent between 2007 and 2011 to reach 966.3 kt CO_2. Emissions have subsequently risen to 1,956.5 kt CO_2 in 2022 (and increase of 102.5 per cent between 2011 and 2022), reflecting economic recovery.

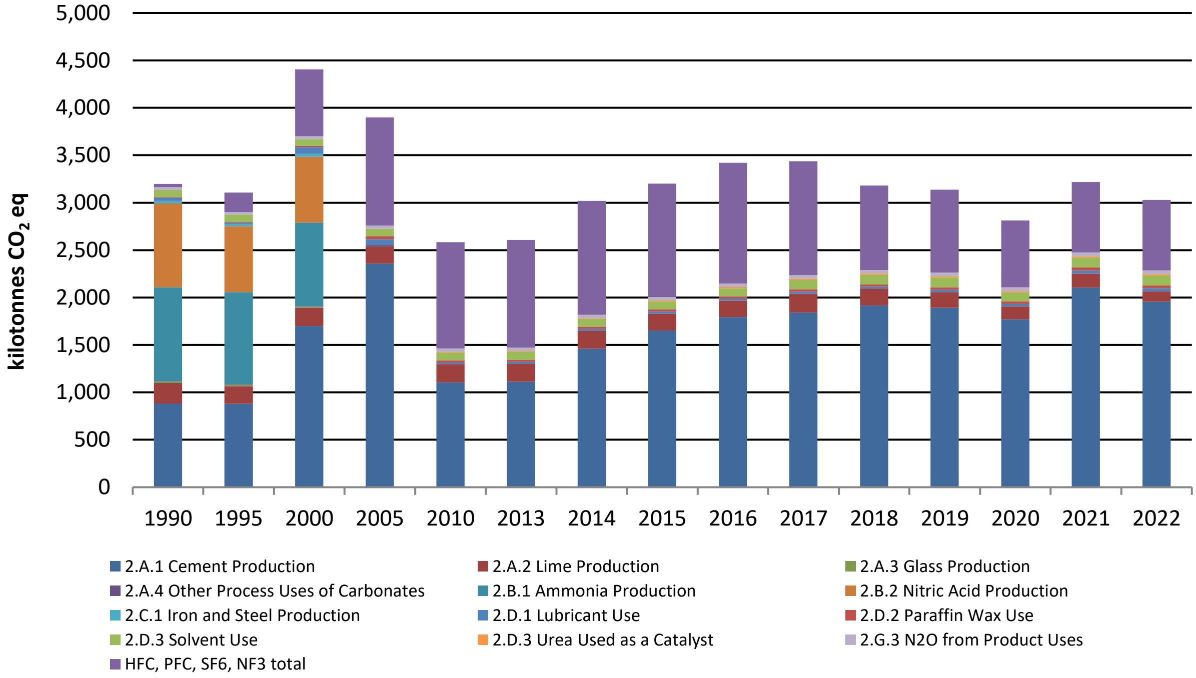


Figure 2.8 Trend in Emissions from Industrial Processes and Product Use 1990-2022

The closure of Ireland's nitric acid and ammonia plants in 2002 and 2003, respectively, significantly changed the level of process emissions in Ireland. As a result, CO_2 emissions from cement production (2.A.1) became the single major component of sector emissions and these emissions increased steadily during the period of economic growth up to 2007, the year when they reached a peak of 2,374.1 kt CO_2 eq (and 61.0 per cent share of the IPPU sector). Emissions from cement manufacture then decreased in line with the economic downturn, accounting for 57.9 per cent of total emissions from IPPU sector in 2008, falling to a 39.3 per cent contribution in 2011. However, emissions in 2012 increased, reflecting economic recovery and were followed by a small decrease in 2013, and increased again in 2014 to 2018. The contribution from cement manufacture to emissions from IPPU sector in 2022 is now 64.6 per cent.

Other sources of emissions within 2.A Mineral Products in Ireland are 2.A.2 Lime Production, 2.A.3 Glass Production (ceased in 2009) and 2.A.4 Other process uses of carbonates (Bricks, Ceramics, Soda Ash and Limestone use), which collectively accounted for 3.7 per cent of total IPPU sector emissions in 2022. The emissions from these sub-categories are small and their effect on overall trends is negligible.

The Non-Energy Products from Fuels and Solvent Use sector 2.D includes emissions from 2.D.1 Lubricant use, 2.D.2 Paraffin Wax use and indirect CO_2 emissions from 2.D.3 Solvent use. In 2022 sector 2.D accounted for 5.9 per cent of IPPU sector, having increased by 53.4 per cent from 116.7 kt CO_2 eq in 1990 to 179.1 kt CO_2 eq in 2022. However, the largest contributing sector in 2D, Non-Energy Products from Fuels and Solvent Use sector with 0.3 per cent share of total national greenhouse gas emissions in 2022 does not affect the overall trend in greenhouse gases in Ireland. The sector in Ireland is largely represented by domestic use of solvents, paint application, degreasing, dry cleaning, printing, chemical products manufacture and processing and the food and beverage industry.

Emissions from 2.F Product Uses as Substitutes for Ozone Depleting Substances were estimated to be 662.9 kt CO_2 eq in 2022 and not occurring in 1990. 2.F.4 Aerosols was the only source of emissions in 2F from 1990 to 1992, showed a steady growth until 2006 where it peaked at 147.2 kt CO_2. It showed a gradual decrease afterwards to reach a level of 52.7 kt CO_2 eq in 2022. 2.F.1 Refrigeration and Air Conditioning was reported first in 1993 having an emissions level of 0.5 kt CO_2 eq which increased sharply to peak at 1,049.5 kt CO_2 eq in 2016. Emissions have declined significantly since then due to the use of lower GWP F-gases in this sector. Emissions are now at 576.3 kt CO_2 eq in 2022, a 45.1 per cent reduction since 2016. 2.F.3 Fire Protection was reported first in 1996 and showed a slow increase from 1.6 kt CO_2 eq to 33.8 kt CO_2 eq from 1990 to 2022.

2.3.3 Trends in Agriculture (IPCC Sector 3)

The trend in emissions from the Agriculture sector is presented in Figure 2.9. Emissions of greenhouse gases from the Agriculture sector amounted to 19,256.5 kt CO_2 eq in 1990 and 22,436.8 kt CO_2 eq in 2022, an increase of 16.5 per cent. Between 1990 and 1998, the total emissions from the Agriculture sector increased by 14.5 per cent, reflecting an increase in animal numbers and increased synthetic nitrogen use on farms. Following this peak in emission levels of 22,040.8 kt CO_2 eq in 1998, emissions from the sector decreased by 15.9 per cent to 18,525.6 kt CO_2 eq in 2011. The decrease post-1998 was a result of reductions in animal numbers and synthetic nitrogen fertiliser use due to reforms of the Common Agricultural Policy. Emissions in 2022 were 22,436.8 kt CO_2 eq, representing a 21.1 per cent increase on the total emissions in 2011. This was primarily driven by an increase in cattle number of 13.7 per cent between 2011 and 2022.

Methane emissions from Agriculture emanate from two sectors 3.A Enteric Fermentation and 3.B Manure Management and are dependent on the type and number of livestock present on farms and in Ireland's case, the amounts are largely determined by a large cattle population. Agriculture accounted for 94.4 per cent of total methane emissions in 2022. The combined total of emissions of CH_4 from enteric fermentation and manure management was 13,986.1 kt CO_2 eq in 1990. This increased by 14.9 per cent to reach 16,074.5 kt CO_2 eq in 1998 and subsequently increased by 3.6 per cent to 16,674.8 kt CO_2 eq in 2022. Cattle account for 87.3 per cent of CH_4 emissions in Irish agriculture in 2022.

The emissions of N_2O from the Agriculture sector follow similar trends to those of CH_4 because cattle also largely determine the amount of nitrogen inputs to agricultural soils from synthetic fertiliser (sector 3.D) and animal manures (sector 3.B), which combined produce the bulk of N_2O emissions (91.2 per cent of total N_2O emissions in 2022). Nitrous oxide emissions in Agriculture increased from 4,818.6 kt CO_2 eq in 1990 by 1.9 per cent yearly in the period 1990-1998 with emissions in 1998 totalling 5,565.3 kt CO_2 eq. Nitrous oxide emissions totalling 5,011.2 kt CO_2 eq in 2022 represent a reduction of 10.0 per cent on the 1998 level and an increase of 4.0 per cent on the 1990 level. Crops contribute very little to N_2O emissions in Ireland and the amount fluctuates annually in response to varying production of the relevant crops.

Carbon dioxide emissions were 750.8 kt CO_2 in 2022 compared to 451.7 kt CO_2 in 1990, a 66.2 per cent increase over the time series. 3.G Liming and 3.H Urea Application are the two subsectors responsible for CO_2 emissions from Agriculture sector accounting for 3.3 per cent share of total CO_2 emissions in 2022.

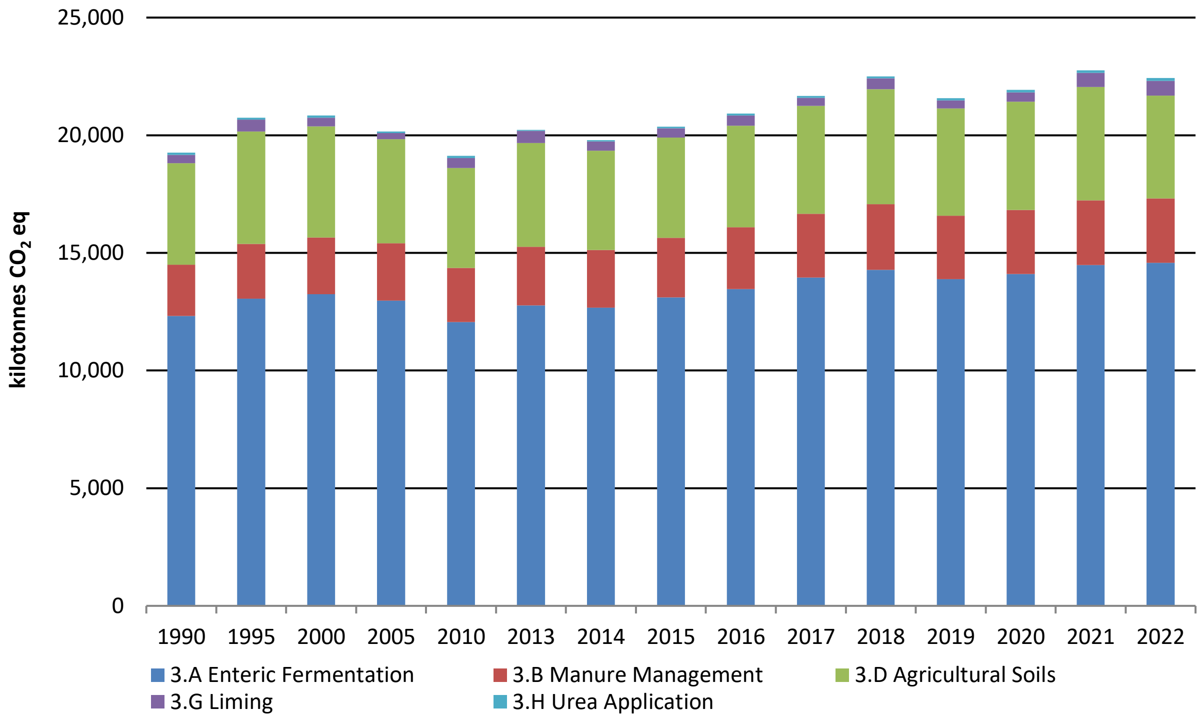


Figure 2.9 Trend in Emissions from Agriculture 1990-2022

2.3.4 Trends in Land Use, Land Use Change and Forestry (IPCC Sector 4)

The full assessment of emissions and removals in the LULUCF sector has given a new understanding of the relative contributions of sub-categories in this sector. In addition, this assessment has identified several land-use categories that are important in terms of either emissions or removals of CO_2. This sector is a net source of carbon in all years (Table 2.1 and Figure 2.10). This result is determined largely by the CO_2 emissions from 4.A Forest Land, which is a major carbon sink, and 4.C Grasslands and 4.D Wetlands which are major sources of emissions due to drainage of organic soils, Harvested Wood Products are a sink of carbon for all years. The complex dynamics of land-use changes between categories and the relative contributions from biomass and soils lead to highly fluctuating estimates of sectoral emissions and removals over the period 1990- 2022.

The increase in carbon stocks in living biomass in the category 4.A.1 Forest Land remaining Forest Land is the dominant removal that offsets CO_2 emissions. The Settlements and Other Land categories are comparatively less important in terms of emissions or removals, but Cropland contribute significant inter annual variability due to sectoral response to external drivers such as potential economic returns for produce.

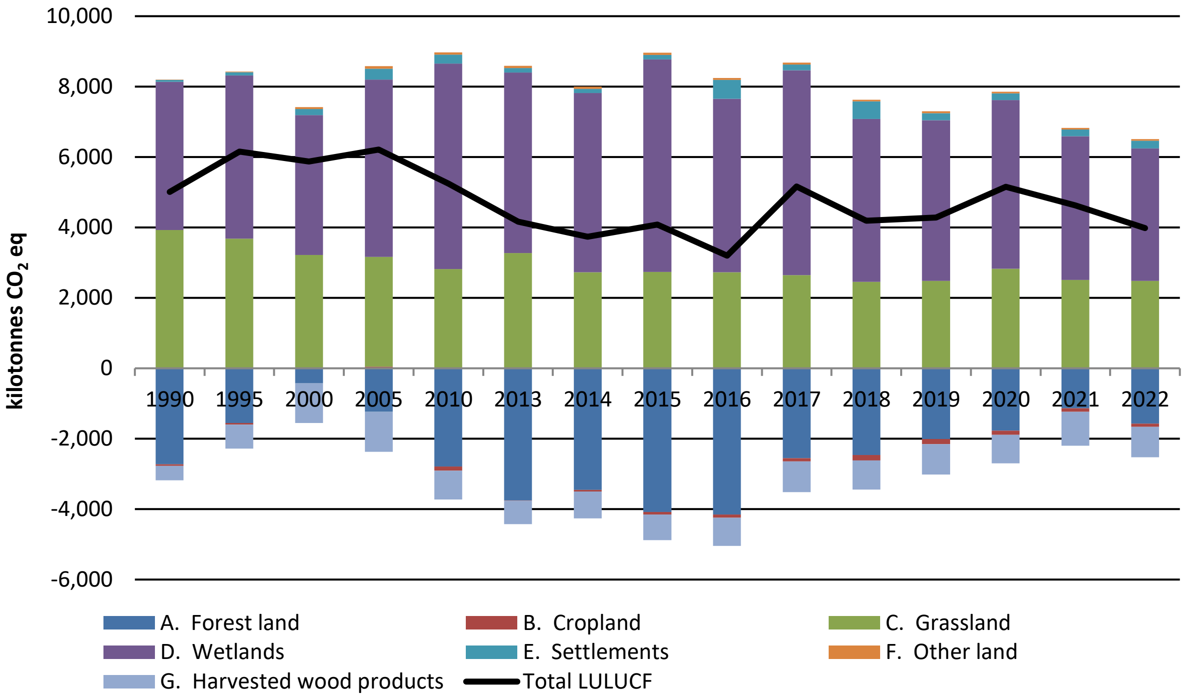


Figure 2.10 Trend in Emissions and Removals from Land Use Land-Use Change and Forestry 1990-2022

2.3.5 Trends in Waste (IPCC Sector 5)

The Waste sector remains an important source of CH_4 emissions (Figure 2.11) due to the continued need of landfills as a means of solid waste disposal in Ireland. Emissions from the waste sector increased by 13.3 per cent from 1,709.2 kt CO_2 eq in 1990 to 1,935.9 CO_2 eq in 2003 (peak) and then decreased by 54.7 per cent to 877.9 kt CO_2 eq in 2022. Overall, emissions in the Waste sector have decreased by 48.6 per cent from 1990 to 2022.

The main contributor to trends in the Waste sector is the CH_4 emissions from municipal solid wastes (MSW) disposed of in solid waste landfills (5.A Solid Waste Disposal on Land) responsible for 72.2 per cent share of Waste emissions in 2022. The decrease in emission levels reflects increasing recovery of landfill gas for energy production and particularly through flaring at landfill sites, without which emissions in this sector would be considerably larger. Biological Treatment of Solid Waste – Composting, however small (5.2 per cent share of Waste emissions in 2022) is a growing source of emissions in Ireland since it commenced in 2001 with emission levels of 3.9 kt CO_2 eq, increasing to 45.7 kt CO_2 eq in 2022. The contribution of this sub-category to overall sectoral trends is negligible.

Since 1990 the quantities of MSW disposed at landfills were between 1.9 to 2.4 million tonnes per annum until 2007. However, the quantities of MSW disposed of at landfills decreased from 2.0 million tonnes in 2008 to 0.5 million tonnes in 2022 due to increased recycling rates and the shift to waste to energy in the last ten years. Total MSW disposed to landfill decreased by 77.4 per cent between 2007 and 2022. The proportion of organic materials (food and garden waste) in MSW has decreased from 39.3 per cent in 1990 to 9.6 per cent in 2022. The proportions of paper and textiles changed from 29.5 per cent and 9.8 per cent, respectively in 1990 to 8.5 per cent and 13.7 per cent, respectively in 2022, reflecting a significant diversion of paper products from landfills. This reduces CH_4 potential, as paper products are the main source of degradable organic carbon in landfills. A major increase in the use of flares as a means of odour control in landfills in recent years offsets a large proportion of the CH_4 generated. This offset from flares and utilisation was 56.6 per cent in 2022, hence there was a 5-fold increase in flaring and utilisation since 1996 (9.9 per cent first year of methane recovery).

Emissions from 5.C Incineration and Open Burning of Waste combined accounted for 97.7 kt CO_2 eq in 1990 and 36.4 kt CO_2 eq in 2022 a decrease of 62.8 per cent which equates to 5.7 and 4.1 per cent of total emissions from the waste sector, respectively in 1990 and 2022. Emissions are reported for clinical waste incineration for all years from 1990-1997, when all hospital waste incinerators were closed. Emissions are also reported for industrial waste incineration, solvent destruction by thermal oxidisers, open burning of waste for all years from 1990-2022. The contribution of this sub-category to the overall sectoral trend is negligible.

Emissions of CH_4 and N_2O from 5.D Wastewater Treatment and Discharge accounted for 135.3 kt CO_2 eq in 1990 and 156.2 kt CO_2 eq in 2022 (15.5 per cent increase on 1990), which equates to 7.9 and 17.8 per cent of total emissions from the waste sector, respectively. The contribution of this sub-category to overall sectoral trends is negligible.

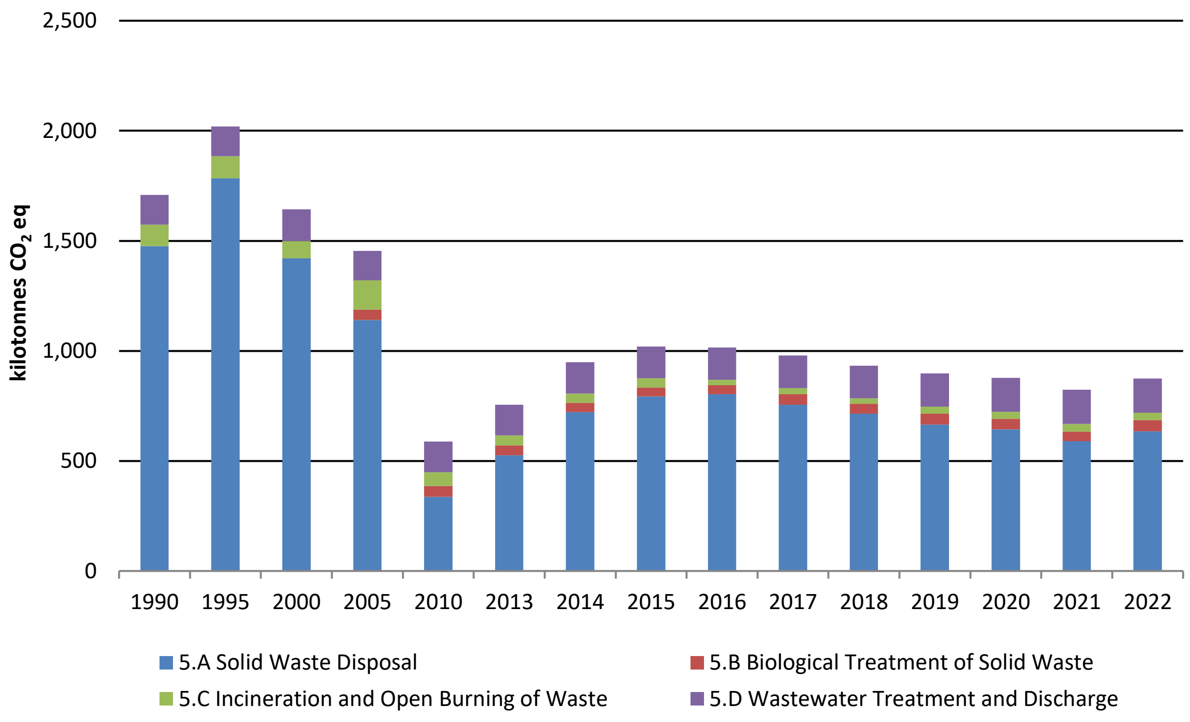


Figure 2.11 Trend in Emissions from Waste 1990-2022

2.4 Emissions of Indirect Greenhouse Gases

The total emissions of SO_2, NO_X, NMVOC and CO for the years 1990 to 2022 are summarised in Table 2.2 and Figure 2.12. As in the case of CO_2, the emissions of SO_2, NO_X and CO in Ireland are dominated by those emanating from fuel combustion activities, while the bulk of NMVOC emissions are generated by agriculture, solvent use and transport. From 1990 to 2022, substantial decreases occurred in the emissions of SO_2 (94.9 per cent) and CO (81.9 per cent). Significant reductions of NO_X emissions (44.0 per cent) and NMVOC (29.4 per cent) also occurred in 2022 in comparison to 1990.

Table 2.2 Emissions of NO_X, SO_2, NMVOC and CO 1990-2022 (Tonnes)

	NOx	SO_2	NMVOC	CO
1990	166,418	183,975	157,169	573,163
1991	168,912	183,890	157,594	561,142
1992	177,647	171,317	152,793	513,258
1993	170,233	162,415	149,984	491,405
1994	170,143	177,313	146,493	452,028
1995	168,644	163,434	144,439	431,589
1996	172,375	150,482	144,890	428,605
1997	167,153	169,265	141,264	390,188
1998	176,420	180,014	143,367	401,537
1999	177,566	161,331	133,843	351,765
2000	179,328	144,604	126,676	340,543
2001	178,191	142,586	126,239	329,791
2002	171,025	106,905	125,828	316,995
2003	169,942	83,034	123,963	302,085
2004	171,759	73,615	123,198	296,425
2005	173,424	74,239	122,707	298,412
2006	168,703	61,978	120,802	278,945
2007	164,754	56,112	120,149	262,273
2008	149,974	46,487	118,226	259,076
2009	125,548	33,285	123,389	243,444
2010	118,821	27,366	113,647	225,360
2011	106,694	25,399	109,982	206,371
2012	108,375	24,040	110,755	198,952
2013	109,924	24,052	112,562	197,334
2014	108,585	18,052	109,367	182,880
2015	111,335	16,504	110,704	182,821
2016	111,290	15,838	112,170	178,143
2017	109,144	15,103	115,228	150,511
2018	110,116	14,193	114,943	144,723
2019	101,891	11,217	114,328	124,306
2020	94,870	10,988	111,298	120,144
2021	98,093	12,909	112,123	120,670
2022	93,176	9,380	110,971	103,998

Total SO_2 emissions decreased from 183,975 tonnes in 1990 to 9,380 tonnes in 2022. This decrease in emissions reflects the economic downturn in recent years, reductions in the sulphur content of fuels, fuel switching and use of abatement technologies. Power stations (1.A.1.a) were the largest source of SO_2 emissions until 2012. However, residential (1.A.4.b) became the largest source of SO_2 emissions having a share of 57.7 per cent of the total in 2022, whereas Power stations (1.A.1a) contributed 19.8 per cent of the total. Combustion sources in the industrial (1.A.2) sector account for a contribution of 17.2 per cent in 2022. In 1990, coal combustion accounted for 51.7 per cent of SO_2 emissions and fuel oil contributed 30.1 per cent. By 2022, the share of SO_2 emissions from coal had decreased marginally to 43.5 per cent and that from fuel oil had decreased to 12.0 per cent.

Road transport (1.A.3.b) is the principal source of NO_X emissions, contributing 27.0 per cent of the total in 2022. The reductions in NO_X emissions delivered by catalytic converters in cars and heavy-duty vehicles have been offset by large increases in vehicle numbers and fuel use in the past 10 years. This effect is exaggerated in latter years by so-called fuel-tourism, whereby a significant proportion of the automotive fuel sold in Ireland is used by vehicles in the UK and possibly to some extent in other countries. Combustion in the industrial (1.A.2) sector is another source of NO_X emissions, in 2022 accounting for 8.8 per cent of emissions, followed by power generation with 8.0 per cent share and combined commercial/residential sectors' 8.4 per cent share in the same year.

The emissions of NMVOC are determined mainly by agriculture sectors (3.B Manure management and 3.D Inorganic fertilisers) contributing 38.7 per cent share of total in 2022. Solvent use (2.D) was responsible for 15.4 per cent share and combined commercial/residential sectors produced 7.2 per cent of the 2022 total NMVOC emissions in Ireland. Technological controls for NMVOCs in motor vehicles have been more successful than in the case of NO_X and have given a significant reduction in emissions from road transport over recent years with contributions of transport to the national total of 24.7 per cent in 1990, falling to 3.4 per cent in 2022.

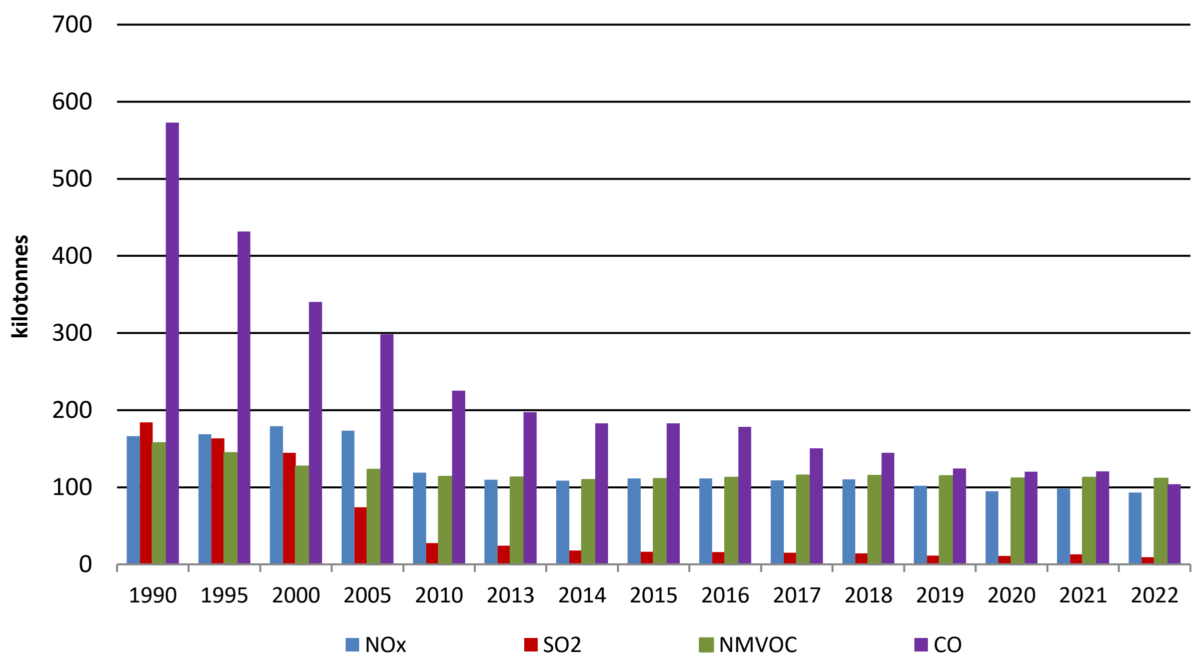


Figure 2.12 Trend in Indirect Greenhouse Gases 1990-2022

Emissions of CO continue to decline, driven by major reductions due to catalysts in gasoline cars, which are the principal sources of CO emissions. A substantial decline in the CO emissions figures over the period of 1990 to 2022 was observed due to a reduction of solid fuels for space heating in the residential sector. The commercial and residential sectors combined are the largest source and contributed 61.3 per cent to 2022 total. In 2022, Road transport (1.A.3.b) contributed to 16.7 per cent of the total CO emissions. Further reductions in the emissions of SO_2, NO_X and NMVOC will occur in the coming years as Ireland continues to implement programmes to comply with various EU legislation aimed at air quality improvement and emissions control.

Chapter 3 Energy

3.1 Overview of Energy Sector

The list of activities under *Energy* in the IPCC reporting format is given in Table 3.1 below. A summary of emissions from these activities are given in Table 3.2, Figure 3.1 and Figure 3.2 below.

The *Energy* source category covers all combustion sources of CO_2, CH_4 and N_2O emissions and the fugitive emissions of these gases associated with the production, transport and distribution of fossil fuels.

Estimates are included for all emission sources that occur in Ireland and the required level of disaggregation is achieved for detailed completion of the CRF tables.

3.1.1 Emissions Overview

A summary of emissions from this sector is given in Table 3.2, Figure 3.1 and Figure 3.2 below.

Emissions from *Energy* accounted for 56.2 per cent and 56.5 per cent of total national emissions (including indirect CO_2, without *LULUCF*) in 1990 and 2022, respectively. This sector accounted for 91.7 per cent of total CO_2 emissions, 1.4 per cent of CH_4 emissions and 6.0 per cent of N_2O emissions in 2022. CO_2 emissions make up 98.3 per cent of the total for the sector in 2022.

There are 16 key categories by level assessment and 17 key categories by trend assessment in this sector (see Annex 1 for further details) all of which are encompassed in the following categories:

- ***1.A.1 Energy Industries*** is a significant activity in Ireland, which peaked in 2001 corresponding to the height of coal consumption and has since decreased with the increased share of natural gas and renewables. While there was an increase in emissions in 2012 and 2015 in the sector due to the increasing use of coal, electricity generation in Ireland saw a dramatic reduction in coal use between 2016 and 2020. This was followed by a tripling of coal and oil use in 2021 as gas fired plants were offline, causing a 17.8 per cent increase in emissions for that year. Emissions in the Energy Industries sector decreased by 1.8 per cent or 182.4 kt CO_2eq in 2022. This is attributable to reductions in coal and oil use from 2021 levels.
- ***1.A.2 Manufacturing Industries and Construction*** emissions peaked in 2005 with a significant reduction between 2008 and 2011 due to the impact of the economic downturn. Emissions slowly increased from 2012 to 2018 before stabilising up until 2022. Manufacturing Industries and Construction emissions achieved a 6.8 per cent reduction in 2022 driven by reductions in natural gas combustion in the sector.
- ***1.A.3.b Road Transport*** liquid fuel consumption increased until it peaked in 2007 after which it declined until 2012 with a subsequent return to growth in emissions thereafter until 2016. The trends appear to follow Ireland’s economic growth patterns whereas the 4 years 2016-2019, we have seen emissions relatively stable despite increases in vehicle numbers. This is a result of improved vehicle technologies and increased biofuel penetration. In 2020, there were reductions in road transport emissions due to restrictions on passenger car journeys as a result of the Covid restrictions, with emissions dropping by 16.7 percent. Travel restrictions lessened in 2021 and emissions rose by 6.6 per cent and with restrictions ending in 2022,

emissions again rose 6.7 per cent. Following the rebounding of emissions, road transport at the end of 2022 equates to approximately 95 per cent of pre-covid emission levels.

- ***1.A.4 Other Sectors*** dominated by residential fuel combustion, emissions peaked in 2008 and showed a downward trend in the following years. Economic downturn combined with a switch from coal and peat to less carbon intensive fuels (natural gas and oil) and renewables were the reasons for the decrease in emissions. Emissions in 2020 increased by approximately 4.6 per cent compared to 2019 but with a greater return to the workplace in 2021 emissions reduced again by 3.6 per cent compared to 2020. This trend continued in 2022 with a further reduction of 9.6 per cent driven by further fuel switching away from solid fuels to heat pumps and an increased return to the workplace. Other non-key categories in this sector include:
    - ***1.A.3.a Domestic Aviation*** peaked in 2006 after which emissions have significantly declined due to the reduction in the number of domestic flights due to the improvement of the national motorway network.
    - ***1.A.3.c Railways*** is a minor source of emissions and has remained relatively stable across the timeseries with no significant changes to the rail network in Ireland over this time.
    - ***1.A.3.d Domestic Navigation*** emissions from this minor source steadily grew across the timeseries.
    - ***1.A.3.e Other Transportation*** account for emissions from pipeline transportation of natural gas.
    - ***1.B Fugitive emissions*** include emissions from coal mining and handling and emissions from the oil and gas industries.

The greenhouse gases relevant to *Energy* sector are as follows:

- ***Carbon Dioxide*** emissions which make up 98.3 per cent of total GHG emissions from this sector and originate from all activities involving the combustion of fossil fuels. There was a significant decrease in emissions from 2008-2009 due to the economic downturn. Emissions have decreased in 2022 due to decreased emissions from Manufacturing Industries and Construction, residential, and in the power generation sectors.
- ***Nitrous Oxide*** emissions originate from all combustion sources with emissions from road transport and public electricity and heat production being the most significant sources in 2022.
- ***Methane*** emissions originate from all combustion sources with emissions from solid fuel use in residential combustion being the most significant source.

3.1.2 Methodology Overview

The combustion of fossil fuels accounts for the bulk of CO_2 emissions in most countries. The CO_2 emissions are quantified with reasonable accuracy as the fuel amounts are detailed in the energy balance sheets and information on their carbon contents is well established. The total amount of CO_2 released from combustion can therefore be readily ascertained.

Only small amounts of CH_4 and N_2O are associated with fuel combustion activities. The emissions of these gases are generally not quantified with the same reliability as the emissions of CO_2 because the rates of CH_4 and N_2O production depend on several factors, in addition to fuel type, and consequently there is considerable uncertainty in the available emission factors for these gases.

The overall approach and methodologies used to estimate emissions in the *Energy* sector are in line with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (2006 IPCC Guidelines). For all years since 2005, CO_2 estimates reported under the EU Emissions Trading Scheme (ETS) are used to achieve complete bottom-up results in respect of some important sub-categories in this sector. This is a significant advance in terms of accuracy as the EU ETS estimates are verified and they represent a large proportion of the total emissions from the *Energy* sector.

Ireland's energy data in the expanded energy balance sheets (Table 4.B of Annex 4) are well disaggregated according to fuel and sector for the purposes of estimating emissions in the IPCC Level 3 source categories in a top-down approach. Supplementary sources of information facilitate the use of bottom-up methods in some important sub-categories and they provide greater detail in the overall fuel-sector matrix, making it more compatible with the inventory reporting format required for the Sectoral Approach.

The simple calculation spread sheet given in Table 3.1.1 of Annex 3.1.A shows how the emissions from combustion sources are computed for the year 2022 using the activity data and emission factors described below. The complete allocation to IPCC Level 1 source categories is readily achieved from this compilation, as shown in Table 3.1.2 of Annex 3.1.A. The correspondence between the national disaggregation of sources and IPCC combustion source categories is given in Table 3.1.3 of Annex 3.1.A.

All CO_2 emission factors for fuel combustion in the present submission, except in the case of biomass, are country-specific values, regardless of methodological tier used, which are determined directly from information on the carbon contents and net calorific values of the fuels used in stationary and mobile sources. Information on CO_2 emission factors and net calorific values are available for liquid, solid and gaseous fossil fuels in Table 4.C of Annex 4. The CO_2 emission factor for natural gas takes into account the increasing contribution of imported gas in the national total given by the energy balance. The importation of natural gas from the UK began around 1993 and imported gas accounted for 96.3 per cent of the total in 2015. However, the share of imported natural gas was significantly reduced in recent years with the opening of the natural gas refinery for the Corrib gas field in 2015, and now accounts for 74.0 per cent in 2022. The CO_2 emission factor appropriate to the split between domestic and imported natural gas, which is more carbon intensive, is now used for all years from 1993 to 2022.

The annual returns to the EPA's OES by participants in the EU Emissions Trading Scheme under Directive 2009/29/EC (EP and CEU, 2009, amending Directive 2003/87/EC) comprise an important source of information on CO_2 emissions and emission factors that is now fully utilised for the national inventory compilation. The fuel combustion CO_2 emission factors for solid fuels used by participants under ETS take account of the fact that a very small fraction (typically less than 1 per cent) of fuel carbon may remain un-oxidised and IPCC oxidation factors appropriate to these fuels are applied when estimating the emissions under the scheme. Complete oxidation of carbon is assumed in the case of liquid and gaseous fuels. For other stationary combustion sources, where activity data are in general top-down fuel use quantities taken from the energy balance, the inventory agency adopts the approach that no specific allowance is needed for un-oxidised carbon in the calculation of CO_2

emissions. Default CO_2 emission factors from the 2006 IPCC Guidelines are used only for biomass, which almost invariably refers to wood and wood wastes.

For stationary sources and all mobile sources except road traffic, Ireland relied largely on the default emission factors for CH_4 and N_2O available from the CORINAIR/EMEP Emission Factor Guidebook (McInnes, 1996 and Richardson, 1999) in preparing the submissions up to 2009. A comprehensive internal review of CH_4 and N_2O emission factors was undertaken in 2009 (Annex C NIR 2011), which led to substantial revisions of these emission factors across stationary combustion sources in general so that they now conform to the latest available 2006 IPCC Guidelines values.

Table 4.B of Annex 4 shows the national energy balance sheets for 2022, published by Sustainable Energy Authority of Ireland (SEAI), which form the key activity data for the *Energy* sector. The energy statistics are compiled using a combination of top-down and bottom-up methods and the 2022 example indicates the same form of expanded balance sheet as previously used for all years from 1990.

A full description of the stakeholders and the process used to compile energy statistics in Ireland is described in Annex 4.A. The balance sheets reflect revisions made by SEAI over recent years following a programme to harmonise national energy balances in compliance with the needs of the International Energy Agency (IEA) and EUROSTAT and to facilitate their wider use nationally. The energy balances incorporate additional sectoral disaggregation specific to the needs of the greenhouse gas inventory, following close collaboration between SEAI and the inventory agency. The annual submission of up-to-date energy balances from SEAI to the inventory agency is one of the primary data inputs covered by the Memorandum of Understanding (MOU) in Ireland's national system. A fully consistent set of energy balance sheets for the years 1990-2022 underlies the estimates of emissions for *Energy* in this submission.

Table 3.1 Level 3 Source Methodology for Energy

1. Energy	***CO_2***	**CH_4**	**N_2O**
A. Fuel Combustion			
1. Energy Industries			
*a. Public Electricity and Heat Production**	T1, T3*	T1, T2	T1, T2
b. Petroleum Refining	T3	T1	T1
c. Manufacture of Solid Fuels and Other Energy Industries	T3	T1	T1
2. Manufacturing Industries and Construction			
a. Iron and Steel	T2, NA	T1, NA	T1, NA
*b. Non-Ferrous Metals**	T1, T2*	T1	T1
*c. Chemicals**	T2*	T1	T1
d. Pulp, Paper and Print	T2	T1	T1
*e. Food Processing, Beverages and Tobacco**	T1, T2*	T1	T1
*f. Non-metallic minerals**	T1, T2, T3*	T1	T1
*g. Other**	T1, T2*	T1	T1
3. Transport			
a. Domestic Aviation	T3	T2	T2
*b. Road Transportation**	T2, T3*	T3	T3
c. Railways	T2	T1	T1
d. Domestic navigation	T2	T1	T1
e. Other transportation	T2	T1	T1
4. Other Sectors			
*a. Commercial/Institutional**	T2*	T1	T1
*b. Residential**	T2*	T1*	T1
*c. Agriculture/Fishing**	T1, T2*	T1	T1
5. Other	NA	NA	NA
B. Fugitive Emissions from Fuels			
1. Solid Fuels			
a. Coal mining and handling	NA	T1	NA
b. Solid Fuel Transformation	NA	NA	NA
c. Other	NA	NA	NA
2. Oil and Natural Gas			
a. Oil	NA	T1	NA
b. Natural gas	CS, T3	CS, T3	NA
c. Venting and Flaring	CS, T3	CS, T3	CS, T3
d. Other	NA	NA	NA

* Key Category

T1, T2, T3: Tier 1, Tier 2, Tier 3 as described in the 2006 IPCC Guidelines

NA: “not applicable” because emissions of the gas do not occur in the source category

Table 3.2 Emissions from Energy 1990-2022

		Gas	Unit	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
1.A.1.a	Public Electricity and Heat Production	CO2, CH4, N2O	kt CO2 eq	10946.8	13125.6	15747.2	15234.8	12880.0	10993.5	10831.3	11380.3	12136.1	11362.0	10100.0	8953.8	8242.1	9795.9	9613.4
1.A.1.b	Petroleum Refining	CO2, CH4, N2O	kt CO2 eq	168.7	181.3	274.8	411.8	310.5	294.6	279.5	358.7	313.6	311.2	322.2	274.5	301.0	294.4	308.3
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries	CO2, CH4, N2O	kt CO2 eq	100.5	69.4	87.1	171.9	173.3	161.1	133.6	114.5	125.4	128.7	118.5	107.2	91.8	80.8	66.9
1.A.2.a	Iron and Steel	CO2, CH4, N2O	kt CO2 eq	175.9	18.7	18.8	2.4	2.4	2.3	2.4	2.4	2.3	2.3	2.3	2.3	2.4	2.4	2.4
1.A.2.b	Non-Ferrous Metals	CO2, CH4, N2O	kt CO2 eq	811.3	1183.0	1345.9	1134.3	1588.0	1376.8	1334.8	1350.1	1330.2	1387.6	1402.1	1394.2	1502.2	1371.1	1214.7
1.A.2.c	Chemicals	CO2, CH4, N2O	kt CO2 eq	411.3	343.7	458.4	452.8	370.5	354.2	365.3	377.4	387.2	360.1	386.9	389.8	395.0	404.3	369.1
1.A.2.d	Pulp, Paper and Print	CO2, CH4, N2O	kt CO2 eq	28.5	57.2	95.5	37.5	21.6	21.5	21.3	17.1	22.4	29.0	38.4	18.1	29.0	19.1	18.9
1.A.2.e	Food Processing, Beverages and Tobacco	CO2, CH4, N2O	kt CO2 eq	1021.3	1132.6	1522.4	1072.9	856.5	914.0	911.1	959.1	981.1	1052.9	1086.8	1045.9	1109.9	1088.4	1065.7
1.A.2.f	Non-metallic minerals	CO2, CH4, N2O	kt CO2 eq	822.7	487.2	691.1	1777.4	785.0	834.1	1046.3	1103.1	1135.4	1129.6	1224.2	1189.4	1074.4	1243.8	1143.7
1.A.2.g	Other	CO2, CH4, N2O	kt CO2 eq	803.4	1067.2	1293.8	949.9	503.1	489.2	534.5	438.5	467.9	511.1	549.7	539.2	538.0	484.4	487.6
1.A.3.a	Domestic Aviation	CO2, CH4, N2O	kt CO2 eq	48.4	45.7	69.6	80.1	49.5	15.4	14.7	15.6	16.8	17.5	16.8	18.0	14.0	19.7	21.5
1.A.3.b	Road Transportation	CO2, CH4, N2O	kt CO2 eq	4788.8	5877.9	10356.6	12543.4	10980.7	10584.4	10832.1	11318.6	11753.7	11625.6	11762.5	11750.4	9793.5	10438.4	11139.0
1.A.3.c	Railways	CO2, CH4, N2O	kt CO2 eq	147.2	123.1	136.1	135.0	134.8	129.9	119.2	121.4	123.7	127.7	129.0	135.0	107.6	116.3	130.0
1.A.3.d	Domestic navigation	CO2, CH4, N2O	kt CO2 eq	85.7	92.0	152.6	211.1	200.0	179.5	224.7	221.6	266.3	235.1	260.1	277.0	338.7	362.2	305.6
1.A.3.e	Other transportation	CO2, CH4, N2O	kt CO2 eq	73.2	125.0	61.7	152.6	161.3	145.1	145.7	137.2	135.4	127.0	140.1	142.1	147.7	151.9	155.1
1.A.4.a	Commercial/Institutional	CO2, CH4, N2O	kt CO2 eq	2133.2	1995.8	1889.1	1767.8	1541.3	1547.5	1443.6	1578.6	1500.3	1439.6	1540.5	1536.6	1326.9	1436.5	1422.0
1.A.4.b	Residential	CO2, CH4, N2O	kt CO2 eq	7571.3	6647.8	7176.1	8395.5	8982.8	7057.5	6252.6	6691.3	6976.7	6482.0	6976.3	6701.7	7325.7	6878.7	5787.4
1.A.4.c	Agriculture/Fishing	CO2, CH4, N2O	kt CO2 eq	810.9	1156.2	1013.5	1088.6	821.9	668.1	603.0	574.7	594.9	625.3	674.1	683.2	683.4	681.7	920.1
1.B.1.a	Coal mining and handling	CH4	kt CO2 eq	62.2	37.3	30.3	26.4	23.8	22.6	22.2	21.9	21.6	20.6	20.3	20.0	19.8	19.5	19.3
1.B.2.a	Oil	CO2, CH4	kt CO2 eq	0.2	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.4	0.4	0.4
1.B.2.b	Natural gas	CO2, CH4	kt CO2 eq	56.1	68.4	62.5	55.7	73.2	62.4	75.6	76.9	78.4	84.7	85.9	81.3	82.2	71.0	69.9
	Total Energy			**31,067.5**	**33,835.4**	**42,483.6**	**45,702.3**	**40,460.3**	**35,853.9**	**35,193.7**	**36,859.5**	**38,369.9**	**37,060.0**	**36,837.2**	**35,260.1**	**33,125.6**	**34,961.1**	**34,261.0**

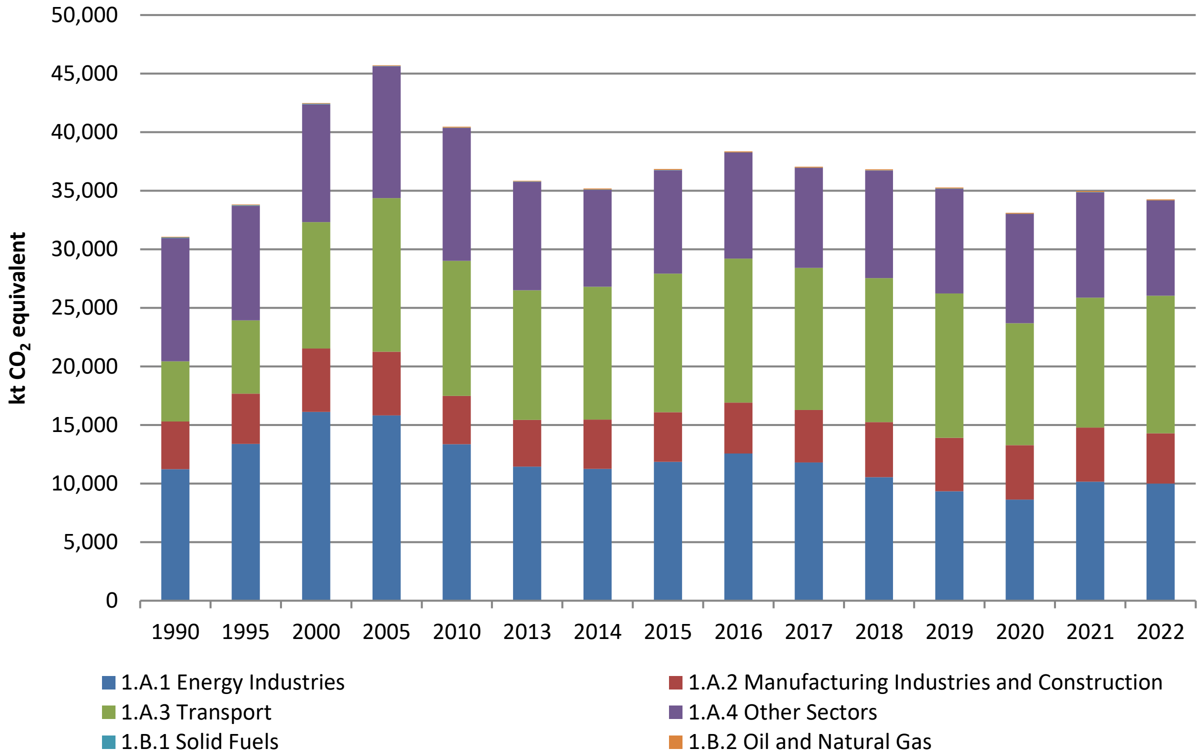


Figure 3.1 Total Emissions from Energy by Category, 1990-2022

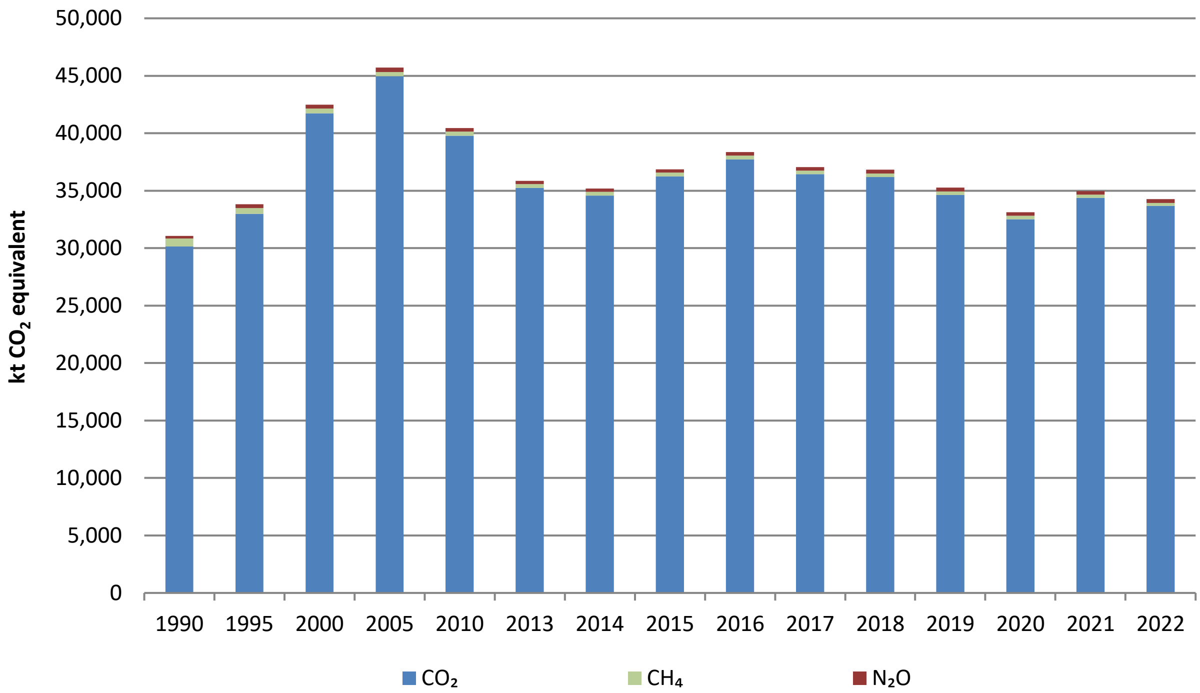


Figure 3.2 Total Emissions from Energy by Gas, 1990-2022

3.1.3 Quality Assurance and Quality Control

Extensive QA/QC procedures have again been followed for the Energy sector during the present reporting cycle by fully implementing the plan that underpins Ireland's formal national system. The inventory agency continues to apply a system of quality control checks and documentation to the front of all calculation workbooks. These workbooks correspond directly to the disaggregation given by the CRF sectoral background data tables and are designed so that calculations may be made on a time-series basis, rather than by individual year. This increases efficiency in the use of the time-series energy data provided by SEAI and allows for rapid recalculation and checking across the time-series and facilitates the transfer of the output emission estimates and energy quantities to the CRF Reporter software. Additional summary sheets are used for aggregation to various levels to provide full cross-checking with completed CRF tables for any year.

The quality checks at inventory level build on the extensive upgrading and quality control of energy balances completed by SEAI in recent years. This work, together with further collaboration with inventory experts and thorough evaluation of the SEAI role in relation to the national system and QA/QC procedures, has resulted in substantial improvements that are now taken into account in the emissions for *Energy* for all years included in the present submission.

In recognition of its role as a key data provider, SEAI is continuing to develop its own procedures to ensure that energy balances fully harmonised with Eurostat and International Energy Agency requirements are made available in a timely manner to facilitate the annual reporting of greenhouse gas emissions estimates. Arrangements have been established whereby the bottom-up energy data reported to the EPA for individual enterprises in all relevant energy-use sectors covered by the EU ETS may be reconciled at an early stage with the corresponding top-down information collected by SEAI. This procedure aims to progressively minimise differences between the energy amounts reported by SEAI and that supplied to the inventory agency for particular sub-categories and fuels.

The incorporation of the ETS data in the *Energy* sector since the commencement of the Emissions Trading Scheme in 2005 is considered an important step towards improved reliability and accuracy of the estimates for categories *1.A.1* and *1.A.2.* Thorough checking of this input is achieved in collaboration with colleagues in the OES of the EPA, which acts as the competent authority for the ETS in Ireland. Following receipt of the raw ETS data from OES, the inventory experts allocate the CO_2 estimates and corresponding energy amounts to the appropriate sub-categories for CRF reporting and then return the compilation to the OES contact person for final checking and accounting of any amendments following the ETS verification process. This ensures that where ETS emissions estimates cover a category completely, such as in *1.A.1*, the verified CO_2 values are transferred directly to the national inventory and consistency of results is guaranteed. In the case where the CO_2 estimates from ETS do not completely cover the category, as for *1.A.2*, the benefit is realised as better information on fuels and more representative emission factors, which improves the top-down estimates of emissions obtained using the energy balance.

3.2 Emissions from Fuel Combustion (1.A)

3.2.1 Comparison of the Sectoral Approach with the Reference Approach

Following the methods decision tree of the 2006 IPCC Guidelines for combustion sources, the information in Table 4.B of Annex 4 allows for the full application of the two available 2006 IPCC

Guidelines methods for emission sources in *Energy*, i.e. the Sectoral Approach and the Reference Approach.

The Sectoral Approach uses the detailed sectoral breakdown of fuel consumption by all end users as the basis of the calculations for CO_2, CH_4 and N_2O. The relevant activity data are represented by the disaggregated entries below TPER (Total Primary Energy Requirement) in Table 4.B of Annex 4.A combination of top-down and bottom-up methods is used in the sectoral application of the national statistics on fuel consumption to derive the emission estimates in the various sub-categories.

The 2006 IPCC Guidelines Reference Approach is a top-down methodology for CO_2 that estimates emissions by accounting for the overall production of primary fuels, the external trade in primary and secondary fuels, stock changes and for the carbon that may enter long-term storage in non-energy products and feedstocks.

It can be used to report national emissions in cases where the detailed activity data required for the Sectoral Approach are not available, but it is more usually applied for verification of the results of the latter for those countries that have the information to apply both methods.

The Reference Approach is used in Ireland as a verification procedure for CO_2 emissions from fuel combustion activities. The calculation sheet for the Reference Approach (Table 1.A (b) of the 2022 CRF) is reproduced as Table 3.1.4 of Annex 3.1.A of this report. The apparent consumption of fuels, the basic activity data in this case, is determined as:

Apparent Consumption = Production + Imports - Exports - International Bunkers - Stock Changes

where production applies only to primary fuels.

The default value of 1.00 is used for the proportion of carbon stored in paraffin wax, lubricants, bitumen and white spirit as outlined in CRF table 1.A(b). Ireland's only oil refinery is a small hydroskimming refinery where there is no production of other petroleum products normally used for non-energy purposes, such as bitumen, lubricants, plastics and asphalt. The associated emissions with the non-energy use of these fuels are presented in section 3.2.3 and the IPPU sector, chapter 4 of this report.

The expanded SEAI energy balance sheets now record the import of some of these products, thereby allowing improved completeness in the Reference Approach estimation of CO_2 emissions and carbon storage.

A significant amount of natural gas feedstock was traditionally used in ammonia production in Ireland, but the company closed in 2003 and there is consequently no feedstock use of natural gas since then.

The national energy consumption and CO_2 emissions estimates obtained using the Sectoral Approach usually differ to some extent from the corresponding values resulting from the Reference Approach. According to the UNFCCC reporting guidelines, discrepancies between the approaches (greater than 2 per cent) should be investigated and documented to see whether they indicate systematic underestimation or overestimation of energy consumption by one or other of the methods.

The overall differences in the Reference Approach for 2022, energy use (excluding non-energy use, reductants and feedstocks) and CO_2 emissions were; 0.30 per cent lower and 0.67 per cent lower, respectively than in the Sectoral Approach. The differences between the two approaches for liquid, solid, gaseous, peat and other fuels are presented in Table 3.1.5 of Annex 3.1.A and CRF Table 1.A(c) for 2022.

3.2.2 International Bunker Fuels

The memo items of the IPCC reporting format refer to activities for which the emissions are excluded from national totals. The use of fuels in international aviation and marine bunkers is the most important of these activities.

Some of the associated emissions, particularly CO_2 emissions from international aviation, are increasing very rapidly and it is therefore important that they are closely monitored for comparison with other sources and for the benefit of the international organisations that will have to develop control strategies for them in the future.

The national energy balance sheets include marine bunkers and international aviation as specific items and the emissions may be calculated directly. The allocation of fuels to marine bunkers in the national energy balance is achieved on the basis of particular tax and excise rates applicable to the sale of such fuels.

The allocation of jet kerosene use to international aviation (bunker fuel) is done by subtracting jet kerosene used in civil aviation estimated by the inventory agency from total jet kerosene fuel sales compiled by SEAI. In 2022, the amount of jet kerosene fuel allocated to domestic aviation was 0.6 per cent of the total recorded under air transport in the energy balance. Emissions of CH_4 and N_2O have been estimated for all years for fuel used in marine bunkers. Emissions factors from Tables 3.5.2 and 3.5.3 Chapter 3, Vol 2 2006 IPCC Guidelines of 7 kg/TJ and 2 kg/TJ, for CH_4 and N_2O respectively, have been used to estimate emissions.

3.2.3 Feedstocks and Non-energy Use of Fuels

This category includes fossil fuels used for non-energy purposes (Table 3.3); without the combustion and oxidation process.

There are a number of fuel types applicable in Ireland:

- Lubricants – IPCC default oxidation value of 0.2 is used, see category 2.D.1;
- Bitumen – IPCC default value of 1.0 is used for the proportion of carbon stored;
- Paraffin wax – IPCC oxidation value of 1.0 is used for candles and 0.2 for all other paraffin wax, see category 2.D.2;
- White spirit – IPCC default value of 1.0 is used for the proportion of carbon stored;
- Natural Gas – a significant amount of natural gas feedstock was used in ammonia production from 1990-2003.

Emissions from the non-energy use of fossil fuels have been included in the Industrial Processes and Product Use sector, CRF Category 2.D (Chapter 4 of this report).

Table 3.3 Allocated CO_2 emissions from fuel used for non-energy purpose

CO_2 emitting process	CRF Category (Sectoral Approach)	Type of fuel used for non-energy purpose such as feedstock	Emission factor (t C/TJ)	Net Calorific Value (TJ/ktonne)
Automobile engine oils	2.D.1	Lubricants	20.00	42.29
NA*	NA (RA)	Bitumen	22.00	37.70
Candle production and other	2.D.2	Paraffin wax	20.00	40.20
Ammonia production	2.B.1	Natural Gas	14.98	49.00
Indirect CO_2 from NMVOC	NA (RA)	White spirit	20.00	44.00

*All carbon is stored

3.2.4 Energy Industries (1.A.1)

The emission categories relevant under *1.A.1 Energy Industries* are: *1.A.1.a Public electricity and heat production, 1.A.1.b Petroleum refining, 1.A.1.c Manufacture of solid fuels and other energy industries.*

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

3.2.4.1.1 Category Description

The emissions data from a total of 15 electricity generating stations are the basis for compiling the results in this important category. The verified CO_2 estimates reported by the ETS participants were used directly and the corresponding fuel use, as given in the national energy balance, was used to estimate CH_4 and N_2O emissions using the appropriate 2006 IPCC Guidelines emission factors mentioned in the previous section. Emissions are presented by gas and fuel in Figure 3.3.

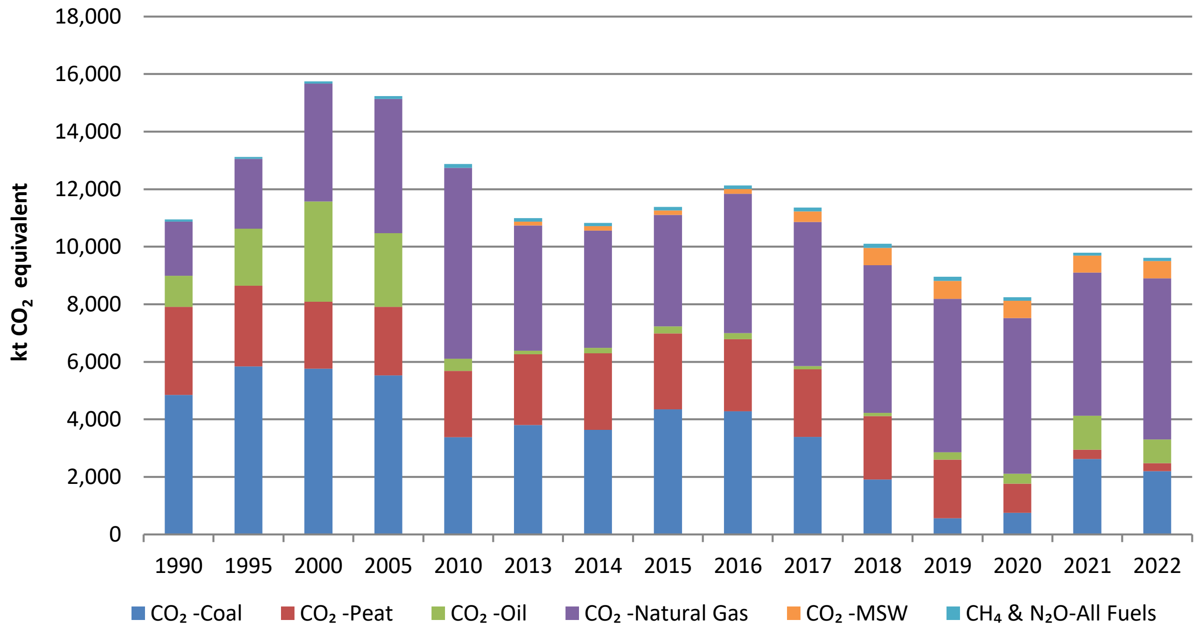


Figure 3.3 Emissions from 1.A.1.a Public Electricity and Heat Production 1990-2022

3.2.4.1.2 Methodological Issues

CO_2 emissions obtained from AEMs (Annual Emission Monitoring Reports) are estimated by ETS operators using tier 3 methodologies (as is the case with the years 2005-2022) in accordance with the monitoring and verification guidelines for combustion activities set down in Decision 2004/156/EC (EP and CEU, 2004), which were developed for the implementation of Directive 2003/87/EC and amended by Directive 2009/29/EC. AEM reports are provided by operators via the emissions trading scheme website for Ireland (ETSWAP).

Two types of biomass fuel are also used in this sub-category which are not reported under ETS; landfill gas (LFG) used in engines at solid waste disposal sites, and municipal solid waste (MSW) used in a waste to energy (WtE) plants which were commissioned in 2011 and 2017. The CO_2 emissions are sourced from the European Pollutant Release and Transfer Register for both waste-to-energy plants and the renewable portion and energy input to the plants is taken from the energy balance. Detailed information on these biomass fuels and information on the fraction of MSW which is non-biogenic are shown in Annex 3.1.A Tables 3.1.1-3. Emission factors have been used for each type of biomass fuel, sourced from Table 2.2 (for landfill gas (1.00 kg CH_4 /TJ and 0.1 kg N_2O /TJ) and municipal waste (30 kg CH_4 /TJ and 4.0 kg N_2O /TJ) and Table 2.6 (for wood/wood waste boilers 11.00 kg CH_4 /TJ and 7.0 kg N_2O /TJ) from Vol. 2, Ch. 2 of the 2006 IPCC guidelines.

The bottom-up CO_2 emission estimates received from the ETS participants, along with the emissions of CH_4 and N_2O estimated by the inventory agency, are aggregated on the basis of six main fuel types (peat, coal, oil, natural gas, biomass and other fuels (MSW)) in the calculation sheets shown in Annex 3.1.A and also by solid, liquid, gaseous, biomass and other fuels for reporting in the CRF. However, the corresponding energy use as reported in the CRF is taken from the national energy balance, rather than from the ETS returns, following Ireland's established practice to always reflect the published official national energy data in emission inventories. The resulting implied emission factors (IEFs) appearing in the CRF may have large inter-annual fluctuations, which are often identified in the UNFCCC review process. These IEF fluctuations are a consequence of the difference between energy data reported to the inventory agency through the ETS and that reported by SEAI in the national energy balance. The inventory agency is working closely with SEAI to minimise these differences so that the IEF will better represent the reported emissions and activity data in future years. The inventory agency meets with SEAI regularly to resolve any issues regarding the national energy balance pending the outcome of the latest UNFCCC review. The national energy balance data now corresponds more closely to the data supplied directly to the inventory agency from ETS returns in sub-category *1.A.1.a* which can be seen by the IEF comparison for liquid and solid fuels for this sub-category in Tables 3.1.6 and 3.1.7 of Annex 3.1.A.

3.2.4.1.3 Uncertainties and Time-series Consistency

The ETS data almost fully (except WtE MSW incineration and LFG used for energy production) cover sub-category *1.A.1.a,* these estimates match those reported separately under parallel arrangements that have been in place for many years for the same plants, it is assumed that time-series consistency is not seriously affected and that there is no impact on the emission trend from using the ETS data.

Where higher tier methods are used for combustion sources, such as those covered by ETS and road transport, the activity data uncertainty estimates are those indicated for the tier concerned. Accordingly, low estimates of uncertainty apply to the activity data for category *1.A.1.a*. Country-specific CO_2 emission factors are used for all combustion sources, which gives a basis for assigning the uncertainties for emission factors while again taking into account the applicable tiers. Uncertainties in the emission factors for CH_4 and N_2O released from combustion sources are high and not well established quantitatively. For CH_4 and N_2O emission factors for combustion categories, the 2006 IPCC Guidelines are used and an indicative uncertainty of 50 per cent is used for both gases.

3.2.4.1.4 Category-specific QA/QC and verification

The implementation of the ETS incorporates two layers of verification. The operator's report for the installation is verified independently in accordance with requirements specified in Directive 2009/29/EC before being submitted to the competent authority. This verification assesses whether the report contains omissions, misrepresentations or errors that lead to material misstatement of the reported information. Verification undertaken by the competent authority involves resolution of issues identified in the verified reports through consultation and installation site visits. The CO_2 emissions estimates compiled through ETS for sub-category *1.A.1.a* are cross-checked with a separate long-standing data flow to the inventory agency covering plant-specific emissions for electricity generating stations that are used to report on the Large Combustion Plant Directive and the Convention on Long-Range Transboundary Air Pollution. The aggregated CO_2 emissions reported in the latter data-flow correspond to the compilation available under the ETS for all years since the ETS data became available in 2005.

These methods involve a rigorous accounting of fuel consumption and detailed information on fuel properties based on fuel sampling protocols agreed in the greenhouse gas emission permits for each installation and the application of specific emission factors for each fuel determined by accredited laboratories. The summarised CO_2 emissions compiled in the ETS database according to fuel type for all installations that constituted sub-category *1.A.1.a* in 2022 are aggregated to report the CO_2 emissions for this category.

The rigour of the monitoring and verification process for CO_2 emissions under the ETS provide for estimates for sub-category *1.A.1.a* that are more accurate and reliable than previously reported plant-specific estimates for the same source activities. The ETS estimates are available only since 2005 and the detailed information that underlies these data cannot reasonably be acquired by the inventory agency for historical years of the relevant UNFCCC time-series. As such, the application of the improved methodology introduces a degree of inconsistency in the time-series that is unavoidable in this instance.

3.2.4.1.5 Category-specific Recalculations

There was a very minor recalculation to emission estimates in Public electricity and heat production (1.A.1.a) in this submission for the years 2020 and 2021 due to small adjustments to the energy balance for those years within the sector.

3.2.4.1.6 Category-specific Planned Improvements

Emissions of CO_2 from this sector, account for 98.9 per cent of this category in 2022, are accurately quantified and there is therefore little scope for further improvement in future versions of the inventory.

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

3.2.4.2.1 Category Description

The Annual Emission Monitoring report, under ETS, of the single oil refinery in Ireland is the basis for compiling the results in this category.

3.2.4.2.2 Methodological Issues

Similar to *1.A.1.a Public electricity and heat production* emissions in this category are estimated using tier 3 methodologies in accordance with the monitoring and verification guidelines for combustion activities set down in Decision 2004/156/EC. The emissions are estimated from the use of high-pressure gas, low-pressure gas (refinery gas), Natural Gas, LPG and small amounts of other gases as well as gasoil and historically residual fuel oil using country-specific emission factors. However, those fuels are aggregated in the national energy balance into fewer and hence less detailed categories than fuels reported under ETS. Since activity data is derived from the energy balance and CO_2 emissions originate from ETS the resulting implied emission factors for CO_2 fluctuate significantly. The issue raised during reviews regarding national energy balance fuel proportions in comparison with ETS data has progressed in this reporting round. Total energy reported under ETS is now harmonised to total energy reported in the national energy balance for all years from 2013 to 2022. Differences still exist between Refinery Gas and Natural Gas, due to the different reporting to SEAI for energy balance purposes, and under the EU ETS. It is very difficult to retrospectively align fuel data from the two collection systems for historical years, given the relatively small amount of energy.

The use of residual fuel oil had been phased out at this plant in recent years and replaced with natural gas. The CH_4 and N_2O emissions are estimated by the inventory agency using the emission factors presented in Table 2.2 Chapter 2, Volume 2 of the 2006 IPCC Guidelines.

3.2.4.2.3 Uncertainties and Time-series Consistency

The ETS results fully cover sub-category *1.A.1.b* for all years from 2005. Ireland has only one refinery and the energy consumption by fuel relating to this facility is well known from national energy statistical surveys and corresponds closely with ETS data in recent years. It is assumed that time-series consistency is not affected and that there is no impact on the emission trend from using the ETS data.

Low estimates of uncertainty apply to the activity data for category *1.A.1.b.* Country-specific CO_2 emission factors are used for all combustion sources, which gives a basis for assigning the uncertainties for emission factors while again taking into account the applicable tiers. Uncertainties in the emission factors for CH_4 and N_2O released from combustion sources are high and not well established quantitatively. For CH_4 and N_2O emission factors for combustion categories, the 2006 IPCC Guidelines provide an indicative uncertainty of 50 per cent for both gases.

3.2.4.2.4 Category-specific QA/QC and verification

The procedures described in section 3.2.4.1.4 are also undertaken for this source category.

3.2.4.2.5 Category-specific Recalculations

There are no recalculations to emission estimates from *Petroleum Refining* in this submission.

3.2.4.2.6 Category-specific Planned Improvements

Emissions of CO_2 from this sector, which accounts for 99.9 per cent of this category's emissions in 2022, are accurately quantified and there is therefore little scope for further improvement. It was identified during the UNFCCC review in 2023 that some emissions reported in this category may be from refinery flares. The inventory agency will consider this issue and see if it is possible to take these flared emissions from 1.A.1.b Petroleum refining and report in fugitive under category 1.B.2.c.i Flaring of Oil, in the 2025 submission.

3.2.4.3 Manufacture of Solid Fuels and Other Energy Industries (1.A.1.c)

3.2.4.3.1 Category Description

The Annual Emission Monitoring Reports were used to report the inventory for this category. The emissions data from two peat briquetting plants, one natural gas production platform and one natural gas refinery are the basis for compiling the results in this category.

3.2.4.3.2 Methodological Issues

Emissions for *1.A.1.c Manufacture of Solid Fuels and Other Energy Industries* refer to the production of peat briquettes from milled peat in two plants, one natural gas production platform and one new natural gas refinery.

The values for CO_2 for natural gas and peat fuels are taken from ETS returns which are based on tier 3 methodologies in accordance with the monitoring and verification guidelines for combustion activities set down in Decision 2004/156/EC. The country-specific CO_2 emission factor were applied for liquid fuels which are consistent with Table 2.3, Chapter 2, Volume 2 of the 2006 IPCC Guidelines. The CH_4 and N_2O estimates are estimated by the inventory agency using the IPCC default emission factors presented in Table 2.2 and 2.3, Chapter 2, Volume 2 of the 2006 IPCC Guidelines.

3.2.4.3.3 Uncertainties and Time-series Consistency

Milled peat is the principal fuel used in this sub-category. While the plant-specific annual CO_2 emission factor may fluctuate in response to peat quality and moisture content, both the emission factor and activity data are sufficiently well established to ensure that the emissions time-series for this sub-category is consistent.

Plant-specific CO_2 emission are obtained for natural gas and peat fuels, and country-specific emission factors are applied for CO_2 emission for liquid fuels which provide a basis for assigning lower uncertainties for CO_2 emission factors in the uncertainty analysis. Uncertainties in the emission factors for CH_4 and N_2O released from combustion sources are high and an indicative uncertainty of 50 per cent for both gases are considered according to the 2006 IPCC Guidelines.

3.2.4.3.4 Category-specific QA/QC and verification

The procedures described in section 3.2.4.1.4 are also undertaken for this source category.

3.2.4.3.5 Category-specific Recalculations

There are no recalculations to emission estimates from *Petroleum Refining* in this submission.

3.2.4.3.6 Category-specific Planned Improvements

Emissions of CO_2 from this sector, which account for 99.6 per cent of this category's emissions, are accurately quantified and there is therefore little scope for further improvement in the inventories as delivered in the 2024 submission.

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

3.2.5.1 Category Description

The emission categories relevant under *1.A.2 Manufacturing Industries and Construction* are: *1.A.2.a Iron and Steel; 1.A.2.b Non-Ferrous Metals; 1.A.2.c Chemicals; 1.A.2.d Pulp, Paper and Print; 1.A.2.e Food Processing, Beverages and Tobacco; 1.A.2.f Non-metallic minerals* and *1.A.2.g Other*.

Figure 3.4 shows the trend in emissions from *1.A.2 Manufacturing Industries and Construction* over the period 1990-2022.

The emissions from this category peaked in 2005 with a significant drop between 2008 and 2009 due to the impact of the economic downturn. Emissions slowly increased between 2011 and 2020 before experiencing successive reductions of 0.8 per cent in 2021 and 6.7 per cent in 2022. The large reduction in emissions in 2022 is predominantly driven by lower emissions in sectors *1.A.2.b Non-Ferrous Metals (-11.4 per cent)* and *1.A.2.f Non-metallic minerals (-8.0 per cent)*.

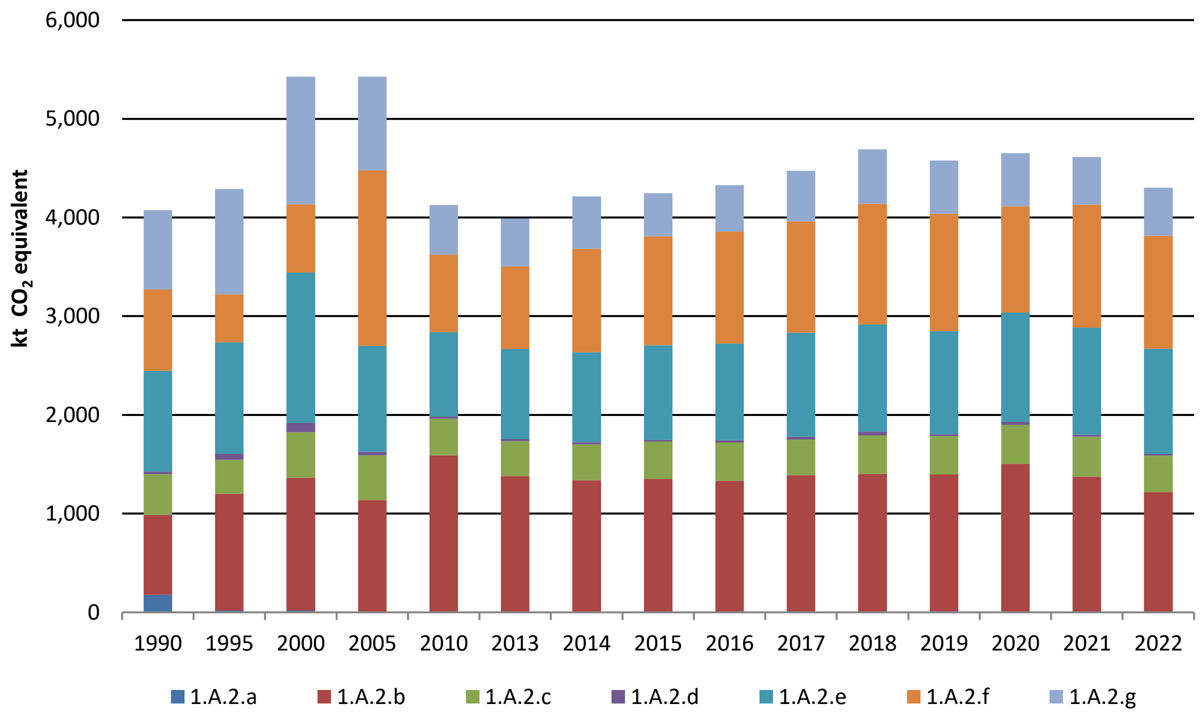


Figure 3.4 Emissions from 1.A.2 Manufacturing Industries and Construction 1990-2022

3.2.5.2 Methodological Issues

The expanded annual energy balance sheets published by SEAI incorporate a mapping of industrial fuel use in combustion into the CRF sub-categories *a-g* under *1.A.2 Manufacturing Industries and Construction*. This facilitates the complete disaggregation of emissions in this source category for completion of the CRF Table 1.A(a)s2.

The combustion CO_2 emissions in a variety of installations across the CRF sub-categories *1.A.2.a* through *1.A.2.g* are covered by the ETS Directive 2009/29/EC but the total CO_2 emissions in any sub-category cannot be reported for Ireland using ETS data alone.

The ETS data are instead used to compare fuel quantities reported under ETS with corresponding amounts given in the preliminary national energy balance and to determine improved country-specific emission factors that can be applied for particular fuels and sub-categories. The emissions of CO_2 are estimated by the inventory agency on a top-down basis using the agreed final energy balance activity data and country-specific emission factors as shown in Table 3.1.8 of Annex 3.1.A. The emissions of CH_4 and N_2O are estimated using the default emission factors presented in Table 2.3 Chapter 2, Volume 2 of the 2006 IPCC Guidelines.

Information provided from the ETS on fuel data have been used to develop an annual country-specific CO_2 emission factor for petroleum coke since 2005. Petroleum coke is used in sub-categories and years: *1.A.2.b* (1991-2000), *1.A.2.c* (2005-2022), *1.A.2.e* (1991-2003), *1.A.2.f* (1990-2000, 2002-2022) and *1.A.2.g* (1991-2003, 2008-2009, 2015-2016). The 2006 IPCC Guidelines emission factor of 97.5 t CO_2/TJ compares well with the year specific emission factors which vary from 92.8 to 95.8 CO_2/TJ. The average (93.65 CO_2/TJ) of the five years between 2005 and 2009 of yearly specific emission factors is applied to all years from 1990 to 2004, as ETS data is only available from 2005 onwards.

Petroleum coke is included with “liquid fuels”, because it is derived from petroleum. However, the properties of petroleum coke are similar to those of solid fuels. As a result, when considered at an aggregated level, properties of liquid fuels can be heavily influenced by the amount of petroleum coke consumed. When the country-specific emission factor for petroleum coke is taken into account, the implied emission factors for liquid fuels in sub-category *1.A.2.f* fluctuate significantly depending on the proportion of petroleum coke included in liquid fuels. It is mostly evident in sub-category 1.A.2.f as petroleum coke accounts for a high proportion of all liquid fuels in this category (73.0 per cent on average across the time series). Other sectors with a smaller proportion of this fuel to their liquid fuel totals were less affected by fluctuating CO_2 implied emission factor. This can be seen in Table 3.1.8 of Annex 3.1.A.

For sub-category *1.A.2.e*, the largest quantities of petroleum coke are used in 2000 to 2002, giving rise to a peak in the liquid fuels implied emission factor of 81.0 t CO_2/TJ in 2001. However, the average implied emission factor for years 2004-2022 was 71.5 t CO_2/TJ for liquid fuels as no petroleum coke had been consumed in the sub-category since 2004.

In *1.A.2.f*, the implied emission factor for liquid fuels decreases from 83.8 t CO_2/TJ in 1990 to 74.0 t CO_2/TJ in 2001 as no petroleum coke was consumed that year, subsequently the IEF increases to reach maximum at 91.8 t CO_2/TJ in 2005 but then decreases to 87.8 t CO_2/TJ in 2010 reflecting the decline in petroleum coke use in cement production. The IEF for liquid fuels rises again to an average of 90.4 t CO_2/TJ over 2015-2022 as result of increased use in the cement sector in recent years due to increased production.

For sub-category *1.A.2.g*, the largest quantities of petroleum coke are used in 2001, giving rise to a peak in the liquid fuels implied emission factor of 80.8 t CO_2/TJ in 2001. However, the average implied emission factor for years 2004-2022 is 71.6 t CO_2/TJ with petroleum coke only used in the years 2008, 2009, 2015 and 2016 in very small quantities.

3.2.5.3 Uncertainties and Time-series Consistency

The ETS data partially covers category 1.A.2 and this data is provided to SEAI annually to help improve the disaggregation of fuel amounts within the sector. All emissions are estimated based on data provided in Ireland's national energy balances provided by SEAI.

Where higher tier methods are used for combustion sources, such as those covered by ETS and road transport, the activity data uncertainty estimates are those indicated for the tier concerned. Accordingly, low estimates of uncertainty apply to the activity data for category 1.A.2. Country-specific CO_2 emission factors are used for most combustion sources, which gives a basis for assigning the uncertainties for emission factors while again taking into account the applicable tiers. Uncertainties in the emission factors for CH_4 and N_2O from combustion sources are high and not well established quantitatively. For CH_4 and N_2O emission factors for combustion categories, the 2006 IPCC Guidelines values are used and an indicative uncertainty of 50 per cent is applied for both gases.

3.2.5.4 Category-specific QA/QC and verification

Extensive QA/QC procedures were followed for 1.A.2 during the present reporting cycle by fully implementing the plan that underpins Ireland's formal national system. The quality checks at inventory level build on the extensive upgrading and quality control of energy balances completed by SEAI in recent years.

3.2.5.5 Category-specific Recalculations

There was a significant redistribution of fuel within this sector in the 2023 submission compared to submission 2022.

- Approximately 171 TJ per annum of oil has been moved into Industry (1A2) from both Commercial and Services (1A4a) and Residential (1A4b) from 1990-2021.
- On average 726 TJ of natural gas has been redistributed from Industry (1A2) into Commercial and Services (1A4a) from 2001-2021, with the exception of 2020 where 1,742 TJ of natural gas is added to Industry from the commercial sector.

On average, there is 229 TJ less fuel consumed per annum in the sector throughout the timeseries compared to the previous submission.

In terms of emissions, these fuel reallocations caused an average annual decrease of 0.2 per cent over the timeseries 1990-2021. See table 3.10.

In previous releases, the distribution of total fuel purchase costs from the CSO Annual Services Inquiry (ASI) and the CSO Census of Industrial Production (CIP) were largely done using pre-2009 ASI and CIP returns that had a breakdown by fuel. For the 2019 results, the methodology changed whereby the results of a retrospective Business Energy Usage Survey (BEUS) provided greater detail in terms of the allocation of fuel between sectors. This change used more recent data, allowed variation from year to year, and allowed the transition to newer fuels to be incorporated. In the previous methodology some of the distributions were done at enterprise level whereas the new approach uses 10 aggregated NACE sectors.

The 2019 BEUS was conducted during 2020 and the response rate was impacted by Covid-19. To adjust for this, the CSO had imputed some 2019 survey returns based on 2018 and previous year's figures. The energy data for 2022 includes updates of the CSO's BEUS surveys for 2020 and 2021.

The 2022 energy balance figures (source of 2024 submission) encountered a further reallocation of fuel for previous years following greater access to national metered electricity data, which allowed more accurate reweighting to a number of NACE categories.

3.2.5.6 Category-specific Planned Improvements

The inventory agency continues to undertake discussions with SEAI to further improve activity data estimates as provided in the national energy balance. Ireland's national Energy statistics do not provide an estimate of fuel used in mobile construction. All emissions associated with the category 1A2g are reported in 1A2gviii, and mobile emissions, 1A2gvii, are reported as "included elsewhere" (IE) in 1A2gviii. Currently all fuel is assumed to be stationary as the energy balance does not provide an estimate for fuels used in mobile machinery within category 1A2g. The inventory agency had previously funded research to be undertaken to quantify the extent and amounts of fuel used by mobile combustion on construction sites, but the COVID-19 pandemic had a negative impact on its outcome as it affected the collection of activity data. As a result, it was concluded that changing the methodology to estimate emissions from off-road vehicles and other machinery to take into account the results of the research project would not improve the accuracy of the inventory.

3.2.6 Transport (1.A.3)

Figure 3.5 shows the trend in emissions from *1.A.3 Transport* over the time series. Road transport is the main driver in the trend. Transport emissions declined between 2007 and 2012 reflecting the impact of the economic downturn in Ireland. However, emissions have been rising between 2012 and 2016 reflecting a return to economic growth. The trends appear to follow Ireland's economic growth patterns whereas the 4 years 2016-2019, we have seen emissions relatively stable despite increases in vehicle population. In 2020, emissions reduced significantly as a result of the covid pandemic enforced travel restrictions, however in 2021 and 2022 emissions have increased by more than 6 per cent per annum and are now approximately 95 per cent of 2019 pre-covid levels.

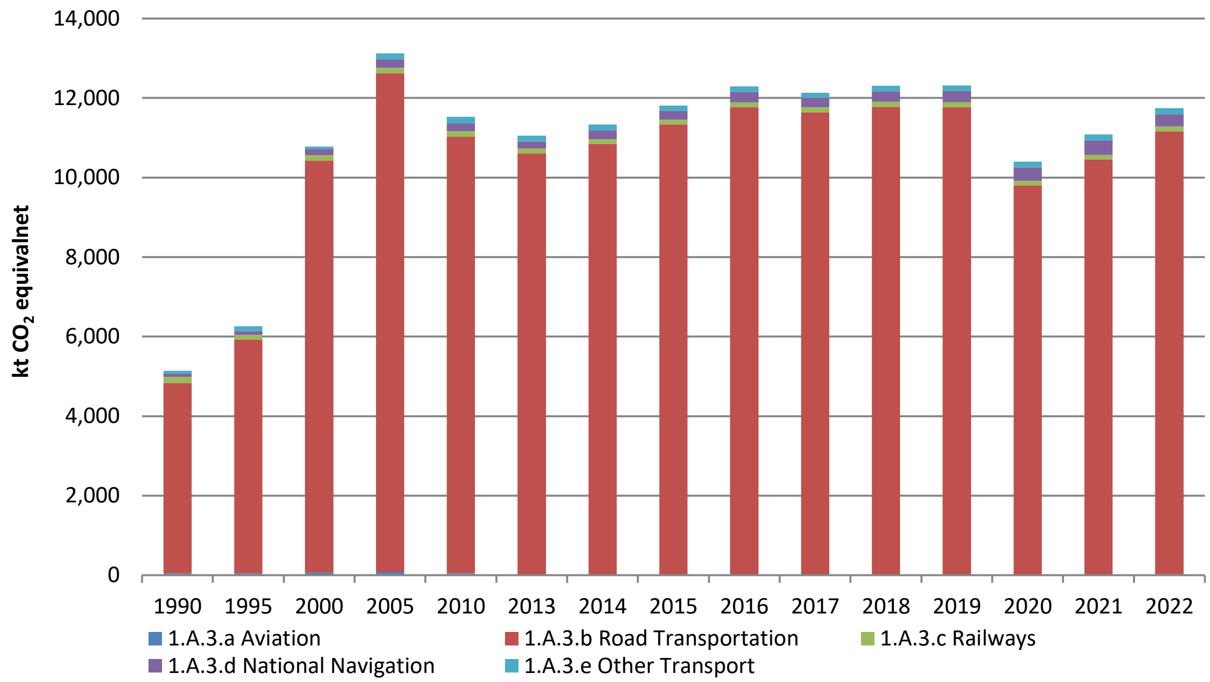


Figure 3.5 Emissions from 1.A.3 Transport 1990-2022

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

3.2.6.1.1 Category Description

This source category includes emissions from all civil commercial use of airplanes, including private jets and helicopters. Operations of aircraft in *Domestic Aviation* are divided into; Landing/Take-off (LTO) cycle and Cruise. All international aviation is reported as a Memo item.

3.2.6.1.2 Methodological Issues

The fuel consumption within Ireland associated with sub-category *1.A.3.a Domestic Aviation* is estimated using a Tier 3b approach (Table 3.6.2, 2006 IPCC Guidelines) based on origin and destination data for domestic air travel provided by EUROCONTROL using an Advanced Emission Model (AEM) to estimate fuel burned and emissions (CO_2, CH_4 and N_2O) for the full trajectory of each flight segment using aircraft and engine specific information. This approach, replaced the previous approach, tier 3a, using data provided by the Irish Aviation Authority (IAA) and the fuel consumption rates given by the EMEP/EEA emission inventory guidebook (EMEP/EEA 2013) appropriate to the type of aircraft concerned, and the length of the flights within Ireland.

EUROCONTROL's AEM does not split CH_4 and N_2O emissions between jet kerosene and aviation gasoline. National energy statistics in Ireland show a small proportion of aviation gasoline use, therefore the inventory agency assigns all CH_4 and N_2O emissions from the AEM to jet kerosene. All CH_4 and N_2O emissions from aviation gasoline are therefore include elsewhere (IE), under jet kerosene. The inventory agency assigns total CO_2 emissions from the AEM into both jet kerosene and aviation gasoline in the CRF submission.

This new approach is used for all years from 2005 to 2021 where EUROCONTROL data are available. For the years 1990 to 2004, the number of flights for each airport was estimated based on domestic passenger and aircraft movement statistics as well as the relationship between all Irish airports and Dublin airport which is the principal destination of all domestic flights. Domestic LTO and Cruise fuel consumption rates for 1990-2004 are based on an average (2005 to 2011) for each departure airport using EUROCONTROL consumption rates. Additional information on LTO data and fuel rates are provided in Tables 3.1.9 to 3.1.11 of Annex 3.1.B.

Figure 3.6 and Table 3.1.9 of Annex 3.1.B shows the number of LTOs for each of these nine airports and all remaining airports together under "*other*". Tables 3.1.10 and 3.1.11 of Annex 3.1.B show weighted average fuel consumption rates for both the LTO and Cruise segments for each of the airports.

Recent submissions' verification exercises highlighted the need to consider a revised approach for Domestic aviation, due to widening differences between IAA and EUROCONTROL LTO data for Ireland. See section 3.2.6.1.4 below.

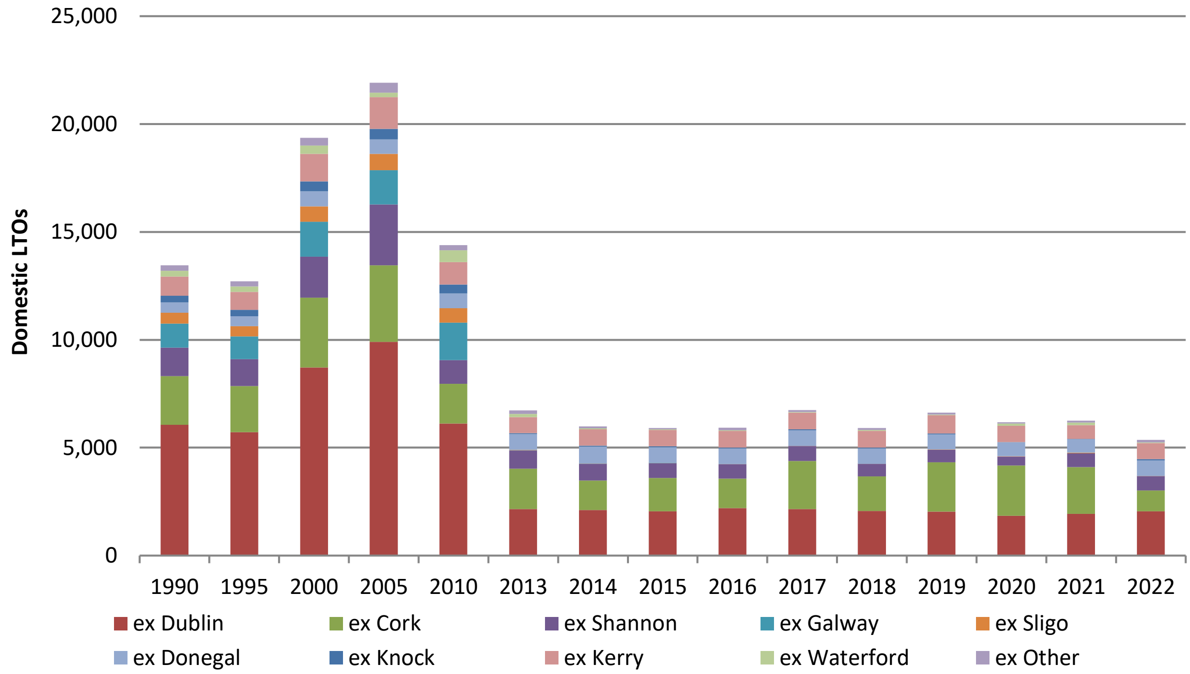


Figure 3.6 Number of LTOs from Irish airports 1990-2022

3.2.6.1.3 Uncertainties and Time-series Consistency

The activity data uncertainty for this source category is considered to be very low as the data provided by EUROCONTROL to the inventory agency accurately splits all flights based on airport pairs, both domestic and international. An emission factor uncertainty of 2.5 per cent is used as the data supplied to the inventory agency identifies both aircraft and end type.

3.2.6.1.4 Category-specific QA/QC and verification

The inventory agency continues to receive annual flight data for all Irish airports from the IAA, for all years from 2004 to 2021. These data included all flights, domestic and international, on an origin and destination basis and by aircraft type for over 25 different Irish origin airports. This data is now used for verification of EUROCONTROL data, as was the case in previous years when EUROCONTROL data was used to verify IAA data. The verification exercises in recent submissions, and again in this submission, highlighted the widening gap in IAA LTO data and EUROCONTROL data for the latest years, as IAA data does not include a substantial number of LTOs from Cork airport which are training flights.

The inventory agency continues to use the EUROCONTROL fuel burn and emissions data (CO_2, CH_4 and N_2O) instead of national data, as mentioned in NIR 2018, and as recommended in previous reviews. The main findings of this verification procedure are outlined in Figures 3.7 to 3.9. The verification exercise no longer includes emission and fuel burn estimates based on the tier 3a approach using the EMEP/EEA emission inventory guidebook methodology due to the additional resource implications of keeping this methodological approach up to date.

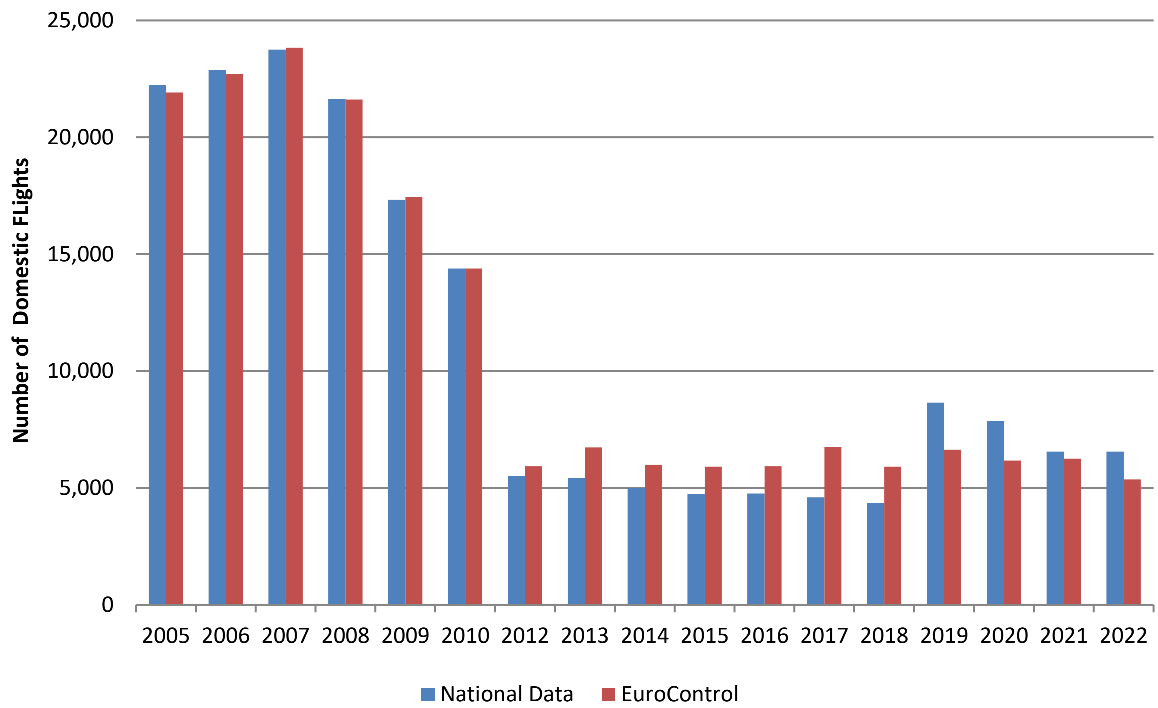


Figure 3.7 National LTO data and EUROCONTROL LTO data for 2005-2022

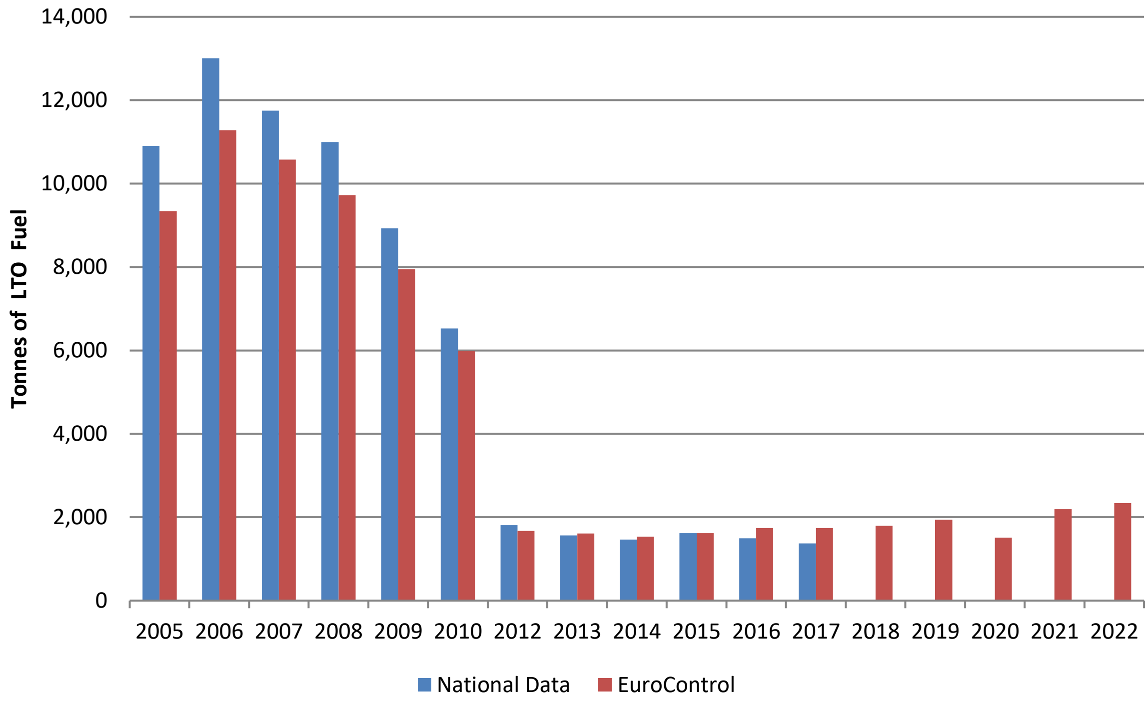


Figure 3.8 National LTO fuel data and EUROCONTROL LTO fuel data for 2005-2022

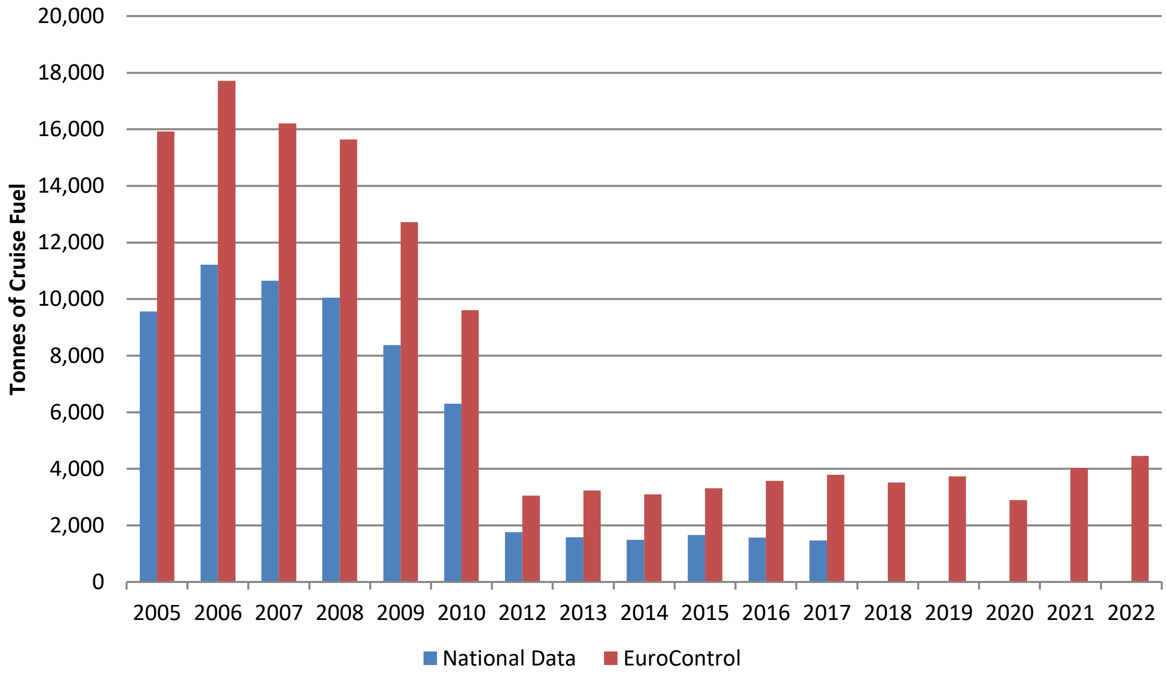


Figure 3.9 National Cruise fuel data and EUROCONTROL Cruise fuel data for 2005-2022

3.2.6.1.5 Category-specific Recalculations

There was a recalculation to emission estimates in *Domestic Aviation (1.A.3.a)* for the years 2015 to 2021 due to a revision of the Eurocontrol model for these years. The revision increased emissions by 0.1 per cent in 2015 and increased emissions by 0.3 per cent in 2021.

3.2.6.1.6 Category-specific Planned Improvements

The inventory agency will continue to update the fuel burn and emissions data as provided by EUROCONTROL, including any historical revisions if necessary.

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

3.2.6.2.1 Category Description

Emissions of CO_2 reported under *1.A.3.b Road Transportation* are computed from the amounts of petrol, diesel, LPG, CNG and biofuels provided for road transport in the national energy balance and country-specific emission factors for these fuels as shown in Table 3.1.1 of Annex 3.1.A.

Following the 2006 IPCC Guidelines, the activity data are based on fuel sales within Ireland, even though 6.4 per cent of automotive fuels purchased in Ireland were used outside of Ireland in 2022. For CO_2 emission estimates, complete oxidation of carbon content of the fuel is considered as per the 2006 IPCC Guidelines; however, the proportion of emissions by vehicle category type are estimated using the COPERT model. The CH_4 and N_2O emissions from road traffic are estimated directly from the COPERT 5 model (Pastramas N. et al., 2014), developed within the CORINAIR programme for estimating a range of emissions from this important source. Figure 3.10 shows the trend in emissions from *1.A.3.b Road Transport* over the time series.

3.2.6.2.2 Methodological Issues

The COPERT 5. model estimates emissions of CH_4 and N_2O on the basis of distance travelled using a detailed bottom-up approach (Tier 3) that accounts for such factors as fuel type, fuel consumption, engine capacity, driving speed and a range of applicable technological emission controls that may be applied on the basis of the age of the vehicle. The model is applied annually in Ireland to derive CO_2 emission proportions between vehicle categories and CH_4 and N_2O emissions estimates. The resultant 2022 emission factors have been converted to national average values per fuel type for the purpose of Table 3.1.1 of Annex 3.1.A. The COPERT 5 methodology is part of the EMEP/EEA air pollutant emission inventory guidebook (emep-eea-guidebook-2019) for the calculation of air pollutant emissions and is consistent with the 2006 IPCC Guidelines for the calculation of greenhouse gas emissions. An overview of the methodology has been provided below, however, a detailed methodology for activity data modelling and calculation of emissions can be obtained from a journal publication (Alam, et al. 2017).

There is an extensive number of variables which make up the suite of input data prior to running the COPERT model. The parameters and values selected are based on either default values of country-specific factors as a result of sourced national information that is relevant to Ireland's fleet.

The data surrounding actual fleet numbers per vehicle category and the total fuel sales is based on credible sources i.e. NCT / CRVT actual km travel data along with national revenue receipts per fuel type for the total fuel sold. There is a quantity of fuel between fuel sales and fuel used which remains unspecified, but this excess fuel must form part of the reported emissions. Therefore, there is a distribution task required on an annual basis as part of the COPERT model run.

The unaccounted petrol was distributed across all petrol categories using the differential multiplier between raw data and the statistical input from the total fuel sales. The excess diesel was distributed only throughout the commercial fleet using the same methodology as the petrol approach. The diesel passenger car fleet was left untouched, therefore allowing the uncertainty within this sub-category to be relatively small. Once the km travel data and the total statistical input values are relatively close, the COPERT model is run and in turn is permitted to balance the remainder of the fuel differential which is below approximately 0.5 per cent each year.

The emissions from biodiesel and bioethanol are calculated in COPERT 5 by vehicle type, which assumes each vehicle consumes the same split of biofuel and fossil fuel. COPERT does not disaggregate the emissions for biofuels (i.e. biodiesel and bioethanol) from the fossil portion. Appropriate blends are specified within the model input data for the relevant vehicle categories and the emissions are calculated (i.e. fossil plus biofuel per fleet category). In order to balance the statistical and the calculated energy consumption, the software matches the fossil/bioenergy consumption ratio defined in the statistical values by modifying the blend type and blend share and in turn the average mileages are updated. In terms of calibration, it follows the formal step-by-step process that is in-built within the software and cross-checks are carried out to ensure mileage is adjusted by comparing the input data with the updated modified data.

There was a new fuel added for the first time in this year’s submission to include CNG use within the HGV category in road transport. The current COPERT model version cannot facilitate this fuel and vehicle type, but it is expected to be part of an update in a newer version of COPERT in 2024. However, following the recommendation to include the relevant emissions from this fuel, emissions were estimated from this fuel retrospectively from its first use in 2014 up to 2022. There were approximately 1 ktCO_2e per annum emitted over the last 8 years. The CO_2 was calculated using the known activity data in terms of TJ multiplied by a country specific emission factor. CH_4 emissions were calculated using the 2019 EMEP/EEA guidebook [(Table 3-48: Methane (CH_4) emission factors (mg/km)] value of kg CH_4/km, along with the known terajoules and establishing an average yearly kilometres per terajoule for this particular vehicle category. This allowed a back-calculation for calculating a CH_4 emission factor and in turn total CH_4 emissions. The associated N_2O emissions were not estimated but we expect to include this gas quantity following the inclusion of this fuel and vehicle category within COPERT.

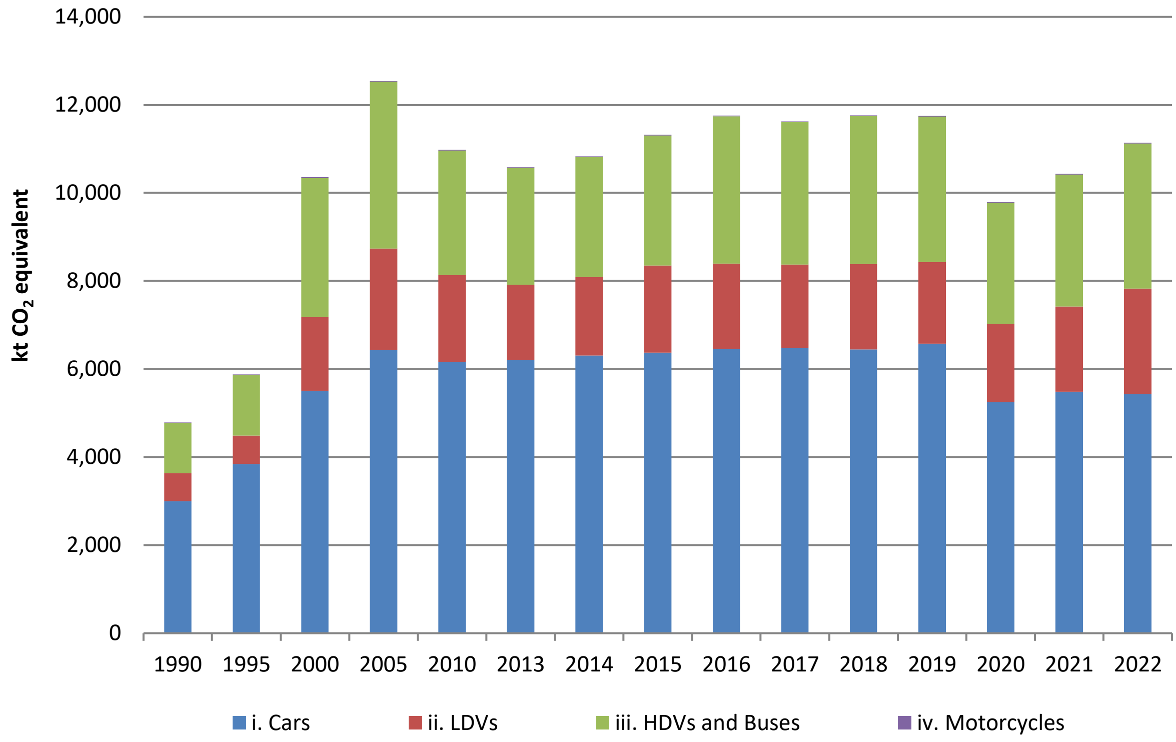


Figure 3.10 Emissions from 1.A.3.b Road Transport 1990-2022

3.2.6.2.3 Data Modelling: Fleet and Mileage

Detailed information on vehicle population by type is presented in Table 3.1.12 of Annex 3.1.B. The historical vehicle fleet and mileage were calculated from the year 1990 to 2021 from national statistics- Vehicle Bulletin of Driver Statistics (DOE, DELG, DEHLG, DOT, DOTTS, 1990-2022). The structuring of the fleet was consistent with the vehicle category structure and subsequent emissions by each fuel in a given category corresponding with the 2006 IPCC Guidelines. For the timeseries, vehicles were derived from national statistics into disaggregated level; firstly, vehicle category (e.g. passenger car), then fuel technology (e.g. petrol) and subsequently engine size (e.g. Large, or >2 litre). The final split of vehicle categories was based on Emission bands using the following formula for the number of vehicles in Emission band E_i:

$$N_{E_{i_p}^{q}} = \sum_{x=p}^{x=q} N_x$$

Where, x represents the vehicle registration year. 'i' represents, emissions Band: Pre-Euro to Euro-6 or Euro VI.

Each vehicle class was bounded by the technology commencement year 'p' and new technology commencement year 'q' in the Table 3.4 below. The results are presented in Figures 3.10.1, 3.10.2 and 3.10.3.

Table 3.4 EURO class vehicle commencement years

Technology	Passenger car	LDVs	HDVs	Buses	Coaches	Mopeds and Motorcycles
Pre-ECE	Up to 1969					
ECE 15/00-01	1970-1978					
ECE 15/02	1979-1980					
ECE 15/03	1981-1985					
ECE 15/04	1986-1991					
Conventional		Up to 1993	Up to 1994	Up to 1993	Up to 1993	Up to 1999
Euro-1 / Euro I	1992-1996	1994-1997	1995-1997	1994-1996	1994-1996	2000-2003
Euro-2 /Euro-II	1997-2001	1998-2001	1998-2001	1997-2001	1997-2001	2004-2006
Euro-3 /Euro-III	2002-2005	2002-2005	2002-2005	2002-2006	2002-2006	2007-present
Euro-4 /Euro-IV	2006-2010	2006-2010	2006-2010	2007-2009	2007-2009	2020
Euro-5 /Euro-V	2011-2014	2011-2014	2009-2012	2010-2013	2010-2014	2021
Euro-6 /Euro-VI abc	2015-2018	2015-2018	2013-Present	2013-Present	2013-Present	
Euro-6 /Euro-VI d-temp	2019-2020	2019-2020				
Euro-6 /Euro-VI d	2021-present	2021-present				

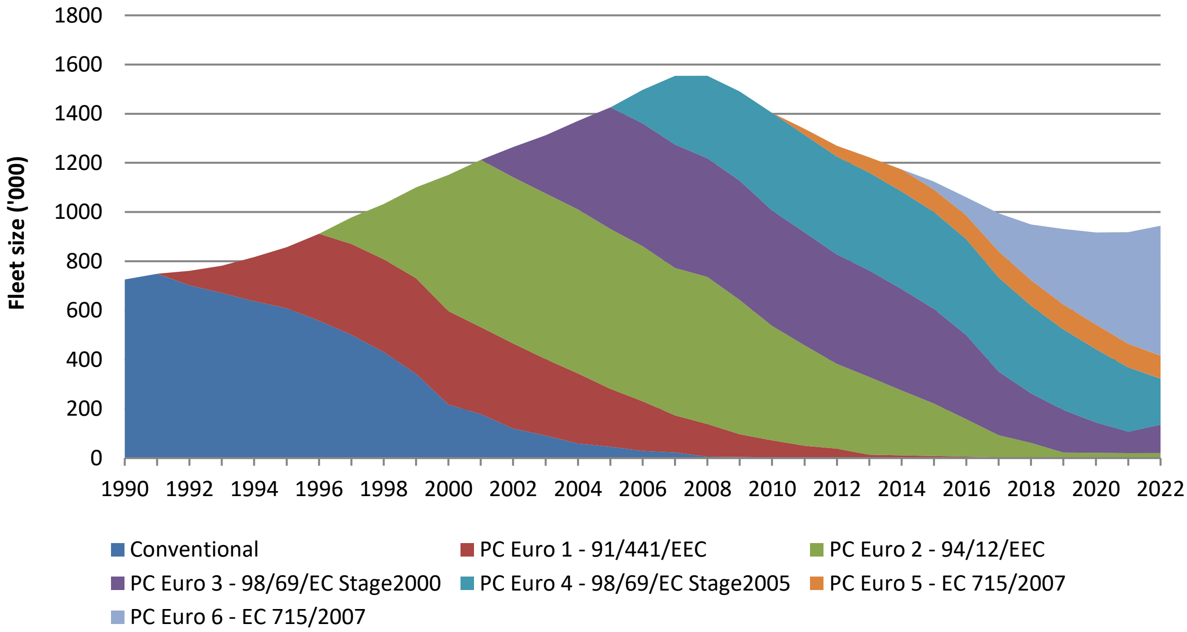


Figure 3.10.1(a) Historic passenger car fleet in Irish transport sector, Petrol

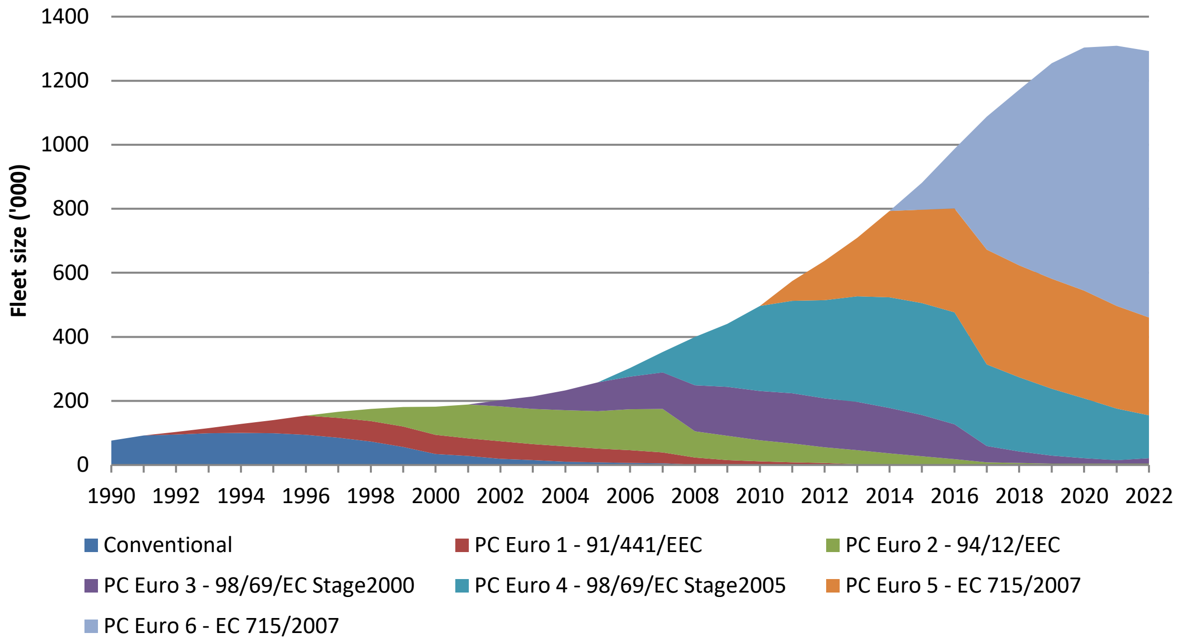


Figure 3.10.1(b) Historic passenger car fleet in Irish transport sector, Diesel

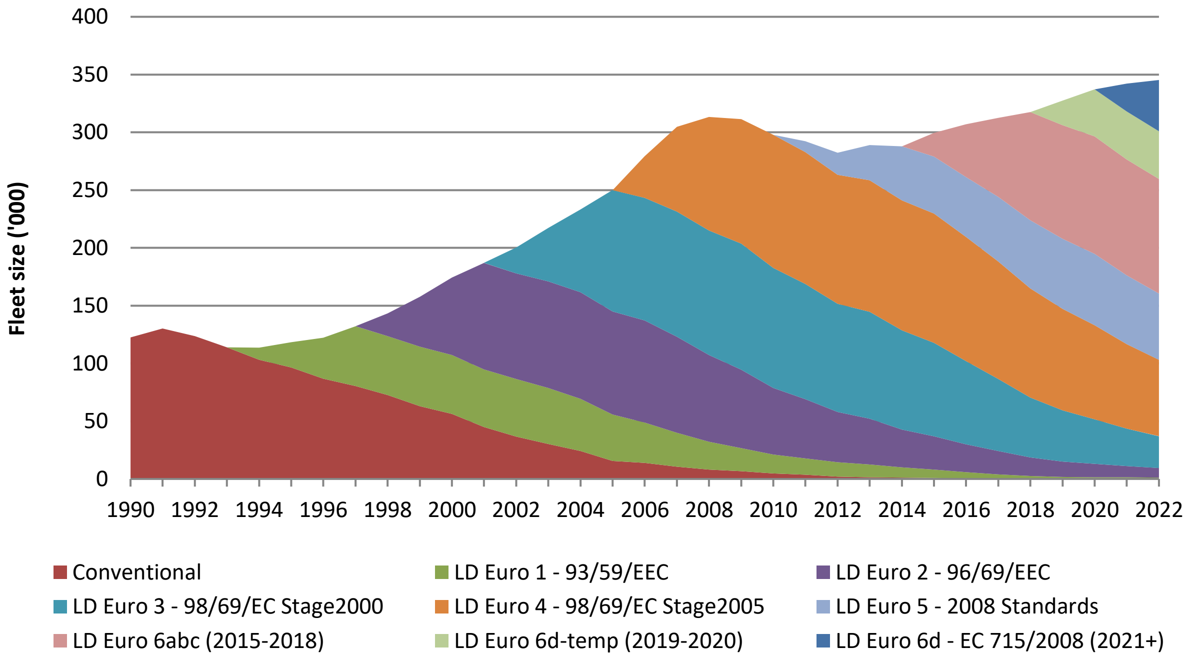


Figure 3.10.2 (a) Historic LDV fleet in Irish transport sector

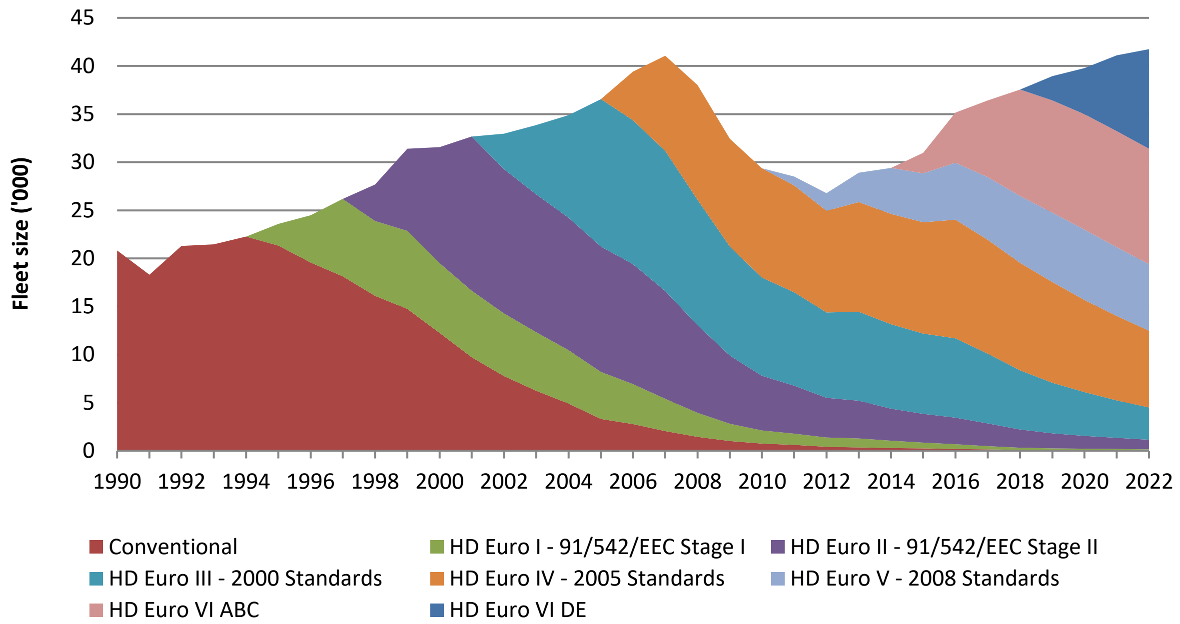


Figure 3.10.2 (b) Historic HDV fleet in Irish transport sector

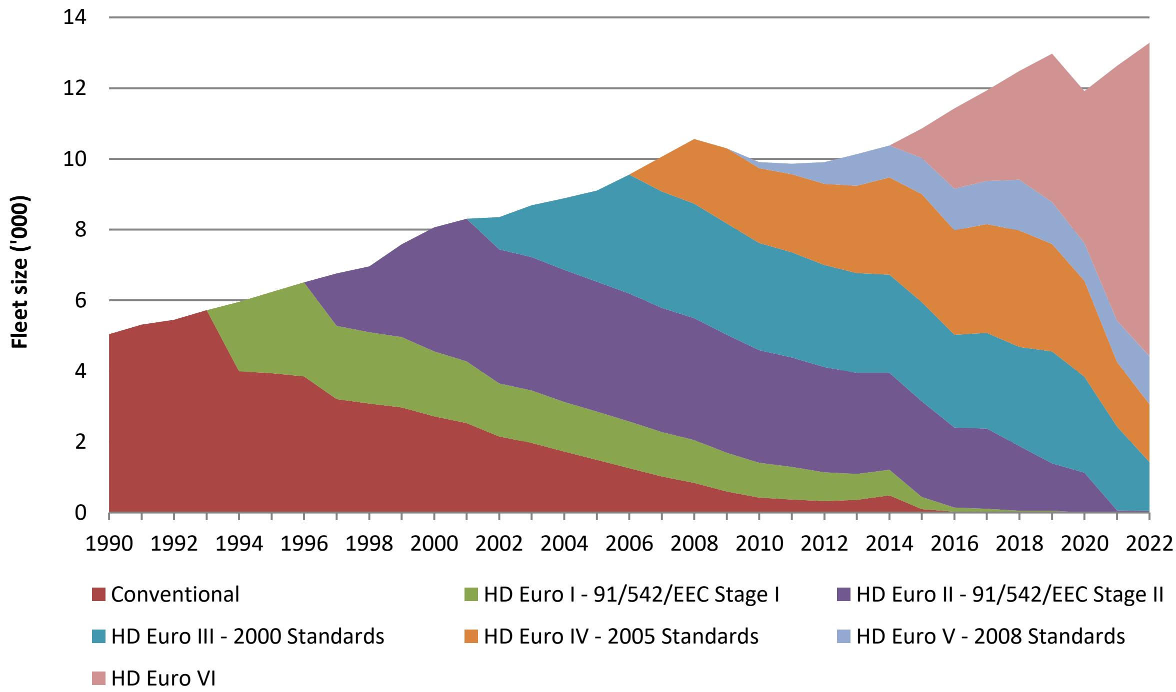


Figure 3.10.3(a) Historic Buses and coaches fleet in Irish transport sector

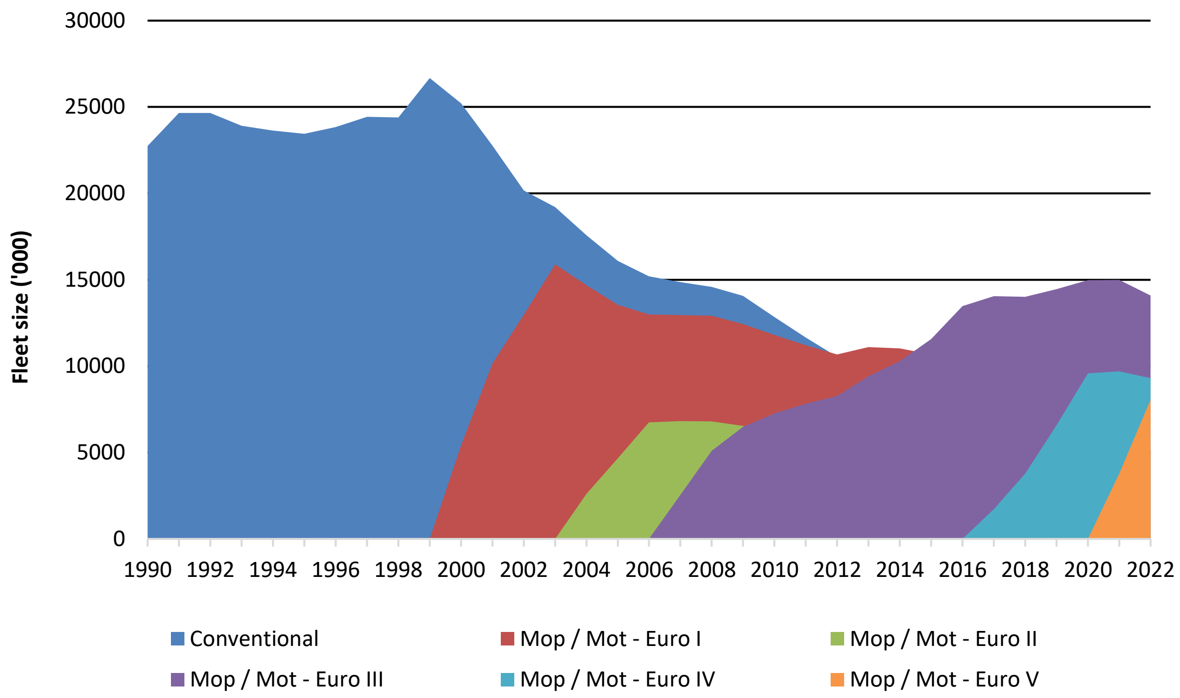


Figure 3.10.3 (b) Historic Mopeds and Motorcycle fleet in Irish transport sector

The estimation of mileage in modelling emissions from 1990-2022 has two distinct periods: 1) When data are available to estimate mileage; 2) When back extrapolation is required. The estimation of mileage for the available years is described here and the back-extrapolation is described in the Annex 3.1.14. The average mileage for each vehicle category such as petrol powered or diesel-powered passenger cars, light duty vehicles and heavy-duty vehicles are classified in the following equation according to the Euro class split above. Mileage data at the level of vehicle technology, according to engine size/unladen weight is available for 2000 and from 2008 onwards for these vehicle categories from the National Car Test (NCT) and Commercial Vehicle Roadworthiness Test (CVRT). A sample result is presented in the Figure 3.10.4 for petrol passenger car (1.4-2L), which displays average mileage data for Euro 1 to 6 categories after it has been balanced with national total fuel consumption. Some results for diesel passenger cars, LDV and HDV for the latest year are presented in the Figures 3.10.5 and 3.10.6. It is noticeable from the mileage values that the fleet average for different technology and size of vehicle is degrading with each consecutive year.

$$M_{E_{i_p}^{q},Y} = \frac{\sum_{z=l}^{z=m} M_z * N_z}{\sum_{z=l}^{z=m} N_z}$$

Where, $M_{E_{i_p}^{q},Y}$ represents Mileage for Emission Band i (vehicles penetrated the market between year p and year q), Y is the year of calculation for the mileage where Y=p, p+1, p+2,…., p+n=q (q=new technology commencement year). M_z and N_z represent the mileage and corresponding number of vehicles in Emissions band 'i', respectively. Subscript 'z' corresponds to the different vehicle tested numbers assigned during national car testing in the year Y for the emissions band 'i'.

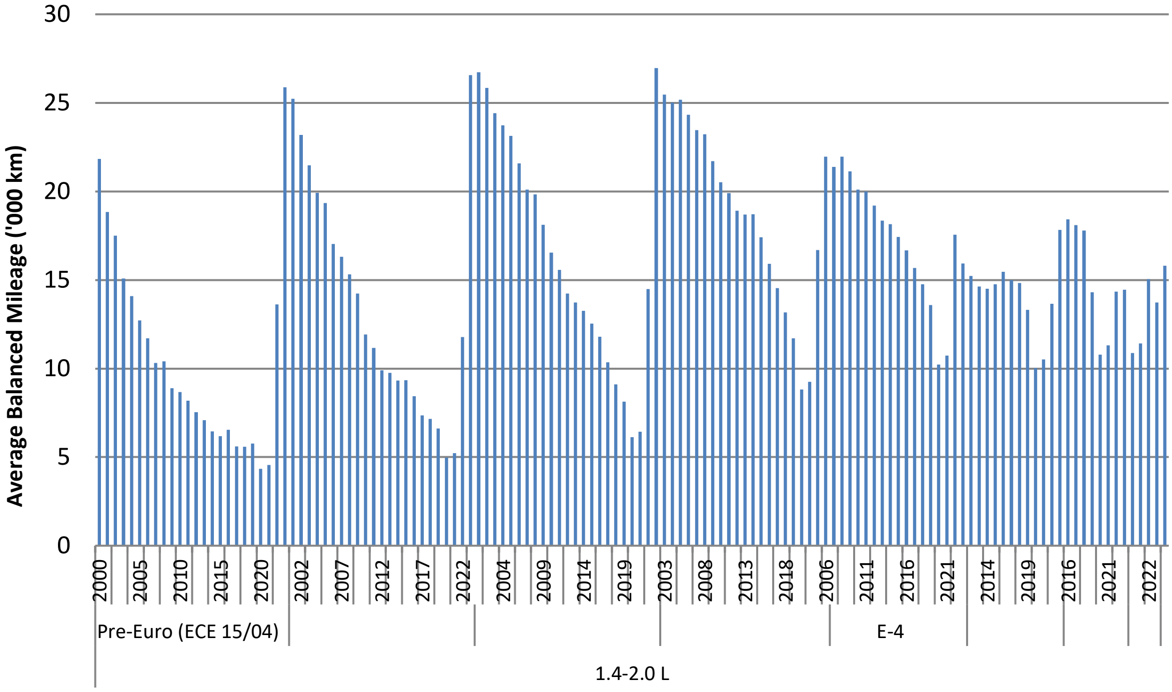


Figure 3.10.4 Average Balanced Vehicle mileage for Petrol PC 1.4-2L (2000-2022)

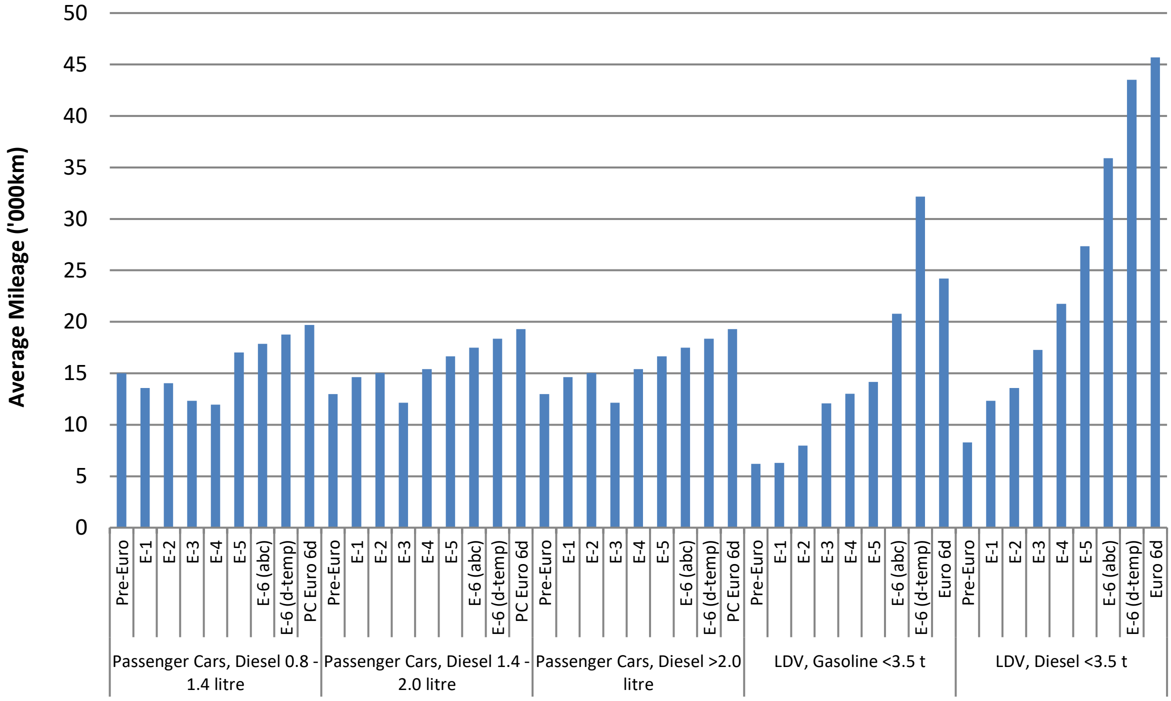


Figure 3.10.5 Average Balanced Vehicle mileage for Diesel Passenger car and LDV (2022)

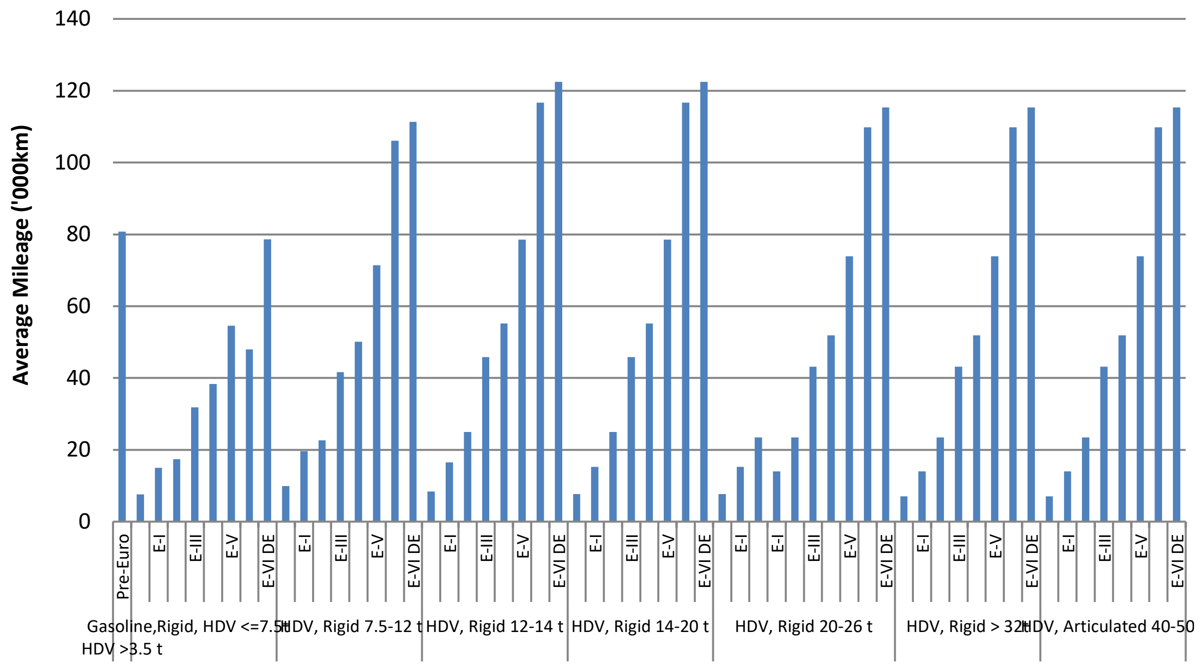


Figure 3.10.6 Average Balanced Vehicle mileage for HD Vehicle categories (2022)

Mileage data for Mopeds and Motorcycle is available from the CSO for 2001 onwards. Mileage for buses and coaches were obtained/estimated since 1999 based on annual total mileage, fleet size and passenger number.

3.2.6.2.4 Emissions modelling using COPERT

Ireland uses a detailed Tier 3 method as detailed country specific information is available. These data were used with the COPERT 5 model to estimate annual GHG emissions from 1990 to the latest inventory year. The parameters such as vehicle share in different roads, fuel tank size, canister size and percentage of fuel-injected vehicles, etc. required in COPERT were obtained for previous year's emissions inventory reports and applied similarly for this year. The sulphur content of fuels was obtained from the annual survey 2021 for fuel quality monitoring under Directive 98/70/EC. The speed data was obtained from several national surveys and is mentioned in the Annex 3.1.14.

3.2.6.2.5 COPERT 5 Background

COPERT 5 (Computer Programme to calculate Emissions from Road Transport) is an emissions model used to calculate emissions from the road transport sector. It draws its origins from a methodology developed by a working group which was set up explicitly for this purpose in 1989 (COPERT 85). This was then followed by COPERT 90 (1993), COPERT II (1997), COPERT III (1999) and COPERT IV 11.3 (2015). The current version COPERT 5 (5.7.1 – Sep 2023) is a synthesis of results of several large-scale activities and dedicated projects, such as:

- Dedicated projects funded by the Joint Research Centre / Transport and Air Quality Unit;
- The annual work-programme of the European Topic Centre for Air Pollution and Climate Change Mitigation (ETC/ACM);

- The European Research Group on Mobile Emission Sources (ERMES) work programme;
- The MEET project (Methodologies to Estimate Emissions from Transport), a European Commission (DG VII) sponsored project within 4th Framework Program (1996-1998);
- The PARTICULATES project (Characterisation of Exhaust Particulate Emissions from Road Vehicles), a European Commission (DG Transport) PROJECT within the 5th Framework Program (2000-2003);
- The ARTEMIS project (Assessment and Reliability of Transport Emission Models and Inventory Systems), a European Commission (DG Transport) PROJECT within the 5th Framework Program (2000-2007);
- A joint JRC/CONCAWE/ACEA project on fuel evaporation from gasoline vehicles (2005-2007) etc.

3.2.6.2.6 COPERT 5 Methodology

The methodology in COPERT 5 is the part of the EMEP/EEA air pollutant emission inventory guidebook 2019 and is consistent with the 2006 IPCC Guidelines for the calculation of GHGs. In the current version of COPERT 5 emissions are estimated based on the energy rather than the fuel use.

The emissions from biodiesel and bioethanol are calculated in COPERT as the biofuels are entered in the Statistical Energy Consumption input to COPERT. The COPERT 5 model has 5 fuel entries for Ireland: gasoline, diesel, LPG, bioethanol and biodiesel.

COPERT does not disaggregate the emissions for biofuels (i.e. biodiesel and bioethanol) from the fossil portion. Appropriate blends are specified within the model for the relevant vehicle categories (e.g. 95per cent fossil; 5 per cent Biodiesel or B5) and the emissions are calculated (fossil + biofuel) per fleet category.

In order to balance the statistical and the calculated energy consumption the software matches the fossil/bio energy consumption ratio defined in the statistical values by modifying the blend type and blend share and in turn the average mileages are updated.

In terms of calibration, we follow the formal step-by-step process which is in-built within the software. We use country-specific data where possible and default factors in other instances. Following the model run, we carry out cross-checks to ensure mileage is adjusted by comparing the input data with the updated modified data.

Total emissions for N_2O and CH_4 as an output from the model correspond exactly with the CRF submission for road transportation. The model provides emissions by vehicle type and the model assumes each vehicle consumes the same split of biofuel and fossil fuel. The option to balance the mileage based on statistical fuel consumption in COPERT 5 was selected.

The methodology supports the calculation of CO_2 and two other greenhouse gases (CH_4 and N_2O) according to four broad vehicle technologies that are consistent with the CRF categories:

- 1.A.3.b.i Passenger cars;
- 1.A.3.b.ii Light-duty trucks (< 3.5 t);
- 1.A.3.b.iii Heavy-duty vehicles (> 3.5 t and buses);

- 1.A.3.b.iv Motorcycles (and mopeds).

Exhaust emissions from road transport arise from the combustion of fuels such as gasoline, diesel, liquefied petroleum gas (LPG), and natural gas in internal combustion engines. For more detailed emission estimation methods, the CRF categories (1.A.3.b.i-iv) are often subdivided according to the fuel used (in the Irish model there are three fuel types: gasoline, diesel and LPG), and by the engine size, weight or technology level of the vehicle, giving a total of 282 vehicle categories.

In the following Tier 3 approach, total exhaust emissions from road transport are calculated as the sum of 'hot' emissions (when the engine is at its normal operating temperature) and emissions during transient thermal engine operation (named 'cold-start' emissions). It should be noted that, in this context, the word "engine" is used as shorthand for "engine and any exhaust after treatment devices". The distinction between emissions during the 'hot' stabilised phase and the transient 'warming-up' phase is necessary because of the substantial difference in vehicle emission performance during these two conditions. Concentrations of some pollutants during the warming-up period are many times higher than during hot operation, and a different methodological approach is required to estimate the additional emissions during this period.

To summarise, total emissions can be calculated by means of the following equation:

$E_{TOTAL} = E_{HOT} + E_{COLD}$

where,

E_{TOTAL} = total emissions (g) of any pollutant for the spatial and temporal resolution of the given input,

E_{HOT} = emissions (g) during stabilised (hot) engine operation,

E_{COLD} = emissions (g) during transient thermal engine operation (cold start).

Hot exhaust emissions depend upon a variety of factors, including the distance that each vehicle travels, its speed (or road type), its age, its engine size and its weight. The basic formula for estimating hot emissions for a given time period, and using experimentally obtained emission factors, is:

Emission [g] = EF [g/km] × number of vehicles [veh] × mileage per vehicle [km/veh]

In the case of annual emission estimation, the above equation includes different emission factors; numbers of vehicles and mileage per vehicle are used for each vehicle category and class, where:

$E_{HOT;\, i,\, k,\, r} = N_k \times M_{k,r} \times e_{HOT;\, i,\, k,\, r}$

where,

$E_{HOT;\, i,\, k,\, r}$ = hot exhaust emissions of the pollutant i [g], produced in the period concerned by vehicles of technology k driven on roads of type r,

N_k = number of vehicles [veh] of technology k in operation in the period concerned,

$M_{k,r}$ = mileage per vehicle [km/veh] driven on roads of type r by vehicles of technology k,

$e_{HOT;\, i,\, k,\, r}$ = emission factor in [g/km] for pollutant i, relevant for the vehicle technology k, operated on roads of type r.

Cold starts result in additional exhaust emissions. They take place under all three driving conditions. However, they are most likely for urban and rural driving, as the number of starts in highway conditions is relatively limited. In principle, they occur for all vehicle categories, but emission factors are only available, or can be reasonably estimated, for gasoline, diesel and LPG cars and – assuming that these vehicles behave like passenger cars – light-duty vehicles, so that only these categories are covered by the methodology. Moreover, they are not considered to be a function of vehicle age. Cold-start emissions are calculated as an extra emission over and above the emissions that would be expected if all vehicles were only operated with hot engines and warmed-up exhaust catalysts. A relevant factor, corresponding to the ratio of cold over hot emissions, is applied to the fraction of kilometres driven with a cold engine. This factor varies from country to country. Driving behaviour (varying trip lengths) and climatic conditions affect the time required to warm up the engine and/or the catalyst, and hence the fraction of a trip driven with a cold engine.

Cold-start emissions are introduced into the calculation as additional emissions per km using the following formula:

$E_{COLD;\,i,\,j} = \beta_{i,\,k} \times N_k \times M_k \times e_{HOT;\,i,\,k} \times (e^{COLD} / e^{HOT}|_{i,k} - 1)$

where,

$E_{COLD;\,i,\,k}$ = cold-start emissions of pollutant i (for the reference year), produced by vehicle technology k,

$\beta_{i,\,k}$ = fraction of mileage driven with a cold engine or the catalyst operated below the light-off temperature (300^{O}C) for pollutant i and vehicle technology k,

N_k = number of vehicles [veh] of technology k in circulation,

M_k = total mileage per vehicle [km/veh] in vehicle technology k,

$e^{COLD} / e^{HOT}|_{i,k}$ = cold/hot emission quotient for pollutant i and vehicles of k technology.

Vehicle emissions are heavily dependent on the engine operation conditions. Different driving situations impose different engine operation conditions, and therefore a distinct emission performance. In this respect, a distinction is made between urban, rural and highway driving. Different activity data and emission factors are attributed to each driving situation. Cold-start emissions are attributed mainly to urban driving (and secondarily to rural driving), as it is expected that there are a limited number of cold starts at highway conditions. Therefore, as far as driving conditions are concerned, total emissions can be calculated by means of the equation:

$E_{TOTAL} = E_{URBAN} + E_{RURAL} + E_{HIGHWAY}$

where,

E_{URBAN}, E_{RURAL} and $E_{HIGHWAY}$ are the total emissions (g) of any pollutant for the respective driving situations.

Total emissions are calculated by combining activity data for each vehicle category with appropriate emission factors. The emission factors vary according to the input data (driving situations, climatic conditions). Also, information on fuel consumption and fuel specification is required to maintain a fuel balance between the figures provided by the user and the model calculations. More details on the methods, vehicle specifications, calculation algorithms and other parameters used for calculating relevant road traffic exhaust emissions can be found in EMEP/EEA emission inventory guidebook, 2019.

The fossil fuel content of biofuels was calculated in this submission for the relevant years 2012-2021 using the “Note on fossil carbon content in biofuels” (Sempos, 2018). The fatty acid methyl ester (FAME) content of biodiesel was taken from Irelands National Oil Reserves Agency (NORA) reports. The carbon content of FAME default value of 76.5 per cent was used and the default fossil part of this carbon content of 5.4 per cent was used to estimate the fossil emissions associated with FAME.

3.2.6.2.7 Uncertainties and Time-series Consistency

The CO_2 emission factor uncertainty is 2.5 per cent and is subject to fuel consumption and fuel blends as per the 2006 IPCC Guidelines. Uncertainties in emission factors for CH_4 and N_2O are in the range of 71 and 68 per cent respectively and depend on a number of factors including fuel composition (e.g. fuel adulteration, sulphur content), uncertainties in fleet age distribution and technical characteristics of vehicle stock, uncertainties in combustion conditions (climate, altitude), driving practices, such as speed, proportion of running distance to cold starts, or load factors, etc. These sources of uncertainty may be classified into three broad categories: fuel related, model parameter related, and activity data related (i.e. stock and mileage). The fuel data has been taken from the SEAI national energy balance where fuel sales data are well known. The COPERT software covers most of the parameters (e.g. temperature, load factors etc.) that reduced model parameter related uncertainty. The vehicle stock and mileage were calculated at the most disaggregated level of data for most of the vehicle classes and consistency was ensured between fleet and mileage in terms of both relative mileage distributions among vehicle categories as well as fleet mileage in relation to vehicle class commencement years.

A consistent time series of fuel data was obtained from the national energy balance. In addition, the historical vehicle fleet from national statistics (Vehicle Bulletin of Driver Statistics) provides a very detailed dataset which is further disaggregated with additional information from other published sources as well as expert judgment. The final product of this process provides a consistent time series of fleet data from 1990 to 2022.

The 2024 submission consists of a number of changes/improvements to the disaggregated input data:

- Previously, the mopeds and motorcycles fleet were divided into Euro class I, II and III. The 2024 submission includes for the latest euro classes i.e. Euro I to V inclusively
- A correction was carried out to the diesel consumption of fuel whereby approximately 7,600 terajoules was added between 2017 and 2021. This equates to an annual increase of 1.1 percent in emissions. This additional diesel was reallocated from industry, services, residential and agriculture.
- The new COPERT model version included a number of changes e.g.:
    - Updated emission factors of Euro VI diesel and diesel hybrid buses
    - Updated emission factors of non-exhaust emission factors
    - Corrected calculation for cold emissions of CO, NOx, VOC for petrol and diesel PCs and LCVs
    - Bug corrections and update to emission factors

- Natural gas was included as a fuel for the first time in this submission. The fuel was allocated to vehicles within the heavy goods vehicle category. This additional fuel source accounts for approximately 1 kt CO_2e per annum since 2014.

Different forms of disaggregated km travel data are available for different time series: passenger cars since 2000, LDV and HDV since 2008, bus and coaches since 2005 and mopeds and motorcycles since 2000. These datasets have been back extrapolated using appropriate regression methods with macro-economic variables (Section 3.1.14 of Annex 3.1.B).

3.2.6.2.8 Category-specific QA/QC and verification

A QA/QC check for the fleet and km travel was conducted. Verification of the emissions figures against estimated emissions from the total fuel ensured that the result is applicable to Ireland. The fleet data was obtained from national statistical bulletin and disaggregated into different emissions technology following several steps. Every step of disaggregation included cross checks against the total fleet size.

In the case of vehicle mileage estimation, NCT and CVRT data is provided by SEAI. This is then processed and compared with CSO data and knowledge of disaggregation according to published journal articles.

However, in 2021, NCT mileage data for passenger cars was unavailable to a large extent due to the continuation of COVID-related lockdown periods and as a result the following methodology was applied for 2022:

Step 1

- Balanced mileage linked across from last year's file for 1990-2021
- Mileage data is sourced from national testing centres and processed for all passenger cars, light goods vehicles and heavy goods vehicles so that average yearly mileages are allocated per engine size and euro class.
- Bus and coach annual mileage is sourced from national bus operator's annual publication or if unavailable, extrapolated subject to the fuel increase / decrease. The motorcycle and moped mileage is sourced from the national transport bulletin produced each year.

Step 2

- COPERT model ran unbalanced
- The differences in petrol are spread across all petrol vehicles i.e. the adjusted mileage was multiplied by the excess / deficit in fuel
- The diesel car mean mileages were left untouched whilst the excess or lower fuel is distributed amongst the commercial fleet so as to keep the passenger car fleet annual mileage as close as possible to the reported figures.

Step 3

- Once the statistical fuel input is within approx. 0.5 per cent of the fuel output (energy consumption), the model can be run balanced.

COPERT 5.7.1. was then run in "energy balance" mode and in turn the small difference between the statistical quantities input and the energy consumption values was balanced.

For early years within the timeseries, the mileage back extrapolation was modelled using software applications like SPSS, R, and MS Excel and ensured consistency with approaches found in published literature. An analysis was carried out between each version change to ensure no discrepancies had occurred with the input data. Once satisfied with the input data, further interrogation and analysis of the output findings were undertaken to ensure the findings for various gases aligned with our expectations and input changes.

3.2.6.2.9 Category-specific Recalculations

1.A.3.b: The most recent submission included a number of changes and improvements to the input data as listed above in section 3.2.6.2.7. As a result of those changes, we have seen on average a recalculation of 0.2 per cent per annum over the entire timeseries within this submission compared to last year's submission.

- Across the time series from 1990-2021, emissions from 1.A.3b Road Transport increased by on average 0.2 per cent. The largest recalculations occurred between 2017 to 2021, where a total of 7,600 TJ of road diesel was added to the sector, resulting in an average annual increase in emissions of 1.1% for that period. This additional diesel was reallocated from industry, services, residential and agriculture.
- CO_2 emissions are responsible for 99 per cent of all road transport emissions, however, we do encounter some variation within CH_4 and N_2O throughout the timeseries. The recalculation differences for CH_4 and N_2O have been relatively small in absolute terms i.e. (0.03 kt CH_4 and 0.3 kt N_2O per annum). There was a bug in the cold emissions parameter for both NOx (and therefore N_2O was affected) and CH_4 for cars and LCVs in 5.6.1 (model version used within 2023 submission for CH_4 / N_2O emission factors). This has now been corrected in the 5.7.1 version (model version used within 2024 submission). Some of the Euro VI vehicles were overestimated while some of the older classes of from Euro II to Euro 5 N1-1 for petrol.
- Natural gas included as a fuel for the first time within road transport. The fuel was allocated to vehicles within the heavy goods vehicle category. This additional fuel source accounts for approximately 1 kt CO_2e per annum since 2014.

Overall recalculations are presented in Table 3.10a and 3.10b.

3.2.6.2.10 Category-specific Planned Improvements

The inventory agency intends to use the latest COPERT model software when available.

3.2.6.3 Railways (1.A.3.c), Navigation (1.A.3.d) and Other Transportation (1.A.3.e)

3.2.6.3.1 Category Description

Emissions from railways (1.A.3.c) are estimated for diesel used in shunting or yard locomotives, railcars and line haul locomotives. There are no coal-fired locomotives in regular use in Ireland. Emissions from navigation (1.A.3.d) are estimated for residual oil and diesel used in all water borne transport including recreational craft. Emissions from other Transportation (1.A.3.e) are estimated for natural gas use in offshore natural gas production platforms and in natural gas pipeline compressor stations.

3.2.6.3.2 Methodological Issues

The CO_2 emissions under *1.A.3.c Railways* and *1.A.3.d Navigation* are estimated using a Tier 1 approach, equations 3.4.1 and 3.5.1 from the 2006 IPCC Guidelines, from the amount of oil used by these activities as recorded in the energy balance and the country specific emission factors for oil. The emissions of CH_4 and N_2O are estimated using the 2006 IPCC Guidelines default emission factors. Emissions factors used in these two sub-categories are presented in Table 3.5.

Table 3.5 Emission factors for Rail and Navigation

IPCC Category	Fuel	CO_2 t/TJ	Reference	CH_4 kg/TJ	N_2O kg/TJ	Reference
Railways	Gasoil	73.30	CS	4.15	28.60	2006 IPCC Guidelines Table 3.4.1
Navigation	Fuel Oil	76.00	CS	7.00	2.00	2006 IPCC Guidelines Table 3.5.3
Navigation	Gasoil	73.30	CS	7.00	2.00	2006 IPCC Guidelines Table 3.5.3

The emissions reported in sub-category *1.A.3.e Other Transportation* are due to natural gas combustion at offshore production platforms and in natural gas pipeline compressor stations. The fuel use is estimated as the difference between the value given for natural gas under own use/losses in the national energy balance (Table 4.B of Annex 4) and the amount of gas estimated to be lost from the distribution network, as reported under fugitive emissions in sub-category *1.B.2.b Natural Gas*. The country-specific emission factor for CO_2 and the default values for CH_4 and N_2O (Table 2.2, Vol 2, Chapter 2 of the 2006 IPCC Guidelines) used in the Energy Sector (Section 3.1.2) are used. Emissions are reported as “NO” not occurring for subcategory 1.A.3.e.ii as there are no known emissions related to off road vehicles in category “1.A.3.e Other transportation”.

3.2.6.3.3 Uncertainties and Time-series Consistency

The uncertainties applicable to Railways, Navigation and Other Transportation are provided in Annex 2. The emission time series for 1990-2022 is consistent. Key activity data such as fuel use statistics are available for all years and are used in a consistent manner.

3.2.6.3.4 Category-specific QA/QC and verification

Standard QA/QC procedures have been applied to these categories. Details of Ireland’s QA/QC process can be found in Chapter 1 of this report.

3.2.6.3.5 Category-specific Recalculations

There are no recalculations in Railways (1.A.3.c) and Other Transportation (1.A.3.e) in this submission.

Emissions from 1.A.3.d National Navigation were revised for 2021, with emissions increasing by 3.3 per cent or 11.6 kt CO_2 eq.

3.2.6.3.6 Category-specific Planned Improvements

There are no planned improvements for this category.

3.2.7 Other Sectors (1.A.4)

3.2.7.1 Category Description

The CRF sub-category *1.A.4 Other Sectors* covers combustion sources in the commercial/institutional (1.A.4.a), residential (1.A.4.b) and Agriculture/Forestry/Fishing (1.A.4.c) sectors. The residential sub-category *1.A.4.b* remains the most important source of emissions in this category in Ireland. This is evident from Figure 3.11, which shows the trend in the principal components of emissions in *1.A.4 Other Sectors* over the time series.

While the shift from carbon-intensive fuels, such as coal and peat, to oil and natural gas in *1.A.4.b* has been sufficient to maintain sectoral emissions relatively constant up to 2007, the benefits from fuel switching have been largely realised and the emissions from oil and gas are increasing in line with higher overall fuel consumption resulting from greater housing stock and population.

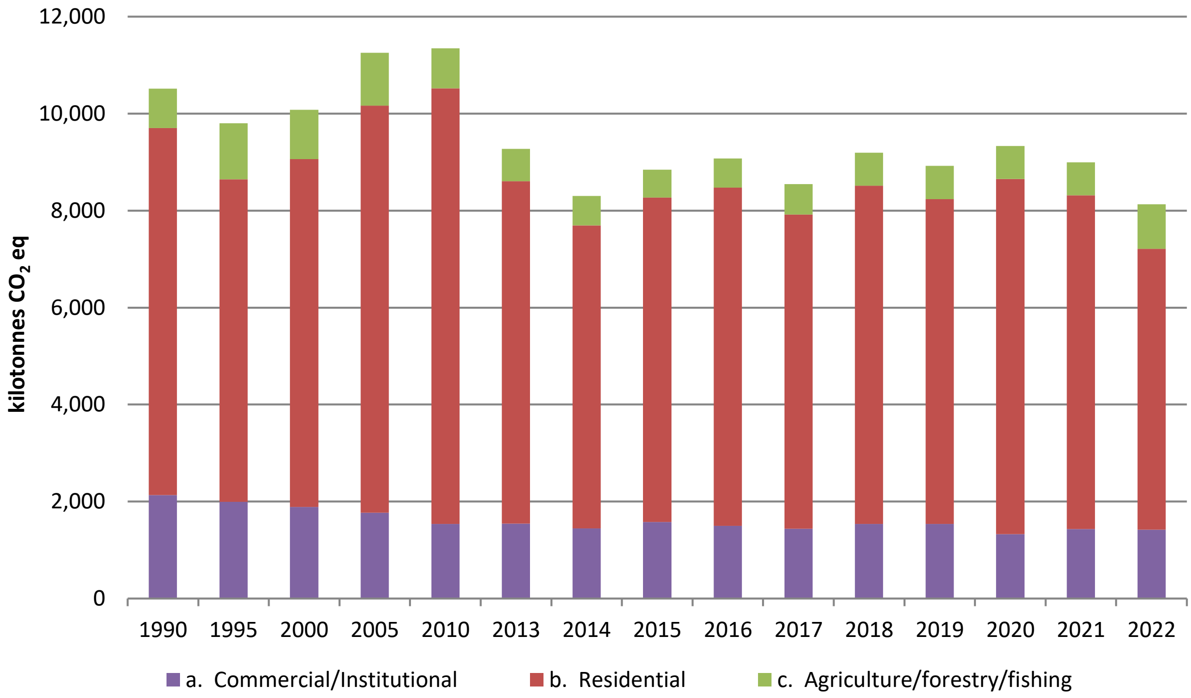


Figure 3.11 Emissions from 1.A.4 Other Sectors 1990-2022

3.2.7.2 Methodological Issues

Table 3.1.1 of Annex 3.1.A shows the estimation of emissions for sub-category *1.A.4 Other Sectors*, using the fuel quantities as provided in the national energy balance (Table 4.B of Annex 4).

The inventory agency uses country-specific emission factors for CO_2, including that for petroleum coke referred to in methodology for 1.A.2 Manufacturing Industries and Construction (Section 3.2.5.2), and 2006 IPCC Guidelines default values for CH_4 and N_2O. The energy balance provides no indication on the specific end-use of gasoil in the agricultural sector *1.A.4.c(i-ii)* or for forestry activities *(1.A.4.c iii)*. For agricultural activities, a split based on information from agricultural experts (10 per cent stationary sources and 90 per cent mobile sources) is used by the inventory agency to distinguish between the use of this fuel in stationary and mobile combustion sources. This split has no bearing on emissions of CO_2, but it is important in relation to CH_4 or N_2O and the indirect greenhouse gases.

Emissions factors used for stationary and mobile sources in sub-category *1.A.4.c(i-ii) agriculture*, are presented in Table 3.6. No biomass is used as fuel in sub-category *1.A.4.c(i-ii) agriculture*.

Emissions from charcoal used for cooking are reported in sub-category *1.A.4.b* for all years. The quantity of charcoal used in Ireland is provided by the CSO and emission factors used for estimating emissions from this biomass fuel are presented in Table 3.7.

In this submission, there are small recalculation changes based on a revision to the historical energy balances going back as far as 1990. This is because SEAI have incorporated an update to the data set on business energy use. This is the Business Energy Use Survey (BEUS), first published by the Central Statistics Office (CSO) in December 2018 and updated annually. This valuable data source provides a basis for the breakdown of energy use in the commercial services, public services and industrial sectors. SEAI have revised the National Energy Balances from 1990 to 2019 incorporating this new improved data. In some cases, the revisions to estimates of business energy use have had knock on effects in other sectors, particularly residential, leading to revisions there also.

The national energy balance was previously based on a top-down approach whereas the new Business Energy use survey compiles aggregated data based on a bottom-up approach with individual businesses grossed to national level. The revised bottom-up approach now draws on a cross-sourcing of data using the emissions trading scheme, large industry energy network, public sector energy programme, census of industrial production and others. The revised approach (BEUS) has focused on data from 2009 to 2019 with the 2018 -2022 splits based on the latest 2018 BEUS splits with a further recalculation in this year's submission as a result of greater access to national electricity data, which has allowed for more accurate reweighting to a number of categories.

Table 3.6 Emission factors for fuel use in Agriculture

IPCC category	Fuel	CO_2 t/TJ	Reference	CH_4 kg/TJ	N_2O kg/TJ	Reference
Agriculture Stationary	Gasoil	73.30	CS	10.00	0.60	2006 IPCC Guidelines Table 3.4.1
Agriculture Mobile	Gasoil	73.30	CS	4.15	28.60	2006 IPCC Guidelines Table 3.3.1
Fishing	Gasoil	73.30	CS	7.00	2.00	2006 IPCC Guidelines Table 3.5.3

Table 3.7 Emission factors for Charcoal use in Residential

IPCC category	Fuel	Gas	kg/TJ	Reference
Residential	Charcoal	CO_2	112,000	2006 IPCC Guidelines Table 2.5
Residential	Charcoal	CH_4	200	2006 IPCC Guidelines Table 2.5
Residential	Charcoal	N_2O	1	2006 IPCC Guidelines Table 2.5

3.2.7.3 Uncertainties and Time-series Consistency

The uncertainties applicable to sub-category 1.A.4 Other Sectors are provided in Annex 2. The emission time series for 1990-2022 is consistent. Key activity data such as fuel use statistics are available for all years and are used in a consistent manner.

3.2.7.4 Category-specific QA/QC and verification

Standard QA/QC procedures have been applied to these categories. Details of Ireland's QA/QC process can be found in Chapter 1 of this report.

3.2.7.5 Category-specific Recalculations

There are recalculation changes in this submission due to the reallocation of oil and natural gas quantities historically between 1.A.2 'Manufacturing Industries and Construction', 1.A.3 'Transport', and 1.A.4 'Other Sectors'.

- In 1.A.4.a, Commercial/Institutional, these revisions included the reallocation oil into 1.A.2 Manufacturing Industries and Construction, 1.A.3.b Road Transport, and 1.A.4.b Residential, with an average of 118 TJ of oil per annum from 1990 to 2019 and increasing to 1,450 TJ of oil per annum in 2020 and 2021. From 2001 to 2021, an average of 726 TJ of natural gas was added to the sector from 1.A.2. Manufacturing Industries and Construction, except for 2020 where 1,742 TJ of natural gas was reallocated from the sector into 1.A.2. In terms of emissions, these changes resulted in an average recalculation of -0.4 per cent from 1990-2001, +2.2 per cent from 2002-2019, and -13.5 and -3.9 per cent in 2020 and 2021 respectively.
- In 1.A.4.b Residential, the historical revisions include minor quantities of oil being reallocated between 1.A.2 'Industry' and 1.A.4.a 'Commercial/Institutional' from 1990-2016 with an average change of 40 TJ per annum. An average of 1,116 TJ of oil was moved from the sector into 1.A.2 Manufacturing Industries and Construction and 1.A.3.b Road Transport from 2017-2021. As a result of these reallocations, emissions there was an average annual recalculation of -0.03 per cent from 1990-2016 increasing to -1.2 per cent from 2017-2021.
- In 1.A.4.c Agriculture/Forestry/Fishing, there were recalculations in 2019, 2020, and 2021 for this subsector due to minor changes in oil quantities for these years resulting in an average increase of 0.5 per cent for these years.

These redistributions caused a minor average decrease of 0.1 per cent in emissions per annum over the entire timeseries within the 1.A.4 'Other Sectors' category as a result of the reallocation of fuels occurring predominantly within its subsectors. See table 3.10.

3.2.7.6 Category-specific Planned Improvements

As there are no fuels allocated to the sector 1A4aii Commercial/Institutional: Mobile or 1A4bii Residential: Household and Gardening (Mobile) in national energy statistics, it is accounted for in category 1A3b Road Transport where all gasoline fuel is fully accounted. The inventory agency had previously tendered and finalized research to be undertaken to quantify the extent and amounts of fuel used in off-road mobile combustion, but the COVID-19 pandemic had a negative impact on its outcome as it affected the collection of activity data. As a result, it was concluded that changing the methodology to estimate emissions from off-road vehicles and other machinery to take into account the results of the research project would not improve the accuracy of the inventory.

3.2.8 Other (fuel combustion activities) (1.A.5)

Emissions associated with military operations, stationary or mobile, are included elsewhere (IE) under category 1.A.4.a for stationary and category 1.A.3 for mobile. Ireland's national energy statistics do not provide a fuel use split for military operations.

3.3 Fugitive Emissions (1.B)

Ireland has no coal or oil industries and therefore fugitive emissions of greenhouse gases are limited to those associated with oil refining/storage, natural gas production and distribution for the timeseries 1990-2022 and from coal mining for the period 1990-1995 (only emissions from abandoned mines are reported after 1995).

3.3.1 Coal Mining and Handling (1.B.1.a)

3.3.1.1 Category Description

The national energy balance includes coal mined in the years 1990 to 1995. The last commercial coal mine in Ireland was closed in 1995. Ireland had no surface coal mines hence all emissions are associated with *1.B.1.a. Underground mines*. The CH_4 emissions from underground mines are calculated for three sub-categories:

- *1.B.1.a.1(i)* Emissions from *Underground mining activities* for years 1990-1995;
- *1.B.1.a.1(ii)* Emissions from *Post-mining activities* for years 1990-1995;
- *1.B.1.a.1(iii)* Emissions from *Abandoned underground mines* for full timeseries 1990-2022.

Only three mines (Arigna, Rossmore and Castlecomer) were active in 1990 when production was reported at 25 kt. Arigna mine closed in 1990 and production of coal between 1991 and 1995 was reported at only one kt per year. The last two mines: Rossmore and Castlecomer, ceased operation in 1995. Emissions from underground mines for three activity sub-categories are presented in Figure 3.12.

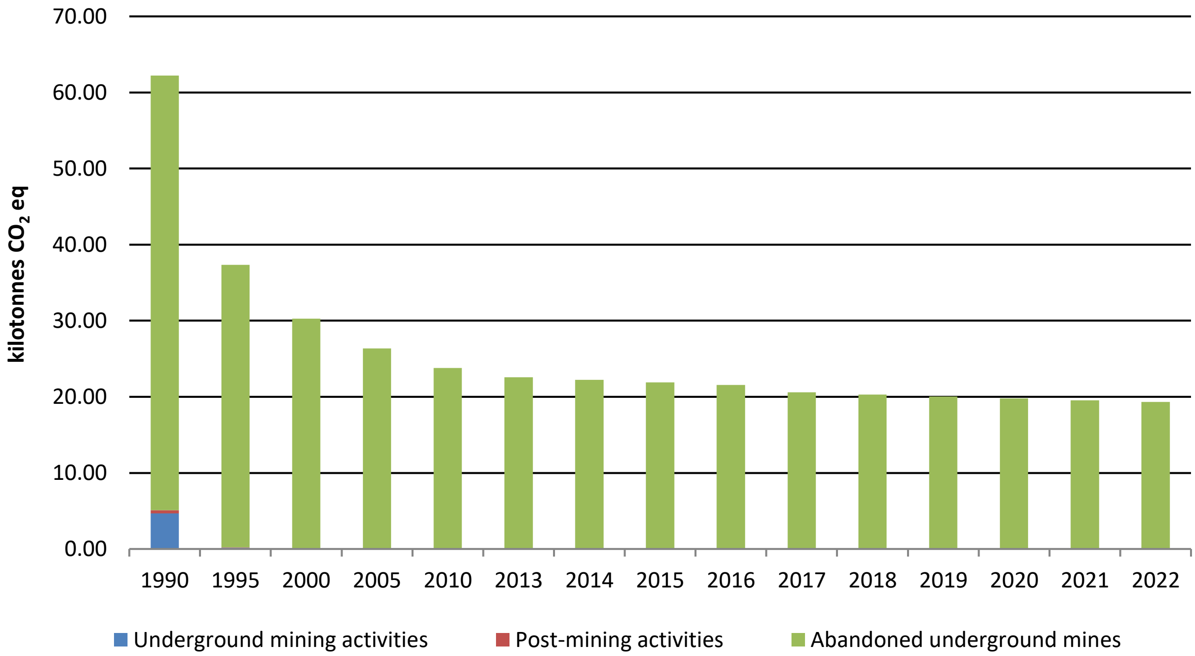


Figure 3.12 Fugitive emissions from Underground Coal Mines 1990-2022

3.3.1.2 Methodological Issues

The emission factors used in category *1.B.1.a Coal Mining and Handling* and the resulting time series of fugitive CH_4 emissions are based on the 2006 IPCC Guidelines default values and are presented in Tables 3.8 and 3.9.

The first two categories, *Underground mining activities* and *Post-mining activities* were applicable during the years of operation of coal mines in Ireland (1990-1995).

Table 3.8 Emission factors for underground mining and post-mining activities

IPCC category	CH_4 EF	Unit	CH_4 Conversion Factor	Unit	Reference
Underground mining activities	10	m^3/t	$0.67 \bullet 10^{-6}$	kt CH_4 /m^3	2006 IPCC Guidelines Equation 4.1.3
Post-mining activities	0.9	m^3/t	$0.67 \bullet 10^{-6}$	kt CH_4 /m^3	2006 IPCC Guidelines Equation 4.1.4

After mining has ceased, abandoned coal mines may also continue to emit methane, hence the third category *Abandoned underground mines* is applicable for the emission time series 1990-2020. This category is based on the number of existing abandoned mines (remaining unflooded) that were closed-down within the six time-bands:

- Years 1990 – 1925;
- Years 1926 – 1950;
- Years 1951 – 1976;
- Years 1976 – 2000;
- Years 2001 – 2025;
- Years 2026 - 2050.

In the time band 1900-1925, the default lower percentage of gassy mines is zero and the consequent emissions are not occurring. In the time band 2001-2025, there were no mines in Ireland closed within that period hence there were no emissions resulting from this time band. Emissions are calculated for the time bands 1926-2000 only. Ireland does not have a history of methane explosions or outbursts and mines were relatively shallow, with the main coal seam reported to be at depths of between 60 and 200m from the surface. Therefore, the low range of the default fraction of gassy mines was seen to be more representative for the Irish conditions.

Table 3.9 Emission factors for Abandoned underground mines (1.B.1.a.1(ii))

Time band	Number of existing abandoned mines	Fraction of gassy mines (%)	CH_4 EF	Unit	CH_4 Conversion Factor	Unit	Reference
1926 - 1950	9	3	0.343 -0.270	Mm^3 /mine	0.67	kt CH_4 /Mm^3	2006 IPCC Guidelines, Eq. 4.1.10, Table 4.1.5. 2019 IPCC Guidelines Refinement, Eq. Table 4.1.6
1951 - 1975	19	5	0.478 -0.324	Mm^3 /mine	0.67	kt CH_4 /Mm^3	2006 IPCC Guidelines, Eq. 4.1.10, Table 4.1.5. 2019 IPCC Guidelines Refinement, Eq. Table 4.1.6
1976 - 2000	20	8	1.561 - 0.413	Mm^3 /mine	0.67	kt CH_4 /Mm^3	2006 IPCC Guidelines, Eq. 4.1.10, Table 4.1.5. 2019 IPCC Guidelines Refinement, Eq. Table 4.1.6

3.1.1.3 Uncertainties and Time-series Consistency

The uncertainties applicable to Coal Mining and Handling are provided in Annex 2. The emission time series for 1990–2021 is consistent. Key activity data such as quantities of coal mined, and other mine statistics are available for all applicable years and are used in a consistent manner.

3.1.1.4 Category-specific QA/QC and verification

Standard QA/QC procedures have been applied to this category. Details of Ireland’s QA/QC process can be found in Chapter 1 of this report.

3.1.1.5 Category-specific Recalculations

There were no recalculations in this submission.

3.1.1.6 Category-specific Planned Improvements

There are no planned improvements for this category.

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

3.3.2.1 Category Description

Natural gas has been produced from gas fields off the south coast of Ireland since the 1970s but this source is being rapidly depleted. Substantial reserves of natural gas have been discovered off the west coast which came into production on the last day of 2015.

3.3.2.2 Methodological Issues

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

The level of drilling exploration activity in Ireland is very low compared to other jurisdictions. Only 7 wells were drilled during the period 2009 – 2022. During the period 1990-2022 a total of just over 65 wells were drilled offshore in Ireland, which includes 10 development wells. Most of these wells were permanently plugged and abandoned upon completion of the drilling operations of that number, a total of 23 wells were tested (i.e. flow tested). During drilling operations any influx of any hydrocarbons or water into the wellbore from the surrounding formation is prevented by using a sufficiently weighted mud. This is a fundamental and critical safety element of drilling operations and, as such, there are no fugitive hydrocarbon emissions during drilling operations.

During a UNFCCC review in 2022 it was recommended that given exploratory drilling activity occurs and despite the use of heavy drilling muds to prevent hydrocarbons from escaping the well, CO_2 and CH_4 emissions from exploration are considered to be below the significance threshold rather than not occurring. Emissions from exploration are reported as NE.

3.3.2.2.2 Production (1.B.2.b.2) and Processing (1.B.2.b.3)

Only two companies are involved in natural gas production and processing in Ireland and one of these has since successfully decommissioned its gas fields and facilities in July 2023[1]. Emissions to the atmosphere from offshore gas production platforms are reported to the Department of Environment, Climate and Communications (DECC) under the OSPAR Convention. Reports have been obtained for several years in the time series and are currently covered by MOU with the inventory agency. These reports clarify that emissions were conservatively assumed to be 100 per cent CH_4 even though they might contain small amounts of CO_2 and other gases.

A 2018 UNFCCC review determined that these reported emissions should be regarded as CH_4 emissions from venting and that the reporting of emissions from production and processing of natural gas should be considered further. See section 3.3.2.2.4 on *Venting and Flaring (1.B.2.c)* below.

Data from both companies, relating to fugitive emissions from Production and Processing of natural gas, has determined that the default EFs and methodologies from the 2006 IPCC Guidelines are not appropriate. In the case of Vermillion Energy (formerly Shell), fugitive emissions are required to be monitored at the gas terminal on a bi-annual basis under industrial licence conditions. The reported cumulative fugitive CH_4 emissions from 2017 to 2022 are 12.7 tonnes, with 0.49 tonnes emitted for 2022. This company started production on the last day of 2015 and did not have an estimated fugitive release for 2016 so the inventory agency estimated emissions for 2016 based on the average of estimated releases for the available years.

Kinsale Energy report that, for non-intentional gas releases, estimates of the mass released are based on the pressure, estimated leak size and the duration of the release. If the release is more than the threshold of 1 kg, it must be reported as a Petroleum Incident Notification to the Commission for Regulation of Utilities in Ireland (CRU). In 2016 and 2017, they reported no releases above this threshold (estimated total 0.84 kg and 0.68 kg respectively) and in 2018 they had one reportable release which was 8.36 kg. Since 2019, Kinsale estimates there were no releases.

The 2006 IPCC default methodology and EFs for natural gas production would result in an estimated CH_4 emission for 2017 of 2,753 tonnes, 2018 of 2,654 tonnes and for 2019 2,071 tonnes, which is not indicative of the actual reported releases.

The inventory agency therefore estimated emissions for 1990-2015 based on the average of estimated reported releases by Kinsale Gas for 3-year period 2016-2018 using an IEF for kt CH_4/ktoe. As Kinsale Energy was the only facility operating for this time period, 1990-2015 (Vermillion Energy started production on the last day of 2015) the average IEF is based on the reported fugitive emissions of CH_4 for this facility. Emissions of CO_2 are reported as not estimated NE, for production and processing as they are below the significance threshold. In order to be below the level of significance, emissions for

[1] Decommissioning - Kinsale Energy (kinsale-energy.ie)

the unique category/gas combination must be below 0.05 per cent of the national total GHG emissions, excluding LULUCF, and not exceed 500 kt CO_2 eq. Ireland's inventory total (excluding LULUCF) was 60,605.7 kt CO_2 eq for 2022, and 0.05 per cent of this is value is 30.3 kt CO_2 eq. As the fugitive methane emissions for Ireland from natural gas production and processing are 0.01 kt CO_2 eq, these sources are below the significance threshold, allowing it to be reported as NE See table 3.1.13 in Annex 3.1.C for further information.

3.3.2.2.3 Natural gas transmission and storage (1.B.2.b.4)

Fugitive emissions from transmission are reported separately from emissions in 1.B.2.b.5 *Natural Gas Distribution* below. Gas Networks Ireland (GNI) performs a monthly analysis of the separate gas streams and provides the EPA with these gas analysis reports annually for each gas stream. The reports give the composition of the gas, calorific values, density and all information required for Ireland to estimate EFs for each gas stream. The amount of gas transmitted is taken from the energy balance so that weighted averages can be estimated. New information was provided by Gas Networks Ireland (GNI) for 2014-2020 resulting in an improvement in the fugitive emissions data (see section Natural gas Distribution below). GNI also provide the estimated fugitive losses from transmission and distribution networks and a percentage breakdown of fugitive emissions across the high-pressure transmission network and the distribution network for 2014–2020, which indicates that there is a ratio of approximately 21:79 for transmission: distribution across the available years. This ratio was used to calculate the transmission portion of fugitive emissions and report these emissions separately from 1.B.2.b.5 *Natural Gas Distribution*.

There is an existing underground storage facility in the Southwest Kinsale reservoir. As the Kinsale field is offshore, emission estimates are prepared by the Marine Institute of Ireland and also reported under the OSPAR Convention. The report covers all fugitive losses associated with offshore production of natural gas, including the 2 platforms at Kinsale and the undersea well at Corrib. As described above, the Kinsale facility is in the process of being decommissioned. Ireland considers that the default EFs for underground storage of natural gas are not applicable for this storage facility and any occurring emissions from the facility are accounted in the OSPAR reports, covering the offshore venting of natural gas.

Correspondence with the Vermillion Energy clarified that the main source of fugitive emissions are from bulk storage tanks and the tanks on Corrib are unique in Ireland and rare in the oil and gas industry as they have a a floating roof tank and a fixed roof tank with a Nitrogen blanket in the void to prevent any fugitive emissions to atmosphere. The floating roof tank is also fitted with high integrity seals.

3.3.2.2.4 Natural gas Distribution (1.B.2.b.5)

The activity data for 1.B.2.b.4 *Natural gas transmission and storage* and 1.B.2.b.5 *Natural Gas Distribution* (kWh) was received from Gas Networks Ireland (GNI) (1997-2022). Data provided by Gas Networks Ireland was taken from a variety of sources including GNI measurement of gas transported in the transmission and distribution networks 2014-2022, networks performance reports[2] (2008-2013) and Commission for Energy Regulation Gas Capacity Statement reports (CER, 2006, 2007) for years 1997-2006. No data was available from GNI for the earliest part of the time series 1990-1996 so this

[2] https://www.gasnetworks.ie/corporate/gas-regulation/regulatory-publications/

was extrapolated using data from national energy balance as consumption in the residential, industrial and commercial sectors.

Gas Networks Ireland provided an estimate of volumes of gas leakage from the transmission and distribution system for years 2010-2013. These estimates were calculated by GNI considering a number of ‘activities’ and applying emission factors associated with each type of activity in line with Marcogaz recommendations. Marcogaz is the technical Association of the European Natural Gas Industry and have produced a document which describes a methodology, based on a bottom-up approach, to identify and to quantify all types of methane emissions from transmission and distribution systems (Marcogaz, 2019). Activities included; the length of distribution and transmission pipelines of varying compositions (steel vs PE), number of pneumatic valves, the number of pressure reduction and regulating stations, combusted fuel gas on the network, the total number of service lines (customers) and the number of city gate and customer supply stations for metering and regulating. In addition, total emissions caused by operational maintenance including Pig trap overhauls, online inspections, function checks, commissioning were considered in the calculations.

Gas Networks Ireland perform monthly analysis of the separate gas streams and provide these gas analysis reports to the EPA annually for each gas stream. The reports give the composition of the gas, calorific values, density and all information required for Ireland to calculate emission factors for each gas stream. The amount of gas transmitted and distributed annually for each gas stream is taken from the energy balance so that weighted averages can be calculated. For the purposes of complete and consistent reporting the inventory agency calculated an IEF of 0.42 t CH_4/m^3 for years 1990-2009 using an average of the known EFs for years 2010-2014 (using years with similar percentage of imported gas to ensure a consistent time-series). The average IEF and the total gas transmitted and distributed were used to estimate the fugitive emissions for the timeseries. The CO_2 emissions were also calculated using the amount of gas leaked, the NCV and the weighted average of the percentage of CO_2 in the various gas streams.

GNI also provide a percentage breakdown of fugitive emissions across the high-pressure transmission network and the distribution network for 2014–2020, which indicates that there is a ratio of approximately 14:86 for transmission: distribution across the available years. This ratio was used to calculate the distribution portion of fugitive emissions and report these emissions separately. Estimates of CO_2 emissions for natural gas distributed is also reported. See table 3.1.14 in Annex 3.1.C for further information on EFs and Natural Gas Distribution emissions estimates.

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

Only two companies are involved in natural gas production in Ireland. Emissions to the atmosphere from venting at offshore gas production platforms are reported to the Department of Environment Climate and Communications (DECC) under the OSPAR Convention. Such reports have been obtained for several years in the time series and are currently covered by MOU with the inventory agency.

The available data, which are determined to relate largely to gas-venting, but which also account for a small amount of flaring in some years, indicate a close relationship between emissions and the amount of gas produced. This relationship has been applied in terms of the indicative emission rates of CO_2 and CH_4 per unit of gas extracted to estimate the emissions for those years for which no reports were received.

Fugitive CO_2 emissions from flaring in natural gas production are reported only for the following years:

- 1999 when a third mobile drilling unit (Glomar Arctic 3) was operating in the Kinsale field;
- 2001 when a drilling vessel (Noble Ton van Langevald) was operating offshore at Kinsale;
- 2015 onwards, when the first gas of from a new gas terminal was brought ashore for processing.

For other years in the time series, Ireland reports these fugitive emissions as “NO”.

Ireland does not consider the default EFs provided in Table 4.2.4 from the 2006 IPCC GL Vol. 2, Ch. 4 appropriate as they are based on Gg of throughput. Ireland’s only natural gas refinery which commenced production in 2015 reports the actual volume of natural and energy amount (TJ) of gas flared annually under the EU ETS and this forms the basis of CO_2 reporting for the years 2015-2022. The CH_4 and N_2O emissions were estimated using the energy amount of gas flared and the EFs from Table 2.2 from Vol. 2, Ch. 2 of the 2006 IPCC guidelines (1 and 0.1 kg/TJ for CH_4 and N_2O respectively). See table 3.1.16 for further information on activity data and fugitive losses from Natural gas Venting and Flaring.

3.3.2.3 Uncertainties and Time-series Consistency

The uncertainties applicable to Oil and Natural gas are provided in Annex 2. The emission time series for 1990-2022 is consistent. Key activity data such as gas and oil statistics are available for all applicable years and are used in a consistent manner.

3.3.2.4 Category-specific QA/QC and verification

Standard QA/QC procedures have been applied to this category. Details of Ireland’s QA/QC process can be found in Chapter 1 of this report.

3.3.2.5 Category-specific Recalculations

There were no recalculations in this submission.

3.3.2.6 Category-specific Planned Improvements

Ireland will continue to work with Gas Networks Ireland, Kinsale Energy and Vermillion Energy to ensure that complete and consistent reporting of fugitive emissions occurs.

Following a UNFCCC GHG inventory review in 2023, it was noted that there are minor emissions from flares at Ireland’s oil refinery, but all emissions are reported under the combustion sector 1.A.1.b. The inventory agency will consider splitting out the emissions from the oil refinery flares in the next submission if data allows and report these emissions in category 1.B.2.c.i, flaring of oil. This submission has changed the notation key from “NO” to “IE” included elsewhere under 1.A.1.b.

3.4 CO_2 Transport and Storage (1.C)

This activity does not occur in Ireland. Emissions are reported as Not Occurring (NO) for all years 1990-2022.

Table 3.10(a) Previous and current emission estimates in the Energy Sector (1990-2021)

	2024 Submission	Unit	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021
1.A.1.a	Public Electricity and Heat Production	kt CO_2e	10,946.8	13,125.6	15,747.2	15,234.8	12,880.0	10,993.5	10,831.3	11,380.3	12,136.1	11,362.0	10,100.0	8,953.8	8,242.1	9,795.9
1.A.1.b	Petroleum Refining	kt CO_2e	168.7	181.3	274.8	411.8	310.5	294.6	279.5	358.7	313.6	311.2	322.2	274.5	301.0	294.4
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries	kt CO_2e	100.5	69.4	87.1	171.9	173.3	161.1	133.6	114.5	125.4	128.7	118.5	107.2	91.8	80.8
1.A.2.a	Iron and Steel	kt CO_2e	175.9	18.7	18.8	2.4	2.4	2.3	2.4	2.4	2.3	2.3	2.3	2.3	2.4	2.4
1.A.2.b	Non-Ferrous Metals	kt CO_2e	811.3	1,183.0	1,345.9	1,134.3	1,588.0	1,376.8	1,334.8	1,350.1	1,330.2	1,387.6	1,402.1	1,394.2	1,502.2	1,371.1
1.A.2.c	Chemicals	kt CO_2e	411.3	343.7	458.4	452.8	370.5	354.2	365.3	377.4	387.2	360.1	386.9	389.8	395.0	404.3
1.A.2.d	Pulp, Paper and Print	kt CO_2e	28.5	57.2	95.5	37.5	21.6	21.5	21.3	17.1	22.4	29.0	38.4	18.1	29.0	19.1
1.A.2.e	Food Processing, Beverages and Tobacco	kt CO_2e	1,021.3	1,132.6	1,522.4	1,072.9	856.5	914.0	911.1	959.1	981.1	1,052.9	1,086.8	1,045.9	1,109.9	1,088.4
1.A.2.f	Non-metallic minerals	kt CO_2e	822.7	487.2	691.1	1,777.4	785.0	834.1	1,046.3	1,103.1	1,135.4	1,129.6	1,224.2	1,189.4	1,074.4	1,243.8
1.A.2.g	Other	kt CO_2e	803.4	1,067.2	1,293.8	949.9	503.1	489.2	534.5	438.5	467.9	511.1	549.7	539.2	538.0	484.4
1.A.3.a	Domestic Aviation	kt CO_2e	48.4	45.7	69.6	80.1	49.5	15.4	14.7	15.6	16.8	17.5	16.8	18.0	14.0	19.7
1.A.3.b	Road Transportation	kt CO_2e	4,788.8	5,877.9	10,356.6	12,543.4	10,980.7	10,584.4	10,832.1	11,318.6	11,753.7	11,625.6	11,762.5	11,750.4	9,793.5	10,438.4
1.A.3.c	Railways	kt CO_2e	147.2	123.1	136.1	135.0	134.8	129.9	119.2	121.4	123.7	127.7	129.0	135.0	107.6	116.3
1.A.3.d	Domestic navigation	kt CO_2e	85.7	92.0	152.6	211.1	200.0	179.5	224.7	221.6	266.3	235.1	260.1	277.0	338.7	362.2
1.A.3.e	Other transportation	kt CO_2e	73.2	125.0	61.7	152.6	161.3	145.1	145.7	137.2	135.4	127.0	140.1	142.1	147.7	151.9
1.A.4.a	Commercial/Institutional	kt CO_2e	2,133.2	1,995.8	1,889.1	1,767.8	1,541.3	1,547.5	1,443.6	1,578.6	1,500.3	1,439.6	1,540.5	1,536.6	1,326.9	1,436.5
1.A.4.b	Residential	kt CO_2e	7,571.3	6,647.8	7,176.1	8,395.5	8,982.8	7,057.5	6,252.6	6,691.3	6,976.7	6,482.0	6,976.3	6,701.7	7,325.7	6,878.7
1.A.4.c	Agriculture/Forestry/Fishing	kt CO_2e	810.9	1,156.2	1,013.5	1,088.6	821.9	668.1	603.0	574.7	594.9	625.3	674.1	683.2	683.4	681.7
1.B.1.a	Coal mining and handling	kt CO_2e	62.2	37.3	30.3	26.4	23.8	22.6	22.2	21.9	21.6	20.6	20.3	20.0	19.8	19.5
1.B.2.a	Oil	kt CO_2e	0.2	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.4	0.4
1.B.2.b	Natural gas	kt CO_2e	56.1	68.4	62.5	55.7	73.2	62.4	75.6	76.9	78.4	84.7	85.9	81.3	82.2	71.0
	Total Energy		**31,067.5**	**33,835.4**	**42,483.6**	**45,702.3**	**40,460.3**	**35,853.9**	**35,193.7**	**36,859.5**	**38,369.9**	**37,060.0**	**36,837.2**	**35,260.1**	**33,125.6**	**34,961.1**
	2023 Submission															
1.A.1.a	Public Electricity and Heat Production	kt CO_2e	10,946.8	13,125.6	15,747.2	15,234.8	12,880.0	10,993.5	10,831.3	11,380.3	12,136.1	11,362.0	10,100.0	8,953.8	8,242.1	9,795.1
1.A.1.b	Petroleum Refining	kt CO_2e	168.7	181.3	274.8	411.8	310.5	294.6	279.5	358.7	313.6	311.2	322.2	274.5	301.0	294.4
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries	kt CO_2e	100.5	69.4	87.1	171.9	173.3	161.1	133.6	114.5	125.4	128.7	118.5	107.2	91.8	80.8
1.A.2.a	Iron and Steel	kt CO_2e	175.9	18.7	18.8	2.4	2.4	2.3	2.4	2.4	2.3	2.3	2.3	2.3	2.4	2.4
1.A.2.b	Non-Ferrous Metals	kt CO_2e	811.3	1,182.9	1,345.8	1,134.9	1,609.5	1,384.8	1,324.7	1,356.8	1,332.3	1,369.6	1,372.7	1,391.8	1,324.2	1,323.1
1.A.2.c	Chemicals	kt CO_2e	411.3	343.7	458.6	460.7	379.4	353.7	360.7	377.6	381.0	387.5	423.0	411.9	405.8	396.4
1.A.2.d	Pulp, Paper and Print	kt CO_2e	28.5	57.2	95.6	38.3	22.2	21.5	21.0	17.3	21.8	27.5	37.7	17.1	17.6	17.2
1.A.2.e	Food Processing, Beverages and Tobacco	kt CO_2e	1,021.3	1,132.6	1,522.9	1,084.8	893.5	941.3	935.1	999.8	990.6	1,060.6	1,065.5	1,058.7	1,094.4	1,071.8
1.A.2.f	Non-metallic minerals	kt CO_2e	822.7	487.2	691.3	1,783.3	786.7	834.9	1,052.3	1,107.7	1,147.2	1,129.8	1,258.4	1,142.4	1,062.4	1,223.1
1.A.2.g	Other	kt CO_2e	794.5	1,055.6	1,280.6	936.7	505.1	477.8	565.4	448.1	492.2	526.4	559.9	600.6	605.5	590.6
1.A.3.a	Domestic Aviation	kt CO_2e	48.4	45.7	69.6	80.1	49.5	15.4	14.7	15.5	16.8	17.4	16.7	18.0	13.7	19.4
1.A.3.b	Road Transportation	kt CO_2e	4,788.9	5,882.8	10,352.5	12,536.9	10,976.6	10,580.3	10,827.9	11,314.8	11,750.3	11,506.4	11,642.5	11,624.5	9,692.9	10,327.8
1.A.3.c	Railways	kt CO_2e	147.2	123.1	136.1	135.0	134.8	129.9	119.2	121.4	123.7	127.7	129.0	135.0	107.6	116.3
1.A.3.d	Domestic navigation	kt CO_2e	85.7	92.0	152.6	211.1	200.0	179.5	224.7	221.6	266.3	235.1	260.1	277.0	338.7	373.8
1.A.3.e	Other transportation	kt CO_2e	73.2	125.0	61.7	152.6	161.3	145.1	145.7	137.2	135.4	127.0	140.1	142.1	147.8	152.1
1.A.4.a	Commercial/Institutional	kt CO_2e	2,142.0	2,004.8	1,896.6	1,746.7	1,479.5	1,521.3	1,393.6	1,519.7	1,466.2	1,414.8	1,521.9	1,489.0	1,534.5	1,494.3
1.A.4.b	Residential	kt CO_2e	7,571.4	6,650.5	7,181.1	8,402.7	8,972.0	7,059.6	6,256.9	6,688.7	6,970.6	6,592.2	7,083.8	6,821.6	7,360.9	6,917.5
1.A.4.c	Agriculture/Forestry/Fishing	kt CO_2e	810.9	1,156.2	1,013.5	1,088.6	821.9	668.1	603.0	574.7	594.9	625.3	674.1	688.9	676.4	672.6
1.B.1.a	Coal mining and handling	kt CO_2e	62.2	37.3	30.3	26.4	23.8	22.6	22.2	21.9	21.6	20.6	20.3	20.0	19.8	19.5
1.B.2.a	Oil	kt CO_2e	0.2	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.4	0.4
1.B.2.b	Natural gas	kt CO_2e	56.1	68.4	62.5	55.7	73.2	62.4	75.6	76.9	78.4	84.7	85.9	81.3	82.2	81.7
	Total Energy		**31,067.6**	**33,840.4**	**42,479.4**	**45,695.9**	**40,455.4**	**35,849.9**	**35,189.7**	**36,856.0**	**38,366.9**	**37,057.3**	**36,834.9**	**35,257.9**	**33,122.2**	**34,970.2**

Table 3.10(b) Absolute and Relative % change in the Energy Sector (1990-2021)

	Absolute change	Unit	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021
1.A.1.a	Public Electricity and Heat Production	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-0.0	0.8
1.A.1.b	Petroleum Refining	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.A.2.a	Iron and Steel	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.A.2.b	Non-Ferrous Metals	kt CO_2e	-	0.1	0.1	-0.6	-21.5	-8.0	10.1	-6.8	-2.0	18.0	29.4	2.4	178.1	48.1
1.A.2.c	Chemicals	kt CO_2e	-	0.0	-0.1	-7.9	-8.9	0.5	4.6	-0.2	6.1	-27.4	-36.1	-22.0	-10.8	7.9
1.A.2.d	Pulp, Paper and Print	kt CO_2e	-	-0.0	-0.1	-0.8	-0.6	0.0	0.3	-0.2	0.6	1.5	0.7	1.0	11.3	2.0
1.A.2.e	Food Processing, Beverages and Tobacco	kt CO_2e	-	0.0	-0.4	-11.9	-37.0	-27.3	-24.0	-40.7	-9.5	-7.8	21.3	-12.8	15.5	16.7
1.A.2.f	Non-metallic minerals	kt CO_2e	-	-0.0	-0.2	-5.9	-1.7	-0.8	-6.0	-4.6	-11.7	-0.2	-34.1	47.0	11.9	20.7
1.A.2.g	Other	kt CO_2e	8.9	11.6	13.2	13.2	-2.0	11.4	-30.9	-9.6	-24.2	-15.3	-10.2	-61.4	-67.5	-106.2
1.A.3.a	Domestic Aviation	kt CO_2e	-	-	-	-	-	-	-	0.1	0.1	0.2	0.1	0.0	0.3	0.3
1.A.3.b	Road Transportation	kt CO_2e	-0.1	-4.9	4.2	6.4	4.0	4.1	4.2	3.9	3.4	119.2	120.0	125.9	100.6	110.6
1.A.3.c	Railways	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.A.3.d	Domestic navigation	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	-11.6
1.A.3.e	Other transportation	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-0.1	-0.2
1.A.4.a	Commercial/Institutional	kt CO_2e	-8.8	-9.1	-7.4	21.1	61.8	26.2	50.0	58.9	34.2	24.8	18.7	47.6	-207.6	-57.8
1.A.4.b	Residential	kt CO_2e	-0.1	-2.7	-5.0	-7.2	10.8	-2.1	-4.3	2.6	6.2	-110.2	-107.5	-119.9	-35.2	-38.8
1.A.4.c	Agriculture/Forestry/Fishing	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-5.7	7.0	9.1
1.B.1.a	Coal mining and handling	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.B.2.a	Oil	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.B.2.b	Natural gas	kt CO_2e	-	-	-	-	-	-	-	0.0	0.0	0.0	0.0	0.0	0.0	-10.7
	Total Energy	**kt CO_2e**	**-0.1**	**-4.9**	**4.1**	**6.5**	**4.9**	**4.0**	**4.0**	**3.5**	**3.0**	**2.8**	**2.3**	**2.1**	**3.4**	**-9.1**
	Relative change															
1.A.1.a	Public Electricity and Heat Production	%	-	-	-	-	-	-	-	-	-	-	-	-	-0.0%	0.0%
1.A.1.b	Petroleum Refining	%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries	%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.A.2.a	Iron and Steel	%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.A.2.b	Non-Ferrous Metals	%	-	0.0%	0.0%	-0.1%	-1.3%	-0.6%	0.8%	-0.5%	-0.2%	1.3%	2.1%	0.2%	13.4%	3.6%
1.A.2.c	Chemicals	%	-	0.0%	-0.0%	-1.7%	-2.3%	0.1%	1.3%	-0.1%	1.6%	-7.1%	-8.5%	-5.3%	-2.7%	2.0%
1.A.2.d	Pulp, Paper and Print	%	-	-0.0%	-0.1%	-2.0%	-2.9%	0.1%	1.7%	-1.0%	2.6%	5.6%	1.8%	6.0%	64.2%	11.4%
1.A.2.e	Food Processing, Beverages and Tobacco	%	-	0.0%	-0.0%	-1.1%	-4.1%	-2.9%	-2.6%	-4.1%	-1.0%	-0.7%	2.0%	-1.2%	1.4%	1.6%
1.A.2.f	Non-metallic minerals	%	-	-0.0%	-0.0%	-0.3%	-0.2%	-0.1%	-0.6%	-0.4%	-1.0%	-0.0%	-2.7%	4.1%	1.1%	1.7%
1.A.2.g	Other	%	1.1%	1.1%	1.0%	1.4%	-0.4%	2.4%	-5.5%	-2.1%	-4.9%	-2.9%	-1.8%	-10.2%	-11.1%	-18.0%
1.A.3.a	Domestic Aviation	%	-	-	-	-	-	-	-	0.6%	0.4%	0.9%	0.9%	0.1%	1.9%	1.5%
1.A.3.b	Road Transportation	%	-0.0%	-0.1%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	1.0%	1.0%	1.1%	1.0%	1.1%
1.A.3.c	Railways	%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.A.3.d	Domestic navigation	%	-	-	-	-	-	-	-	-	-	-	-	-	-	-3.1%
1.A.3.e	Other transportation	%	-	-	-	-	-	-	-	-	-	-	-	-	-0.0%	-0.1%
1.A.4.a	Commercial/Institutional	%	-0.4%	-0.5%	-0.4%	1.2%	4.2%	1.7%	3.6%	3.9%	2.3%	1.8%	1.2%	3.2%	-13.5%	-3.9%
1.A.4.b	Residential	%	-0.0%	-0.0%	-0.1%	-0.1%	0.1%	-0.0%	-0.1%	0.0%	0.1%	-1.7%	-1.5%	-1.8%	-0.5%	-0.6%
1.A.4.c	Agriculture/Forestry/Fishing	%	0.0%	-	-	-	-	-	-	-	-0.0%	0.0%	-	-0.8%	1.0%	1.4%
1.B.1.a	Coal mining and handling	%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.B.2.a	Oil	%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.B.2.b	Natural gas	%	-	-	-	-	-	-	-	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-13.1%
	Total Energy	**%**	**-0.0%**	**-0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**-0.0%**

Chapter 4 Industrial Processes and Product Use

4.1 Overview of the Industrial Processes and Product Use Sector

The list of activities under *Industrial Processes and Product Use* in the IPCC reporting format is given in Table 4.1 below. A summary of emissions from these activities are given in Table 4.2, Figure 4.1 and Figure 4.2 below.

Some of these activities are well known sources of a particular greenhouse gas, such as cement production for CO_2 or adipic acid production in the case of N_2O, while others may be more important in terms of their indirect greenhouse gas emissions, such as the use of solvents.

Major industrial processes within the chemical sector and metal production that are common to many other developed countries have never been an important part of the Irish economy. Consequently, many of the production processes listed in Table 4.1 are not relevant to the greenhouse gas emission inventory in Ireland.

Historically, the four key industrial sources were cement and lime production under *2.A Mineral Products* and ammonia and nitric acid production under *2.B Chemical Industry*. The nitric acid and ammonia plants, both operated by Irish Fertiliser Industries, ceased production in 2002 and 2003, respectively. *2.A.3 Glass Production* was a relevant activity up to 2009 when production ceased. *2.A.4 Other process uses of carbonates* includes emissions from ceramics, bricks and tiles, clay pipe products, soda ash use as well as limestone used to abate SO_2 emissions in peat-fired electricity generating stations.

Several studies have been performed to improve and update the emission estimates in this sector. These continual updates ensure that the specified categories are kept up-to-date and that there are regular reviews of the assumptions and activity data availability. Improvement studies for the use of solvents include; Barry & O'Regan (2016), CTC (2005), Finn *et al.* (2001). Improvement studies for emissions from fluorinated gases include; Goodwin *et al.* (2013), Adams *et al*. (2005), O'Leary *et al.* (2002).

Industrial Processes and Product Use is the only sector for which emissions of HFCs, PFCs, SF_6 and NF_3 (collectively known as fluorinated gases) are reported in air emission inventories. There is no production of fluorinated gases in Ireland, but these substances are used in activities such as Ireland's electronics industry and for refrigeration and air conditioning.

All relevant sub-categories are fully covered in Ireland's inventories as shown in Table 4.1 below.

4.1.1 Emissions Overview

A summary of emissions from this sector is given in Table 4.2, Figure 4.1 and Figure 4.2 below.

Emissions from *Industrial Processes and Product Use* accounted for 5.8 per cent and 5.0 per cent of total national emissions (including indirect CO_2, without *LULUCF*) in 1990 and 2022, respectively. This sector accounted for 100 per cent of fluorinated gas emissions (HFCs, PFCs, SF_6 and NF_3), 6.1 per cent of CO_2 emissions and 0.7 per cent of N_2O emissions in 2022.

There are two key categories in this sector (see Annex 1 for further details). Level and Trend key categories:

- **2.*A.1 Cement Production*** (Level and Trend) is a significant activity in Ireland, which peaked in 2007 prior to the economic downturn in 2008.
- ***2.F.1 Refrigeration and Air-Conditioning*** (Level and Trend) has become a significant source in Ireland due to the growth in HFC use as replacement refrigerants across virtually all refrigeration sub-categories since 1993.

Other categories present in this sector include limestone, dolomite and other carbonate uses in:

- ***2.A.2 Lime Production*** emissions originated from three companies up to 1999 and two companies thereafter.
- ***2.A.3 Glass Production*** ceased in Ireland in 2009 prior to which the industry included the production of crystal glass, bottle glass and glass-based insulation.
- ***2.A.4 Other process uses of carbonates*** includes the production of bricks and roof tiles, ceramics, vitrified clay pipes, clay products, wall and floor tiles and the use of limestone to abate SO_2 emissions in peat-fired electricity generating stations.
- ***2.B Chemical Industry*** was a relevant activity in Ireland accounting for approximately two-thirds of the total in 1990 from the nitric acid and ammonia plants, both operated by Irish Fertiliser Industries, which ceased production in 2002 and 2003, respectively.
- ***2.D Non-energy products from fuels and solvent use*** is a relevant activity in Ireland due to the use of lubricants, paraffin wax and solvents. Solvent use is a significant source of NMVOC emissions, whilst lubricants and paraffin wax are minor sources of CO_2 emissions. Indirect CO_2 emissions associated with NMVOCs are included in the national total under IPPU.
- ***2.E.1 Integrated Circuit or Semiconductor Industry*** is responsible for all emissions of PFC, as well as some emissions of HFC, SF_6 and NF_3. Emissions follow a downward trend post-2000, which is due to process optimization, use of alternative chemicals, employment of alternative manufacturing processes and improved abatement systems in the sector. There is an increase in emissions in recent years due to increased economic activity in this sector.
- ***2.F.3 Fire protection*** is a relevant activity in Ireland due to the use of fluorinated gases in large scale fire protection systems.
- ***2.F.4 Product Uses as Substitutes for ODS – Aerosols including MDIs*** is a small category but there has been significant growth in the use of HFCs.
- ***2.G Other product manufacture and use*** includes emissions of SF_6 and N_2O. The sources of SF_6 include electrical equipment, which is the most significant activity, and double glazing, medical applications, sporting goods and gas-air tracers, which are minor sources. N_2O emissions originate from Medical Application through the use of anaesthesia.

The greenhouse gases relevant to *Industrial Processes and Product Use* are as follows.

- ***Carbon dioxide*** emissions originate from *2.A Mineral Production* and *2.D Non-energy products from fuels and solvent use* sectors: *2.D.1 Lubricant Use* and *2.D.2 Paraffin Wax Use*. Historically, *2.B Chemical Production* was also a source, however the plant closed in 2003.

There was a significant decrease in emissions from 2007-2009 due to the economic downturn after which emissions have remained relatively stable. Indirect CO_2 emissions (included in IPPU) originate from NMVOC emissions from sector *2.D.3 Solvents, 2.G.4 Other Solvent use (Use of Tobacco)* and *2.H.2. Food and Beverages industry.*

- ***Methane*** emissions are not occurring in IPPU sector.
- ***Nitrous Oxide*** emissions originate from *2.G.3 Medical* Application with the use of N_2O for anaesthesia. Historically, *2.B.2 Nitric Acid Production* was a significant source, however the plant closed in 2002.
- ***HFCs*** mainly originate from *2.F Product uses as ODS substitutes* and the use of these gases in refrigeration and air-conditioning systems, as well as fire protection equipment, aerosols and metered dose inhalers. Emissions have risen significantly since 1990 due to the use of HFCs as a replacement for Hydro chlorofluorocarbons (HCFCs). There is also a minor source from *2.E Electronic Industry*.
- ***PFCs*** are solely released from *2.E.1 Integrated Circuit or Semiconductor Industry.*
- ***SF_6*** emissions originate from a number of sources with the most significant being *2.E.1 Integrated Circuit or Semiconductor Industry* and emissions from *2.G.1 Electrical Equipment*. Emissions peaked in 2003 but have steadily fallen due to efficiency improvements in these two activities. Other sources of emissions include double glazing, medical applications, sporting goods and gas-air tracers.
- ***NF_3*** are solely released from *2.E.1 Integrated Circuit or Semiconductor Industry.*

The emission estimates clearly indicate that the combined emissions of HFC, PFC, SF_6 and NF_3 have generally increased year on year. This overall trend largely reflects the increasing use of HFCs across a range of applications (e.g. often as replacements in applications where the use of CFC and HCFCs is no longer permitted under the Montreal Protocol) and hence the presence of larger fluid banks from which operational leakage potentially occurs. A significant decrease can be seen in 2018, 2019 and 2020 compared to 2017 and previous years. This would appear to be a result of the implementation of the F-gas regulations EU 517/2014 which limits the amount of the most important F-gases that can be sold from 2015 onwards and phases down in steps the higher GWP gases as well as banning the use of F-gases in many new types of equipment where less harmful alternatives are available.

4.1.2 Methodology Overview

A summary of the Tier methods, consistent with the 2006 IPCC Guidelines, is provided in Table 4.1 below, along with a summary of the activities applicable to Ireland.

The process CO_2 emissions for the relevant source categories under *2.A Mineral Products* are largely covered by Directive 2003/87/EC (EP and CEU, 2003) on emissions trading in the EU and full use is made of this data source for the compilation of the national inventory. In general, the annual verified CO_2 emissions in respect of the installations concerned are used directly for the years covered by the EU ETS. The category-level emission factors indicated by EU ETS data are used together with the best available production data to obtain the emissions estimates for years previous to 2005.

In the chemical industry sector, emissions from *2.B.1 Ammonia production* were estimated based on natural gas feedstock data from Ireland's energy statistics (Table 4.B of Annex 4). Nitrous oxide emissions from *2.B.2 Nitric acid production* were estimated using plant data.

Emissions from 2*.D.1 Lubricant use* and *2.D.2 Paraffin wax* use are estimated using energy data provided in Ireland's energy statistics[3] (Table 4.B of Annex 4). Solvent use and Urea used as a catalyst in road transport are the two sources of emissions in *2.D.3. Emissions from Solvent use* are estimated based on national studies (Barry & O'Regan, 2016). Emissions from Urea used as a catalyst are estimated using data from the COPERT 5 model using Tier 2 approach according to IPCC 2006 guidelines.

Emissions of HFCs and PFCs from the *2.E.1 Integrated circuit or semiconductor* industries use an installation specific emissions data methodology. This is expected to give considerably more accurate emission estimates, and therefore a more certain trend with time.

[3] https://www.seai.ie/data-and-insights/seai-statistics/key-publications/national-energy-balance/

Table 4.1 Level 3 Source Methodology for IPPU

2. Industrial Processes and Product Use	CO_2	CH_4	N_2O	HFCs	PFCs	SF_6	NF_3
A. Mineral industry							
1. Cement production*	T3*	NA	NA	NA	NA	NA	NA
2. Lime production	T3	NA	NA	NA	NA	NA	NA
3. Glass production	T1, T3, NA	NA	NA	NA	NA	NA	NA
4. Other process uses of carbonates	T3	NA	NA	NA	NA	NA	NA
B. Chemical industry							
1. Ammonia production	T1, NA	NA	NA	NA	NA	NA	NA
2. Nitric acid production	NA	NA	T1, NA	NA	NA	NA	NA
3. Adipic acid production	NA	NA	NA	NA	NA	NA	NA
4. Caprolactam, glyoxal and glyoxylic acid production	NA	NA	NA	NA	NA	NA	NA
5. Carbide production	NA	NA	NA	NA	NA	NA	NA
6. Titanium dioxide production	NA	NA	NA	NA	NA	NA	NA
7. Soda ash production	NA	NA	NA	NA	NA	NA	NA
8. Petrochemical and carbon black production	NA	NA	NA	NA	NA	NA	NA
9. Fluorochemical production	NA	NA	NA	NA	NA	NA	NA
10. Other	NA	NA	NA	NA	NA	NA	NA
C. Metal industry							
1. Iron and steel production	T1, NA	NA	NA	NA	NA	NA	NA
2. Ferroalloys production	NA	NA	NA	NA	NA	NA	NA
3. Aluminium production	NA	NA	NA	NA	NA	NA	NA
4. Magnesium production	NA	NA	NA	NA	NA	NA	NA
5. Lead production	NA	NA	NA	NA	NA	NA	NA
6. Zinc production	NA	NA	NA	NA	NA	NA	NA
7. Other	NA	NA	NA	NA	NA	NA	NA
D. Non-energy products from fuels and solvent use							
1. Lubricant use	T1	NA	NA	NA	NA	NA	NA
2. Paraffin wax use	T2	NA	NA	NA	NA	NA	NA
3. Other	T1, T2	NA	NA	NA	NA	NA	NA
E. Electronics industry							
1. Integrated circuit or semiconductor	NA	NA	NA	T2	T2	T2	T2
2. TFT flat panel display	NA	NA	NA	NA	NA	NA	NA
3. Photovoltaics	NA	NA	NA	NA	NA	NA	NA
4. Heat transfer fluid	NA	NA	NA	NA	NA	NA	NA
5. Other	NA	NA	NA	NA	NA	NA	NA
F. Product uses as substitutes for ODS							
1. Refrigeration and air conditioning*	NA	NA	NA	T2, T3	NA	NA	NA
2. Foam blowing agents	NA	NA	NA	NA	NA	NA	NA
3. Fire protection	NA	NA	NA	T2	NA	NA	NA
4. Aerosols	NA	NA	NA	T1, T2	NA	NA	NA
5. Solvents	NA	NA	NA	NA	NA	NA	NA
6. Other applications	NA	NA	NA	NA	NA	NA	NA
G. Other product manufacture and use							
1. Electrical equipment	NA	NA	NA	NA	NA	T3	NA
2. SF6 and PFCs from other product use	NA	NA	NA	NA	NA	T1	NA
3. N2O from product uses	NA	NA	T1	NA	NA	NA	NA
4. Other	T2	NA	NA	NA	NA	NA	NA
H. Other							
1. Pulp and Paper Industry	NA	NA	NA	NA	NA	NA	NA
2. Food and Beverages Industry	T2	NA	NA	NA	NA	NA	NA

* Key Category

T1, 2, 3: Tier 1, Tier 2, Tier 3 as described in the 2006 IPCC Guidelines,

NA: not applicable because emissions of the gas do not occur in the source category

Table 4.2 Emissions from Industrial Processes and Product Use 1990-2022

		Gas	Unit	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
2.A.1	Cement Production	CO_2	kt CO_2e	884.0	879.0	1700.9	2357.1	1105.1	1111.7	1461.1	1652.0	1793.5	1839.6	1916.0	1892.6	1769.6	2102.8	1956.5
2.A.2	Lime Production	CO_2	kt CO_2e	214.1	187.5	190.4	183.5	192.4	189.6	189.0	177.3	173.9	198.9	177.3	163.7	135.5	148.0	107.5
2.A.3	Glass Production	CO_2	kt CO_2e	13.3	12.0	10.7	0.5	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2.A.4.a	Other- Ceramics	CO_2	kt CO_2e	5.23	5.64	6.66	7.53	0.42	0.03	NO	0.50	0.78	0.85	0.95	1.06	0.76	0.85	0.81
2.A.4.b	Other- Soda Ash Use	CO_2	kt CO_2e	0.10	0.07	0.07	0.08	0.07	0.06	0.07	0.06	0.04	0.07	0.10	0.07	0.04	0.03	0.00
2.A.4.d	Other- Limestone use	CO_2	kt CO_2e	NO	NO	NO	4.17	1.03	0.21	0.28	0.45	0.16	0.39	0.19	0.49	1.50	5.24	3.54
				884.0	879.0	1700.9	2357.1	1105.1	1111.7	1461.1	1652.0	1793.5	1839.6	1916.0	1892.6	1769.6	2102.8	1956.5
2.B.1	Ammonia Production	CO_2	kt CO_2e	214.1	187.5	190.4	183.5	192.4	189.6	189.0	177.3	173.9	198.9	177.3	163.7	135.5	148.0	107.5
2.B.2	Nitric Acid Production	N_2O	kt CO_2e	13.3	12.0	10.7	0.5	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2.C.1	Iron and Steel Production	CO_2	kt CO_2e	26.1	24.8	28.8	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2.D.1	Lubricant Use	CO_2	kt CO_2e	35.97	11.78	70.08	59.54	16.82	19.08	19.84	20.35	20.09	22.22	21.50	23.63	24.91	25.43	25.91
2.D.2	Paraffin Wax Use	CO_2	kt CO_2e	6.26	8.59	15.73	35.28	21.84	22.12	21.70	24.49	23.71	25.09	23.65	25.01	25.85	32.02	32.23
2.D.3	Solvent use	Indirect CO_2	kt CO_2e	53.28	53.78	48.90	48.49	42.58	38.50	40.22	39.56	39.20	39.55	41.18	39.37	38.14	37.54	37.63
2.D.3	Urea Used as a Catalyst	CO_2	kt CO_2e	NO	NO	NO	NO	5.21	6.46	7.03	8.68	11.02	11.95	13.18	13.73	12.31	13.84	15.18
				35.97	11.78	70.08	59.54	16.82	19.08	19.84	20.35	20.09	22.22	21.50	23.63	24.91	27.63	27.63
2.E.1	Integrated Circuit or Semiconductor	HFCs, PFCs, SF_6, NF_3	kt CO_2e	1.07	136.96	450.60	289.85	91.58	54.35	38.18	60.25	68.30	87.62	89.59	96.07	82.21	81.11	71.57
2.F.1	Refrigeration and Air Conditioning	HFCs	kt CO_2e	NO	4.52	113.74	666.40	857.10	916.65	1000.54	977.78	1049.45	961.83	652.35	652.16	521.23	572.31	575.64
2.F.2	Foam Blowing Agents	HFCs	kt CO_2e	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2.F.3	Fire Protection	HFCs	kt CO_2e	NO	NO	7.62	14.87	33.67	33.72	33.73	33.75	33.76	33.78	33.79	33.81	33.82	33.83	33.85
2.F.4	Aerosols	HFCs	kt CO_2e	NO	24.97	111.63	134.57	122.41	107.65	104.26	101.26	98.95	95.74	92.59	80.16	62.06	51.33	52.75
2.G.1	Electrical Equipment	SF_6	kt CO_2e	21.15	25.85	7.66	23.12	12.71	19.18	19.74	20.30	19.65	20.48	16.62	7.45	3.24	2.97	3.91
2.G.2	SF_6 and PFCs from Other Product Uses	SF_6	kt CO_2e	13.30	13.39	15.20	12.48	3.49	2.62	2.78	2.93	2.93	2.93	2.93	2.92	2.92	2.92	2.92
2.G.3.a	N_2O from product uses	N_2O	kt CO_2e	27.87	28.63	30.13	32.86	36.21	36.69	36.93	37.27	37.68	38.10	38.61	39.13	39.57	39.84	40.55
2.G.4	Other Solvent and product use	Indirect CO_2	kt CO_2e	0.07	0.08	0.09	0.07	0.05	0.04	0.04	0.04	0.04	0.05	0.02	0.04	0.04	0.04	0.03
2.H.2	Food and beverages industry	Indirect CO_2	kt CO_2e	21.16	22.63	21.45	29.77	40.04	49.41	42.09	44.98	47.56	59.31	59.48	65.11	58.73	66.19	68.09
Total	**IPPU**		**kt CO_2e**	**3198.3**	**3108.1**	**4407.2**	**3900.1**	**2582.8**	**2608.1**	**3017.5**	**3202.0**	**3420.7**	**3438.5**	**3180.0**	**3136.4**	**2812.5**	**3216.3**	**3028.6**

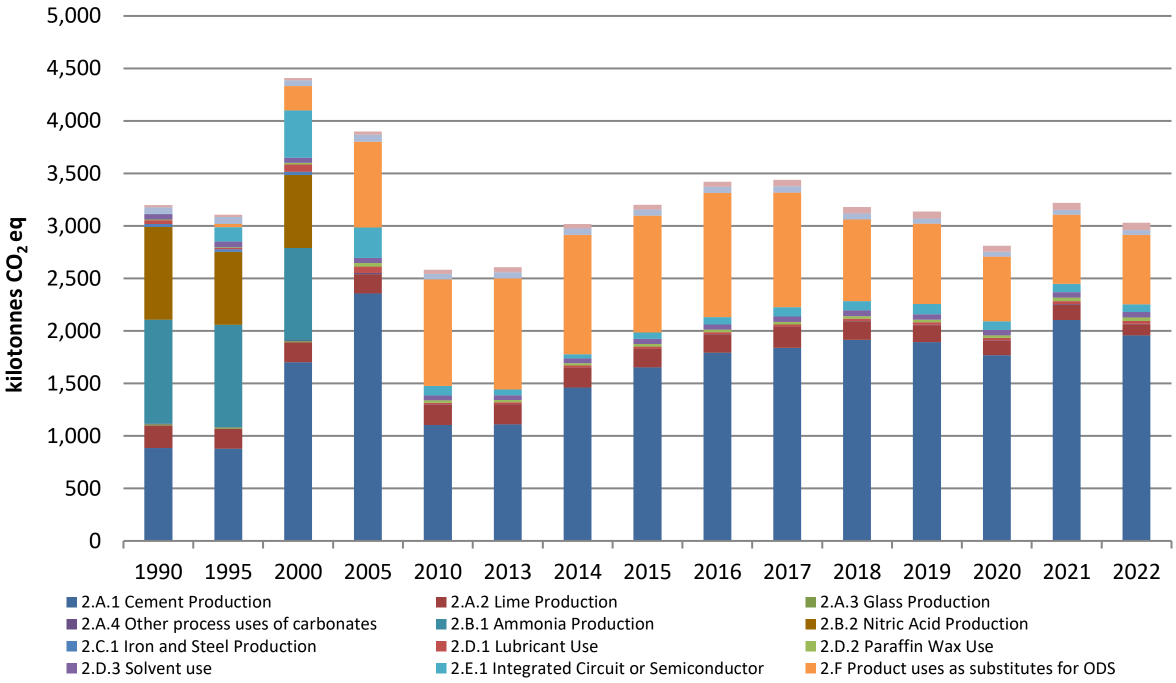


Figure 4.1 Total Emissions from IPPU by Category, 1990-2022

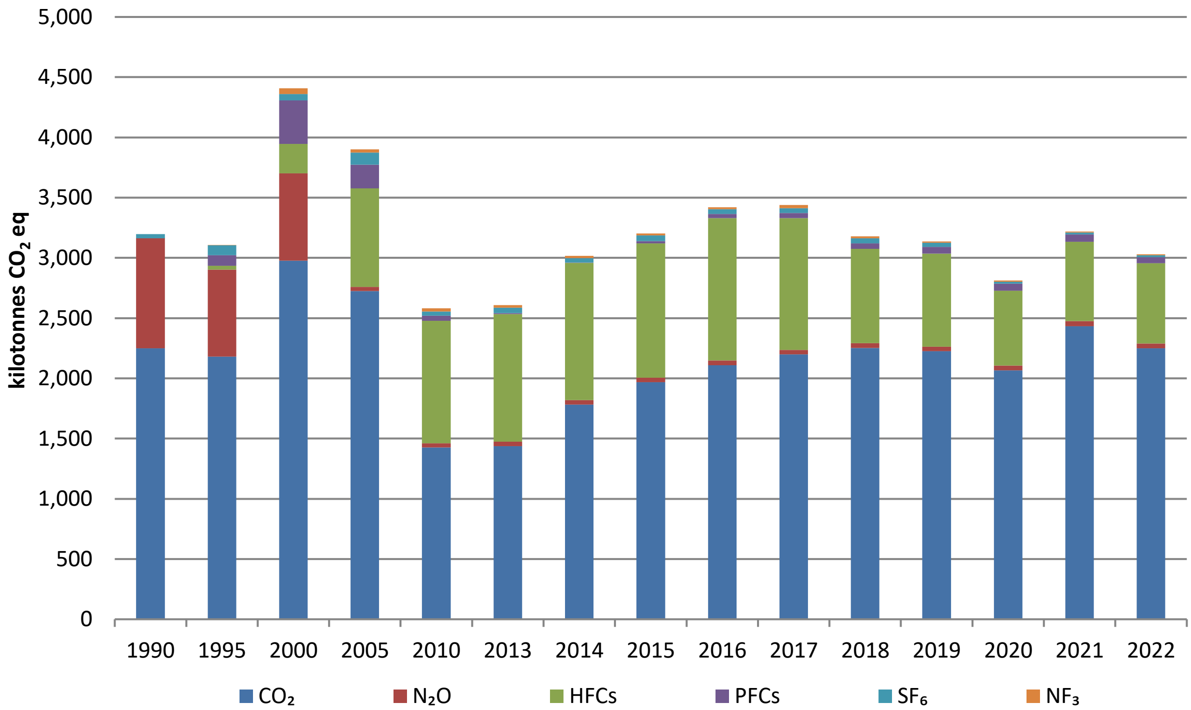


Figure 4.2 Total Emissions from IPPU by Gas, 1990-2022

4.2 Emissions from Mineral Industry (2.A)

The emission categories relevant under *2.A Mineral Products* are: *2.A.1 Cement production, 2.A.2 Lime production, 2.A.3 Glass production, 2.A.4 Other process uses of carbonates*.

Cement production continues to be a key category (both Trend and Level) in the national inventory. The production of glass ceased in Ireland in 2009.

4.2.1 Cement Production (2.A.1)

4.2.1.1 Category Description

During the cement manufacturing process, CO_2 is produced during the production of clinker. Clinker is produced when limestone, mainly calcium carbonate ($CaCO_3$) and small amounts of magnesium carbonate ($MgCO_3$), undergo calcination at high temperature to produce lime (Calcium oxide (CaO) and Magnesium oxide (MgO) and CO_2. The activated lime that results from this process combines with silica and alumina in the kiln feed to form cement clinker. The emissions of CO_2 are usually calculated from the amount of clinker produced and the stoichiometric ratio of CO_2 to CaO and MgO. A small amount of raw material may be converted into cement kiln dust (CKD) due to incomplete calcination. If the CKD is not recycled as part of subsequent kiln input, the CO_2 emissions based on clinker production must be corrected to account for the carbonate fraction lost in CKD. Emissions from clinker, CKD and other components such as non-carbonated elements/lime fines in cement production process are estimated in the Irish emissions inventory.

Up until the year 2000, one company operated two cement plants in Ireland. A second company opened a new cement plant in 2000 and a third cement producer entered the market in 2003, bringing the total number of plants to four.

Process emissions of CO_2 from cement production declined between 2007 and 2011, due to the economic downturn. However, emissions have increased since 2012, in line with post-recession economic growth.

4.2.1.2 Methodological Issues

A Tier 3 approach is used to estimate emissions from this category as described in the 2006 IPCC Guidelines. This methodology is based on collecting disaggregated data on the types and quantities of carbonates (i.e. carbonates, uncalcined CKD not recycled to the kiln and carbon-bearing nonfuel materials) used to produce clinker at each cement plant as well as the respective EFs of the carbonates consumed. Emissions are estimated using equation 2.3 from Chapter 2, Volume 3 of the 2006 IPCC guidelines.

This method has been used for all years from 2005 to 2022. Plant specific CO_2 emissions and corresponding production process data such as clinker, CKD and non-carbonated elements/lime fines are also available for all cement plants for the years 2005 onwards and these data are used directly to report emissions for category *2.A.1 Cement Production* in Ireland. The annual results incorporate verification of fuel use, limestone and carbonate use, combustion and process CO_2 estimates in accordance with Decision 2004/156/EC.

Information on the CaO and MgO content of clinker, for each of the four cement plants, has been provided to the inventory agency by the plant operators for all years from 2008 onwards as recommended in previous annual inventory review reports. This information is not published in the national inventory reports as the cement producers deem it to be confidential, commercially sensitive information. The data are available to the expert review teams for annual GHG inventory reviews upon request.

Prior to the implementation of the EU ETS, in 2004, plant-specific information relating to CO_2 emissions in 2002 and 2003 was obtained by the EPA for all cement plants for the development of Ireland's First National Allocation Plan (NAP1) under Directive 2003/87/EC (EP and CEU, 2003) on emissions trading in the EU. The reported process CO_2 emissions for each plant in 2002 and 2003 were calculated according to the guidelines for the monitoring and reporting of greenhouse gas emissions in Decision 2004/156/EC that supports Directive 2003/87/EC. The method used is fully consistent with the Tier 3 method described above and its application employs reliable data on clinker production, corrected as appropriate for CKD, and CaO/MgO content of the clinker.

For the two original cement plants which were operated by a single cement producer, the company concerned supplied estimates of process emissions for the years 1990-2001 that it had calculated internally in line with the specific information provided for the years 2002 and 2003 and used for NAP1. The associated values of annual clinker production were not provided. For the purposes of complete and consistent reporting, the inventory agency estimated annual clinker production for the years 1990-2001 based on the plant specific process emission factors available for the two plants for the years from 2002 onwards. This is appropriate, as the company has always used the same local on-site supply of limestone at each of the two sites, and the time-series of process CO_2 emissions for cement production overall may therefore be considered consistent for the period 1990-2022.

Additional information on clinker production, emissions and IEFs is provided in Table 3.2.A of Annex 3.2.

4.2.1.3 Uncertainties and Time-series Consistency

The uncertainties applicable to this category can be found in Annex 2.

The uncertainty of the activity data is 1.5 per cent in line with Table 2.3 of the 2006 IPCC guidelines. Production of clinker data are available, so the uncertainty associated with these data is 1-3%, based on plant level weighing of raw materials.

The uncertainty of the emission factor is 1.5 per cent in line with Table 2.3 of the 2006 IPCC guidelines. Overall chemical analysis/composition pertaining to carbonate content/mass/type is known (Tier 3), with an uncertainty range of 1-3 per cent.

4.2.1.4 Category-specific QA/QC and verification

Emissions are estimated from individual plant data, which are subject to verification under Directive 2003/87/EC, and their validity is fully established in the context of the companies' documented methods and data and the associated guidance on emissions estimation methods provided by Decision 2004/156/EC (CEC, 2004). Such verification allows for accurate accounting of combustion emissions and process emissions separately.

Data from each plant for the most recent year in the inventory are checked for consistency with historical data from that plant. Implied emission factors are also calculated and checked for variability or step changes across the time series.

Comparisons are also made across the different plants, to check for consistency. Typically, implied emission factors are compared. These checking procedures help to identify any erroneous point source data and are readily undertaken due to the limited number of plants in Ireland.

Data reported under ETS for plants in this category are also cross checked with data supplied by the same operators for other reporting requirements, such as, Integrated Pollution Prevention and Control directive (IPPC), the Industrial Emissions Directive (IED) and under the European Pollutant Release and Transfer Register (E-PRTR) for consistency.

4.2.1.5 Category-specific Recalculations

There were no recalculations in this source category in this submission.

4.2.1.6 Category-specific Planned Improvements

There are no planned improvements for this source category.

4.2.2 Lime Production (2.A.2)

4.2.2.1 Category Description

Calcium oxide (quicklime) is formed by heating limestone to decompose the carbonates. This is usually done in shaft or rotary kilns at high temperatures and the process releases CO_2. Dolomite and dolomitic (high magnesium) limestone may also be processed at high temperature to obtain dolomitic lime with a loss of CO_2. Quicklime is then further treated by the addition of water, a process called slaking, to produce slaked lime ($Ca(OH)_2$ and $Ca(OH)2.Mg(OH)_2$), which generates large amounts of heat and steam. The finished product can then be packaged and distributed for use.

Currently, there are two companies operating 3 lime plants in Ireland and a fourth that operated until 1999. One of the lime production plants reported here produces magnesia (periclase) as its final product. The process emissions from this plant are reported here in CRF category 2.A.2 and CRF category 2.A.4, as the process emissions are due to the production of lime and soda ash use, which is consistent with the 2006 IPCC Guidelines. It is understood that all three utilised limestone quarries and kilns to burn the limestone raw material. The nature of the fuel used and the abatement in place varies from plant to plant.

4.2.2.2 Methodological Issues

For the period 1990-2004, emissions from lime production are based on a Tier 3 input-based carbonate approach and equation 2.7 Chapter 2, Volume 3 of the 2006 IPCC guidelines. The CO_2 estimates for lime production in 2005-2022 have been obtained from the ETS returns to the EPA.

Historically, statistical data on lime production in Ireland were obtained annually from the lime manufacturers (three companies up to 1999 and two companies thereafter) and form the basis for emissions over the period 1990-2004. As is the case for cement production, lime producers now provide their own estimates of CO_2 emissions from lime manufacture under Directive 2003/87/EC on ETS. These estimates are calculated in accordance with the methods described in the supporting Decision 2004/156/EC, equivalent to a Tier 3 approach, thus providing detailed information on emission estimates and activity data for another important source of CO_2 emissions in Industrial Processes and Product Use.

The implied emission factor for aggregated lime production was 0.76 t CO_2/t lime in 2022. Additional detailed information on lime production, emissions and IEFs is available in Table 3.2.B in Annex 3.2.

4.2.2.3 Uncertainties and Time-series Consistency

The uncertainties applicable to this category can be found in Annex 2.

The uncertainty of the activity data is 5 per cent as the data are plant specific and the uncertainty of the emission factor is 5 per cent which provides a combined uncertainty of 7 per cent. The uncertainty values for the emission was assumed based on observed data for an average CaO content in lime (4-8 per cent), high calcium lime (2 per cent), dolomitic lime (2 per cent), plant-level lime production data (1-2 per cent) and correction for slaked lime (5 per cent) in Table 2.5 of the 2006 IPCC guidelines.

4.2.2.4 Category-specific QA/QC and verification

As the emissions are estimated from individual plant data, which are subject to verification under Directive 2003/87/EC, their validity is fully established in the context of the companies' documented methods and data and the associated guidance on emissions estimation methods provided by Decision 2004/156/EC (CEC, 2004). Such verification allows for accurate accounting of combustion emissions and process emissions separately.

Data from each plant for the most recent year in the inventory are checked for consistency with historic data from that plant. Implied emission factors are also calculated and checked for variability or step changes across the time series.

Comparisons are also made across the different plants, to check for consistency and implied emission factors are compared. These checking procedures help to identify any erroneous point source data and are readily undertaken due to the limited number of plants in Ireland.

Data reported under ETS for plants in this category are also cross checked with data supplied by the same operators for other reporting requirements, such as, IPPC, IED and under E-PRTR for consistency.

4.2.2.5 Category-specific Recalculations

There were no recalculations in this source category in this submission.

4.2.2.6 Category-specific Planned Improvements

There are no planned improvements for this source category.

4.2.3 Glass Production (2.A.3)

4.2.3.1 Category Description

There are many kinds of glass articles and compositions in use commercially. The great bulk of commercial glass is almost entirely soda-lime glass, consisting of silica (SiO_2), soda (Na_2O), and lime (CaO), with small amounts of alumina (Al_2O_3), and other alkalis and alkaline earths, plus some minor ingredients. The major share of commercial glasses includes containers and flat (window) glass. Production of glass in Ireland was limited to bottle glass, crystal glass and glass wool (glass-based insulation). The first two are included in the container category. Glass wool has been included in glass production as per the 2006 IPCC guidelines.

The production of glass completely ceased in Ireland in 2009. The only bottle glass plant closed in 2002, a crystal glass plant closed in early 2006, the glass-based insulation plant closed in 2008 and the last one, a second crystal glass plant closed in 2009.

4.2.3.2 Methodological Issues

A combination of Tier 1 and Tier 3 approaches are used based on the different glass manufacturing processes that were undertaken in Ireland. Similar to other categories under 2.A, information from 2 individual crystal glass plants that were participants in the Emissions Trading Scheme were used to compile the emissions estimates for this category for the years 2005 to 2009.

The production of bottle glass was the major source of emissions in this category. The CO_2 emissions are estimated from the annual production quantities obtained from the company for the development of annual inventories for heavy metals. Equation 2.11 of the 2006 IPCC guidelines and the emission factor of 0.21 kg CO_2/kg glass (Table 2.6 of 2006 IPCC guidelines) are used. Allowance is made for recycled glass, which is assumed to be 5 per cent in 1990, increasing to 30 per cent in 2002 when the plant closed.

In the case of crystal glass, the CO_2 emissions are based on the use of potassium carbonate and sodium carbonate use (soda ash) as reported under ETS, using the emission factors of 0.415 t CO_2/t Na_2CO_3 and 0.267 t CO_2/t K_2CO_3, provided by the ETS monitoring and reporting guidelines. The company concerned supplied estimates for all years up to and including 2009, when the plant closed.

Emissions from the production of glass-based insulation materials are also based largely on soda ash use although small amounts of dolomite and limestone were also used up to 2005.

The emissions of CO_2 from glass production amounted to 13.3 kt in 1990 and reduced to 0.02 kt in 2009, when the last remaining glass manufacturing plant closed. Additional detailed information on glass production, emissions and IEFs is available in Table 3.2.C in Annex 3.2.

4.2.3.3 Uncertainties and Time-series Consistency

The uncertainties applicable to this category can be found in Annex 2.

The uncertainty of the activity data is 5 per cent as the data are plant specific and the uncertainty of the emission factor is 2.5 per cent which provides a combined uncertainty of 5.6 per cent. The 2006 IPCC guideline value of 1-3 per cent for Tier 1 approach with +/- 10 per cent variation for Tier 2 approach are used.

4.2.3.4 Category-specific QA/QC and verification

As the emissions are estimated from individual plant data, which are subject to verification under Directive 2003/87/EC, their validity is fully established in the context of the companies' documented methods and data and the associated guidance on emissions estimation methods provided by Decision 2004/156/EC (CEC, 2004). Such verification allows for accurate accounting of combustion emissions and process emissions separately.

4.2.3.5 Category-specific Recalculations

There were no recalculations in this source category in this submission.

4.2.3.6 Category-specific Planned Improvements

A source of data for glass manufacture, in small artisan glass factories, is currently being investigated for this source category.

4.2.4 Other Process Uses of Carbonates (2.A.4)

4.2.4.1 Category Description

Limestone ($CaCO_3$), dolomite ($CaMg(CO_3)_2$) and other carbonates (e.g., $MgCO_3$ and $FeCO_3$) are basic raw materials having commercial applications in a number of industries. In addition to those industries already discussed individually (cement production, lime production and glass production), carbonates also are consumed in metallurgy (e.g., iron and steel), agriculture, construction and environmental pollution control (e.g., flue gas desulphurisation.) Soda ash (sodium carbonate, Na_2CO_3) is a white crystalline solid that is used as a raw material in a large number of industries including glass manufacture, soap and detergents, pulp and paper production as well as a food additive, drinking water treatment (softener) and wastewater treatment. The CO_2 emissions reported under this category refer to those emissions associated with:

- Limestone ($CaCO_3$) and Urea used for flue gas desulphurisation,
- Limestone used for purification in sugar manufacture,
- Limestone used in the manufacture of bricks, flues and tiles,
- Clays and shale used as a raw material in the manufacture of bricks, flues and ceramics,
- Soda ash use (non-glass manufacture, such as Sintered Magnesium Oxide).

Since 2008, when the last ceramics and tile manufacturing plants closed, the only two sources of emissions in this category are from a brick manufacturing plant and from the use of limestone for flue gas desulphurisation at peat fired electricity generation plants. The emission trend in recent years is almost entirely due to the amount of flue gas desulphurisation required at these plants.

4.2.4.2 Methodological Issues

Emissions of CO_2 have been estimated using a Tier 3, carbonate input approach, for sources in this category. Limestone has been used as environmental pollution control method to reduce the sulphur emitted from peat burning in one electricity generating station since 2001 and in a second such plant since 2007. The CO_2 emissions estimates are taken from ETS Annual Emission Monitoring reports to the EPA. They are estimated on the basis of limestone quantity used by the companies and reported process emissions, giving an implied emission factor in the range from 0.43 to 0.44 t CO_2/t limestone between 2001 and 2022. The stoichiometric ratio of CO_2 to $CaCO_3$ is 0.44.

A further minor use of limestone in Ireland is its application in the purification of sugar produced from sugar beet. However, sugar production ceased in 2006 and the only information on emissions is that obtained under EU ETS AEM reports in respect of 2005 and 2006. Additionally, limestone was used for tile manufacturing by one company in the three years of its operation (2006-2008) and for brick manufacturing by another company until its closure (1990-2008). Data was reported by both companies for relevant years of operation under the EU ETS and for the preceding years it was sourced by the inventory agency from the companies directly.

The emissions of CO_2 from the use of clays and shale as a raw material in the manufacture of bricks and ceramics are estimated using information from individual plants that are participants in the EU ETS.

The emissions associated with soda ash use by one company in Ireland are reported by the company under ETS for the years 2005 onwards and have been used directly in the inventory. The other uses of soda ash are already reported under 2.A.3 glass production. Activity data for years prior to the ETS data were sourced by the inventory agency from the company. Estimates of CO_2 for all years from 1990-2004 were calculated using an emission factor of 0.41 t CO_2/t soda ash, indicated by the average 2005-2008 ETS data. This approach has allowed a full 1990-2022 time series of emissions to be included in the inventory. Additional detailed information on activity data, emissions and EFs is available in Table 3.2.E in Annex 3.2.

In 2022 there is one plant producing bricks and ceramics in Ireland with an emission of 0.81 kt CO_2. Emission estimates for bricks and ceramics were prepared from the ETS data where one company provided estimates of emissions for the years 2005-2013 and 2015-2022, a further one company for the years 2005-2011 and a further two companies for the years 2005-2008. The implied emission factors for this source category range from 0.026 to 0.053 tonne CO_2/tonne carbonate input. The emissions for the years prior to ETS are calculated from the companies' estimates of material use and their respective average ETS emission factors. Additional detailed information on raw material use, emissions and IEFs is available in Table 3.2.D in Annex 3.2. Carbonates and urea used for flue gas desulphurisation and NO_x abatement are also reported under category 2.A.4.d, from 2005 to 2022. See Table 3.D.2 in Annex 3.2.

4.2.4.3 Uncertainties and Time-series Consistency

The uncertainties applicable to this category can be found in Annex 2.

The uncertainty of the activity data is 5 per cent as data is plant specific and the uncertainty of the emission factor is assumed to be 2.5 per cent as the stoichiometric ratio reflecting the amount of CO_2 released upon calcination of the carbonate was applied (Section 2.4.1, Chapter 2, Volume 3 of the 2006 IPCC guidelines) which reduces the uncertainty.

4.2.4.4 Category-specific QA/QC and verification

As the emissions are estimated from individual plant data, which are subject to verification under Directive 2003/87/EC, their validity is fully established in the context of the companies' documented methods and data and the associated guidance on emissions estimation methods provided by Decision 2004/156/EC (CEC, 2004). Such verification allows for accurate accounting of combustion emissions and process emissions separately.

4.2.4.5 Category-specific Recalculations

There were no recalculations in this source category in this submission.

4.2.4.6 Category-specific Planned Improvements

There are no planned improvements for this category.

4.3 Emissions from Chemical Industry (2.B)

The emission categories relevant under *2.B Chemical Industry* are: *2.B.1 Ammonia Production* and *2.B.2 Nitric Acid Production.* All other Chemical Industry activities have not occurred in Ireland over the time series 1990-2022 and are reported as Not Occurring (NO).

Ammonia and nitric acid production in Ireland was undertaken by two plants, both of which were operated by Irish Fertiliser Industries for the production of nitrogenous fertilisers. However, during 1999 and 2000 severe rationalisation and restructuring measures were introduced by the major fertilizer manufacturers, which resulted in the closure of the nitric acid and ammonia plants in 2002 and 2003, respectively.

Fertiliser manufacture in Ireland no longer takes place and all fertilisers are either imported as a finished product or only undergo further blending in Ireland.

4.3.1 Ammonia Production (2.B.1)

4.3.1.1 Category Description

Ammonia (NH_3) is a major industrial chemical and the most important nitrogenous material produced. Ammonia production requires a source of nitrogen (N) and hydrogen (H). Nitrogen is obtained from air through liquid air distillation or an oxidative process where air is burnt and the residual nitrogen is recovered. Ammonia is the basis of all nitrogen fertilisers and is normally manufactured by synthesis of nitrogen (N_2) and hydrogen (H_2), with natural gas (CH_4) as the basic raw material. Utilising the Haber Bosch process, natural gas, air and water were reacted to produce ammonia in liquid form and CO_2 as a by-product.

Urea was one of the main end products of the NH_3 plant, which was formed when the NH_3 produced and the CO_2 by-product reacted together to form prills (small particles) of urea. The other main product, anhydrous ammonia was stored and transported to Irish Fertiliser Industries other plant where it underwent further processing (discussed in section 3.3.2 Nitric Acid Production below).

4.3.1.2 Methodological Issues

Emissions of CO_2 from ammonia production are estimated using a Tier 2/3 approach based on country specific data on fuel type and carbon content of the fuel supplied to the plant. Data on the natural gas feedstocks to the plant are indicated in the national energy balance provided by SEAI. No feedstock carbon is sequestered in urea and the emission factor is 54.94 kg CO_2/TJ, the value for indigenous natural gas, which equates to 2.3 tonne CO_2/tonne natural gas. The CO_2 emissions from ammonia production were 990.23 kt in 1990 and 0.30 kt in 2003, the last year of operation. The following equations outline of the process and sources of CO_2 production using CH_4 in the ammonia industry. Anhydrous ammonia produced by catalytic steam reforming of natural gas (mostly CH_4) involves the following reactions with carbon dioxide produced as a by-product:

Primary steam reforming:

$$CH_4 + H_2O \rightarrow CO + 3H_2$$

$$CO + H_2O \rightarrow CO_2 + H_2$$

Secondary air reforming:

$$CH_4 + air \rightarrow CO + 2H_2 + 2N_2$$

Overall reaction:

$$0.88CH_4 + 1.26Air + 1.24H_2O \rightarrow 0.88CO_2 + N_2 + 3H_2$$

Ammonia synthesis:

$$N_2 + 3H_2 \rightarrow 2NH_3$$

Secondary reformer process gas shift conversion:

$$CO + H_2O \rightarrow CO_2 + H_2$$

4.3.1.3 Uncertainties and Time-series Consistency

The uncertainties applicable to this category can be found in Annex 2.

The uncertainty of the activity data is 1 per cent as data is country specific fuel data and the uncertainty of the emission factor is 5 per cent (Table 3.1 Chapter3, Volume 3 2006 IPCC guidelines).

4.3.1.4 Category-specific QA/QC and verification

There is no country specific QA\QC for this category as the plant is closed in 2002, before the establishment of Ireland's National Atmospheric Inventory System.

4.3.1.5 Category-specific Recalculations

There are no recalculations in this source category in this submission.

4.3.1.6 Category-specific Planned Improvements

There are no planned improvements for this category.

4.3.2 Nitric Acid Production (2.B.2)

4.3.2.1 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. During the production of nitric acid (HNO_3), nitrous oxide (N_2O) is generated as an unintended by-product of the high temperature catalytic oxidation of ammonia (NH_3).

Nitric acid production in Ireland ceased in 2002. Ammonia, transported from Irish Fertiliser Industries ammonia production plant (section 4.3.1) to the ammonium nitrate production plant, was oxidised over a catalyst to form nitric acid. The nitric acid was then combined with more ammonia to produce ammonium nitrate which, when solidified into granules or made into bead-like prills, is applied to land using a fertiliser spreader. Other fertiliser blends were also manufactured at the plant.

4.3.2.2 Methodological Issues

For the years 1990-1995, the inventory agency received direct correspondence from the plant operator specifying the quantities of nitric acid produced and the company's estimates of N_2O emitted during the production process.

Four units at this plant produced 338,000 tonnes of nitric acid in 1990 with associated N_2O emissions of 3,340 tonnes. The emissions were estimated from nitrogen loading and the type of catalyst used in the process.

4.3.2.3 Uncertainties and Time-series Consistency

The uncertainties applicable to this category can be found in Annex 2.

The uncertainty of the activity data is 1 per cent as data was received directly from the plant operator and the uncertainty of the emission factor is 10 per cent (Table 3.3 Chapter 3, Volume 3 2006 IPCC guidelines).

4.3.2.4 Category-specific QA/QC and verification

There is no country specific QA\QC for this category as the plant is closed since 2002, before the establishment of Ireland's National Atmospheric Inventory System.

4.3.2.5 Category-specific Recalculations

There are no recalculations in this source category in this submission.

4.3.2.6 Category-specific Planned Improvements

There are no planned improvements for this category.

4.3.3 Adipic Acid Production (2.B.3)

This activity has not existed in Ireland during the time series 1990-2022. This category is reported as Not Occurring (NO).

4.3.4 Caprolactam, Glyoxal and Glyoxylic Acid Production (2.B.4)

This activity has not existed in Ireland during the time series 1990-2022. This category is reported as Not Occurring (NO).

4.3.5 Carbide Production (2.B.5)

This activity has not existed in Ireland during the time series 1990-2022. This category is reported as Not Occurring (NO).

4.3.6 Titanium Dioxide Production (2.B.6)

This activity has not existed in Ireland during the time series 1990-2022. This category is reported as Not Occurring (NO).

4.3.7 Soda Ash Production (2.B.7)

This activity has not existed in Ireland during the timeseries 1990-2022. This category is reported as Not Occurring (NO).

4.3.8 Petrochemical and Carbon Black Production (2.B.8)

This activity has not existed in Ireland during the timeseries 1990-2022. This category is reported as Not Occurring (NO).

4.3.9 Fluorochemical Production (2.B.9)

This activity has not existed in Ireland during the timeseries 1990-2022. This category is reported as Not Occurring (NO).

4.3.10 Other Chemical Industry (2.B.10)

This activity has not existed in Ireland during the timeseries 1990-2022. This category is reported as Not Occurring (NO).

4.4 Emissions from Metal Industry (2.C)

This section covers emissions of greenhouse gases that result from the production of metals. The source category applicable to Ireland is *2.C.1 Iron and Steel Production.*

4.4.1 Iron and Steel Production (2.C.1)

4.4.1.1 Category Description

Ireland had one Electric Arc Furnace (EAF) in operation in the years 1990 to 2001 producing steel from scrap and recycled metal.

4.4.1.2 Methodological Issues

The process CO_2 emissions for this category was estimated using the emission factor provided in table 4.5 of the 2006 IPCC guidelines, 0.08 t CO_2/t steel. The crude steel production (kt) by the Irish steel company is available from the period 1990 to 2001.

4.4.1.3 Uncertainties and Time-series Consistency

Activity data and emissions factor uncertainties were assumed be similar to glass production.

4.4.1.4 Category-specific QA/QC and verification

There is no country specific QA\QC for this category as the plant is closed since 2002, before the establishment of Ireland's National Atmospheric Inventory System.

4.4.1.5 Category-specific Recalculations

There are no recalculations in this source category in this submission.

4.4.1.6 Category-specific Planned Improvements

An activity data uncertainty of 10 percent and an uncertainty of 10 percent in emissions factor for Material-Specific Default Carbon Contents will be included in the next uncertainty analysis in the next year as per section 4.2.3 in Chapter 4, Volume 3.

4.4.2 Ferroalloys Production (2.C.2)

This activity has not existed in Ireland during the timeseries 1990-2022. This category is reported as Not Occurring (NO).

4.4.3 Aluminium Production (2.C.3)

This activity has not existed in Ireland during the timeseries 1990-2022. This category is reported as Not Occurring (NO).

4.4.4 Magnesium Production (2.C.4)

This activity has not existed in Ireland during the timeseries 1990-2022. This category is reported as Not Occurring (NO).

4.4.5 Lead Production (2.C.5)

This activity has not existed in Ireland during the timeseries 1990-2022. This category is reported as Not Occurring (NO).

4.4.6 Zinc Production (2.C.6)

This activity has not existed in Ireland during the timeseries 1990-2022. This category is reported as Not Occurring (NO).

4.4.7 Other Metal Industry (2.C.7)

This activity has not existed in Ireland during the time-series 1990-2022. This category is reported as Not Occurring (NO).

4.5 Emissions from Non-energy Products from Fuels and Solvent Use (2.D)

4.5.1 Lubricant Use (2.D.1)

4.5.1.1 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. They can be subdivided into (a) motor oils and industrial oils, and (b) greases, which differ in terms of physical characteristics (e.g., viscosity), commercial applications, and environmental fate. The use of lubricants in engines is primarily for their lubricating properties and associated emissions are therefore considered as non-combustion emissions and are reported here in the IPPU Sector. Most waste lubricant oil is collected in Ireland and disposed of in an environmentally safe way. A small proportion of lubricant oils oxidise during use, and CO_2 emissions from this category are reported in 2.D.1 Lubricant use.

4.5.1.2 Methodological Issues

Ireland uses a Tier 1 method to estimate emissions of CO_2 from non-energy use of lubricants based on equation 5.2 in the 2006 IPCC guidelines and an ODU (Oxidising During Use) default factor 0.2 from table 5.2 shown below. The national energy balance provides data on lubricant consumption for the full time series 1990-2022.The carbon content of lubricants value is 20.0 tonne carbon/TJ. Emissions of CO_2 estimated for this category are presented in Table 4.2.

Equation 5.2 Lubricants – Tier 1 Method

$$CO_2\ Emissions = LC \bullet CC_{Lubricant} \bullet ODU_{Lubricant} \bullet 44/12$$

Where:

CO_2 Emissions = CO_2 emissions from lubricants, tonne CO_2

LC = total lubricant consumption, TJ

$CC_{Lubricant}$ = carbon content of lubricants (default), tonne C/TJ

$ODU_{Lubricant}$ = ODU factor (based on default composition of oil and grease), fraction

44/12 = mass ratio of CO_2/C

There is a comparison check carried out between the national statistical data for the use of lubricants and the quantity associated with 2-stroke engines within the 1A3b category. In 2022, CO_2 emissions from 2-stroke engines within 1A3b category accounted for 35.8 tonnes out of 23,449.5 tonnes for the transport sector.

4.5.1.3 Uncertainties and Time-series Consistency

The uncertainties applicable to this category can be found in Annex 2.

The uncertainty of the activity data is 30 per cent based on the expert judgment as the use of the lubricant vehicle engine type is unknown and the uncertainty of the emission factor is 5 per cent.

4.5.1.4 Category-specific QA/QC and verification

Standard QA/QC procedures have been applied to *Lubricant Use*. Details of Ireland's QA/QC process can be found in Chapter 1 of this report.

4.5.1.5 Category-specific Recalculations

There was a recalculation for the year 2021 only in this source category, due to a revision in the energy statistics with a resulting decrease in emissions of 8.0 per cent. See Table 4.4.

4.5.1.6 Category-specific Planned Improvements

There are no planned improvements for this category.

4.5.2 Paraffin Wax Use (2.D.2)

4.5.2.1 Category Description

The category, as defined here, includes such products as petroleum jelly, paraffin waxes and other waxes, including ozokerite (mixtures of saturated hydrocarbons, solid at ambient temperature). Ireland estimates CO_2 emissions from paraffin waxes in the form of candle wax and residual wax. Paraffin waxes are categorised by oil content and the amount of refinement. Paraffin waxes are used in applications such as: candles, corrugated boxes, paper coating, board sizing, food production, wax polishes, surfactants (as used in detergents) and many others. Emissions from the use of waxes derive primarily when the waxes or derivatives of paraffins are combusted during use (e.g., candles).

4.5.2.2 Methodological Issues

Ireland uses a Tier 2 method to estimate emissions of CO_2 from non-energy use of paraffin wax based on equation 5.5 in the 2006 IPCC guidelines and an ODU (Oxidising During Use) factor 1.0 for paraffin wax candles and an ODU factor of 0.2 for all other uses of paraffin wax. The national energy balance provides data on paraffin wax consumption for the full time series 1990-2022. The carbon content of paraffin wax value is 20.0 tonne carbon/TJ. Emissions of CO_2 estimated for this category are presented in Table 4.2. Data on wax candles is provided by the CSO as the data from the national energy balance does not include candle wax use. Detailed information of Paraffin wax use is available in Annex 3.2.F. CO_2 emissions estimated for this category are presented in Table 4.2.

Equation 5.5 Waxes – Tier 2 Method

$$CO_2 \text{ Emissions} = \sum_i (PW_i \bullet CC_i \bullet ODU_i) \bullet 44/12$$

Where:

CO_2 Emissions = CO_2 emissions from waxes, tonne CO_2

PW_i = consumption of wax type i (candle wax and residual wax), TJ

CC_i = carbon content of wax type i, tonne C/TJ

ODU_i = ODU factor for wax type i, fraction

44/12 = mass ratio of CO_2/C

4.5.2.3 Uncertainties and Time-series Consistency

The uncertainties applicable to this category can be found in Annex 2.

The applied uncertainty of the activity data is 30 per cent and the uncertainty of the emission factor is 5 per cent based on the expert judgement, Chapter 5, Volume 3 2006 IPCC guidelines.

4.5.2.4 Category-specific QA/QC and verification

Standard QA/QC procedures have been applied to *Paraffin Wax Use*. Details of Ireland's QA/QC process can be found in Chapter 1 of this report.

4.5.2.5 Category-specific Recalculations

There was a minor recalculation for the year 2021 only due to a revision in the activity data for paraffin wax by the national statistics provider, resulting in an increase in emissions of 0.2 per cent. See Table 4.4.

4.5.2.6 Category-specific Planned Improvements

There are no planned improvements for this category.

4.5.3 Other Non-energy Products from Fuels and Solvent Use (2.D.3)

4.5.3.1 Category Description

The use of solvents manufactured using fossil fuels as feedstocks can lead to evaporative emissions of various non-methane volatile organic compounds (NMVOC), which are subsequently further oxidised in the atmosphere.

Emissions of NMVOCs are reported in this category. NMVOCs are indirect greenhouse gases which result from the use of solvents and various other volatile compounds. The indirect CO_2 emissions associated with these NMVOC emissions are reported under this category. Previously, these estimates were reported in CRF Table 6 and included in Ireland's national total, without LULUCF with indirect.

4.5.3.2 Methodological Issues

Methodologies for estimating these NMVOC emissions can be found in the EMEP/EEA Emission Inventory Guidebook (EEA, 2016). Further information on emissions of NMVOCs and indirect CO_2 emissions can be found in Chapter 9 of this report. Estimates of indirect CO_2 emissions are derived from NMVOCs by assuming that 60 per cent of the mass of NMVOCs is converted to CO_2.

4.5.3.3 Uncertainties and Time-series Consistency

The uncertainties applicable to this category can be found in Annex 2.

4.5.3.4 Category-specific QA/QC and verification

Quality control checks have been included to ensure that the emission estimates calculated in the data processing sheets are the same as those in the inventory dataset that is used for reporting purposes.

4.5.3.5 Category-specific Recalculations

There were recalculations in this source category resulting from an update to activity data for the years 1990 to 2021 in category 2D3i Other Solvent use which resulted in an average decrease of 2.5

per cent in the emissions estimates for the entire time series 1990-2021 in this subcategory. See Table 4.4.

4.5.3.6 Category-specific Planned Improvements

There are no planned improvements for this category. All recalculations are presented in table 4.4.

4.5.4 Other: Urea used as a catalyst (2.D.3)

4.5.4.1 Category Description

Selective catalytic reduction (SCR) technology was introduced in modern vehicles in order to ensure compliance with the EU regulations on air pollution reduction. The SCR technology injects urea solution into the exhaust line as a percentage of fuel use of a vehicle to curb NO_x emissions. The urea solution then releases small amounts of CO_2 and of NH_3 to make a reaction with NO_x to break it down into N_2 and H_2O. However, this small amount of CO_2 from this process causes an additional amount of CO_2 in the exhaust system.

This report considers SCR from Euro 3 technologies and thus urea solution as an additive has been estimated for different years according to the penetration of technologies from Euro 3 onwards for different categories of vehicles in Ireland. Euro IV and V Coaches/Buses and HDV penetrated the Irish market in 2006 and 2010 respectively. Urea additive for passenger cars and LDVs have been included from 2015 onwards for Euro 6 vehicles.

4.5.4.2 Methodological Issues

The amount of CO_2 produced by urea solution in road transport was estimated using the COPERT 5 model which is a Tier 3 approach. In order to estimate CO_2 produced by urea solution, a share of 3 to 6 per cent urea additive of the fuel consumption for eligible vehicles categories (e.g. HDV) and the share of vehicles having SCR technologies of the eligible categories were applied in the model. The estimated CO_2 from the model output was then applied to the following equation (T2 Method, Chapter 3: Volume 2, IPCC, 2006) to calculate amount of urea solution.

$$CO_2 = U * \left(\frac{12}{60}\right) * P * \left(\frac{44}{12}\right)$$

Here, U means mass of Urea based additive; P=Purity means the mass fraction of Urea in the urea additive; Default value for Purity (if country specific value is not available) is 0.325.

4.5.4.3 Uncertainties and Time-series Consistency

As the CO_2 was estimated from a model using parameters based on assumptions, a 30 per cent uncertainty was considered for activity data. As the emissions factor is based on the carbon content, a comparatively lower uncertainty of 5 per cent was applied for uncertainty analysis.

4.5.4.4 Category-specific QA/QC and verification

Standard QA/QC procedures have been applied to *Urea used as a catalyst*. Details of Ireland's QA/QC process can be found in Chapter 1 of this report.

4.5.4.5 Category-specific Recalculations

There was a recalculation in fuel balanced mileage in the COPERT model for road transport, which resulted in changes from 2006 to 2021. The average category recalculation change is a decrease of 1.5 per cent per annum. All recalculations are presented in Table 4.4.

4.5.4.6 Category-specific Planned Improvements

There are no planned improvements for this category.

4.6 Emissions from Electronics Industry (2.E)

4.6.1 Integrated Circuit or Semiconductor (2.E.1)

4.6.1.1 Category Description

The semiconductor industry uses HFCs, PFCs, SF_6 and NF_3 in manufacturing processes. Both HFCs and PFCs are used in the cleaning of chambers used for chemical vapour deposition processes, dry plasma etching, vapour phase soldering and vapour phase blanketing, leak testing of hermetically sealed components and as coolants. Cleaning and etching during semiconductor manufacture account for most emissions from the category. In addition, SF_6 and NF_3 are used in the etching process.

PFC emissions peaked in 2000 in Ireland after which they have gradually decreased. This is due to the economic downturn as well as the voluntary agreement implemented by the European Semiconductor Industry Association (ESIA, 2011) for the reduction of PFC emissions. There has been an increase in PFC emissions from 2014 to 2021 due to increased manufacturing operations in the semiconductor industry. NF_3 emission levels were highest in the period 2000-2007 and have been reducing since 2008 onwards. Emission estimates for Electronics Industry category 2.E.1 are presented in Table 4.3 and Figure 4.3 below.

4.6.1.2 Methodological Issues

Ireland uses a Tier 2a method to estimate emissions from this category using company specific data based on gas consumption and emission control technologies in use in the process, as outlined in the 2006 IPCC guidelines. There are a small number of large semiconductor manufacturers in Ireland. These installations provide data on the annual use and estimated emissions of HFCs, PFCs, SF_6 and NF_3 in their plants over the full time series 1990-2022.

4.6.1.3 Uncertainties and Time-series Consistency

The uncertainties applicable to this category can be found in Annex 2.

An uncertainty analysis was performed for the aggregated emissions derived from a specific consideration of the individual sector uncertainty estimates (Adams et al., 2005) and reviewed in 2013 (Goodwin et al., 2013). An iterative Monte Carlo simulation procedure was used to estimate uncertainties in total and aggregated HFC, PFC and SF_6 emissions. The uncertainty of the activity data is 20 per cent and the uncertainty of the emission factor is 10 per cent were obtained from these studies.

4.6.1.4 Category-specific QA/QC and verification

The QA/QC approach for this category was reviewed and modified in 2013 (Goodwin et al., 2013). This included checks on cell references and detailed calculations and checks to ensure that the sectoral emissions total in calculation sheets is the same as that in the final inventory dataset that is reported to the UNFCCC. Ireland collects company-specific data based on gas consumption and emission control technologies in use in the process. The emissions calculated and reported to the inventory team are checked and reviewed by the team. An ongoing dialogue is documented with the reporting teams from industry as to how they calculate and report this data. An update on manufacturing processes and usage of relevant substances is provided to the inventory team and the data reported by the industry is aligned with data provided to the European Semiconductor Industry Association (ESIA).

4.6.1.5 Category-specific Recalculations

There were revised emissions from a semi-conductor manufacturer with new data for the years 2020 to 2021 in this submission. Emissions were 12.2 and 10.4 per cent respectively lower in 2020 and 2021. See Table 4.4.

4.6.1.6 Category-specific Planned Improvements

There are no planned improvements for this category.

4.6.2 TFT Flat Panel Display Industry (2.E.2)

This activity has not existed in Ireland during the time series 1990-2022. This category is reported as Not Occurring (NO).

4.6.3 Photovoltaics Industry (2.E.3)

This activity has not existed in Ireland during the time series 1990-2022. This category is reported as Not Occurring (NO).

4.6.4 Heat Transfer Fluid Use (2.E.4)

This activity has not existed in Ireland during the time series 1990-2022. This category is reported as Not Occurring (NO).

4.6.5 Other Electronics Industry (2.E.5)

This activity has not existed in Ireland during the time series 1990-2022. This category is reported as Not Occurring (NO).

4.7 Emissions from Product Uses as Substitutes for ODS (2.F)

The compilation of emission estimates for fluorinated gases presents major challenges for inventory agencies because they emanate from diverse sources that are entirely different to those traditionally covered by atmospheric emissions inventories. In addition, the use of many of the substances concerned is continuing to change very rapidly in the marketplace. This sector covers the following categories;

- Refrigeration and air conditioning 2.F.1,
- Foam blowing agents 2.F.2,
- Fire protection 2.F.3,
- Aerosols 2.F.4,
- Solvents 2.F.5,

- Other applications 2.F.6.

Emission estimates for category 2.F are presented in Table 4.3 and Figure 4.3 below.

Table 4.3. Emissions of HFC, PFC, SF_6 and NF_3 from IPPU 1990-2022 (kt CO_2 eq)

IPCC Source Category	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
2.F.1 Refrigeration and Air-Conditioning	NO	0.66	70.52	555.18	653.81	715.72	794.90	769.28	834.45	750.03	452.17	478.02	386.19	444.14	459.01
2.F.1 Mobile Air Conditioning	NO	3.87	43.22	111.22	203.29	200.93	205.64	208.49	214.99	211.80	200.18	174.14	135.05	128.17	116.63
2.F.2 Foams	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2.F.3 Fire-extinguishers	NO	NO	7.62	14.87	33.67	33.72	33.73	33.75	33.76	33.78	33.79	33.81	33.82	33.83	33.85
2.F.4 Aerosols	NO	24.97	77.70	92.55	75.70	61.37	57.56	53.87	50.26	46.74	42.23	29.99	10.86	1.26	1.30
2.F.4 Metered Dose Inhalers	NO	NO	33.93	42.02	46.71	46.27	46.70	47.39	48.69	49.01	50.36	50.17	51.20	50.07	51.45
2.E.1 Semiconductor manufacture	0.50	1.93	12.68	2.36	3.51	2.84	0.48	3.21	1.45	2.11	4.18	4.45	4.06	3.34	3.54
HFCs	**0.50**	**31.43**	**245.68**	**818.21**	**1,016.68**	**1,060.85**	**1,139.02**	**1,115.99**	**1,183.61**	**1,093.46**	**782.91**	**770.57**	**621.18**	**660.81**	**665.77**
2.E.1 Semiconductor manufacture	0.11	88.63	361.34	196.47	42.29	7.57	3.23	18.47	33.55	42.38	44.81	56.65	57.73	59.67	50.37
PFCs	**0.11**	**88.63**	**361.34**	**196.47**	**42.29**	**7.57**	**3.23**	**18.47**	**33.55**	**42.38**	**44.81**	**56.65**	**57.73**	**59.67**	**50.37**
2.E.1 Semiconductor manufacture	0.47	42.30	30.55	64.46	17.95	22.69	15.63	22.21	17.51	16.60	22.22	23.81	10.88	9.37	9.42
2.G.1 Electrical equipment	21.15	25.85	7.66	23.12	12.71	19.18	19.74	20.30	19.65	20.48	16.62	7.45	3.24	2.97	3.91
2.G.2 Other	1.31	1.41	3.21	12.48	3.49	2.62	2.78	2.93	2.93	2.93	2.93	2.92	2.92	2.92	2.92
2.G.2 Other - gas-air tracers	11.99	11.99	11.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SF_6	**34.92**	**81.54**	**53.41**	**100.06**	**34.15**	**44.49**	**38.15**	**45.45**	**40.09**	**40.01**	**41.77**	**34.18**	**17.04**	**15.26**	**16.24**
2.E.1 Semiconductor manufacture	NO	4.09	46.03	26.57	27.83	21.25	18.83	16.36	15.79	26.54	18.38	11.16	9.54	8.72	8.24
NF_3	**NO**	**4.09**	**46.03**	**26.57**	**27.83**	**21.25**	**18.83**	**16.36**	**15.79**	**26.54**	**18.38**	**11.16**	**9.54**	**8.72**	**8.24**
HFC, PFC, SF_6 and NF_3	**35.52**	**205.70**	**706.46**	**1,141.30**	**1,120.96**	**1,134.16**	**1,199.23**	**1,196.27**	**1,273.04**	**1,202.38**	**887.87**	**872.56**	**705.49**	**744.47**	**740.63**

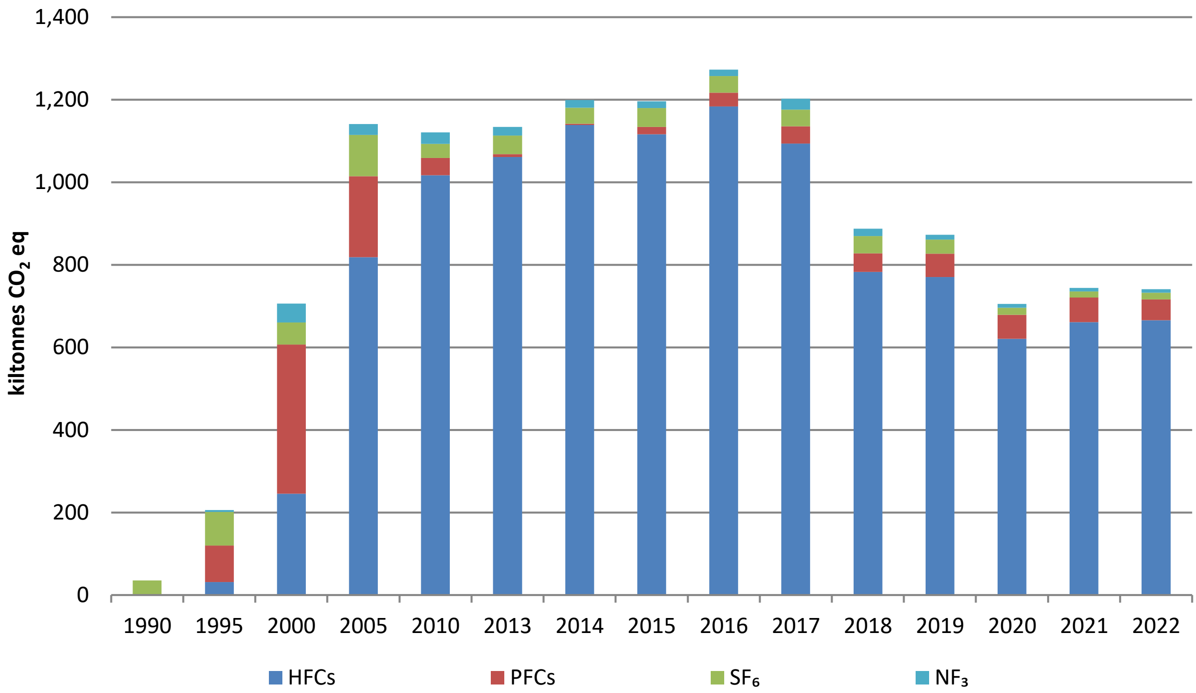


Figure 4.3 Emissions of HFC, PFC, SF_6 and NF_3, 1990-2022

4.7.1 Refrigeration and air conditioning (2.F.1)

4.7.1.1 Category Description

Refrigeration and air conditioning is a key category for Ireland, both in terms of the level assessment (2022) and the trend assessment (1990-2022). It includes the following sub-categories;

- Commercial refrigeration 2.F.1.a,
- Domestic refrigeration 2.F.1.b,
- Industrial refrigeration 2.F.1.c,
- Transport refrigeration 2.F.1.d,
- Mobile air-conditioning 2.F.1.e,
- Stationary air-conditioning 2.F.1.f.

HFCs and HFC blends have been widely used as replacement refrigerants for CFC and HCFC refrigerants across virtually all refrigeration sub-sectors (i.e. domestic refrigeration, small commercial distribution systems, industrial systems, building air conditioning systems and refrigerated transport).

The first HFC refrigerant on the market was R134a in the 1990s. The composition of the HFC refrigerants present on the Irish market has undergone some significant changes across the time series. These changes are due to the rapid phase-in of different HFC refrigerants in various applications, and the introduction of new refrigerant blends i.e. R404A, 407A, 407C, R410A, R404A, R134a and R407C, which have been the main refrigerants since 2000. In 2018, 2019 and 2020 a significant decrease in HFC emissions can be seen compared to 2017, this is due to a reduction in the import of HFCs due to their replacement with Hydrofluoroolefin (HFO) blends HFO/HFC.

In the early part of the time series (1995 to 2000) large quantities of HCFCs were used as refrigerants (mainly R22, which are not subject to greenhouse gas emission reporting as controlled under the Montreal Protocol).

4.7.1.2 Methodological Issues

Data on the quantities of industrial gases supplied to the refrigeration sector is obtained from chemical suppliers and manufacturers of refrigeration units. Sales data is provided for a range of HFCs and blends corresponding to the individual HFC species: HFC-23, HFC-32, HFC-125, HFC-134a, HFC-143a, HFC-152a.

There is no manufacture of fluorinated gases in Ireland. Imported HFCs are calculated using the data supplied as described above. Exports are calculated on the basis of refrigeration unit manufacturers' share of exports. In Ireland there is no known destruction of HFCs. Recovered gas is used either in other equipment or exported for recycling or destruction.

A bottom-up approach is not feasible for estimating emissions from stationary refrigeration and air conditioning in Ireland due to the lack of data available on equipment types and HFC sales data in equipment sub-categories. Therefore, emissions are estimated using a top-down approach based on reported sales data and information on market shares, which are applied to calculate estimates of total HFC sales in the Irish stationary refrigeration and air-conditioning sectors. As a result, emissions arising from sub-categories *2.F.1.b Domestic refrigeration, 2.F.1.c Industrial refrigeration, 2.F.1.d Transport refrigeration* and *2.F.1.f Stationary air-conditioning* are reported under *2.F.1.a Commercial Refrigeration*. The emissions of HFCs in 2.F.1 Refrigeration and Air conditioning (stationary) show a 38.3 per cent decrease in emissions in 2018 (480.0 kt CO_2eq) compared to 2017 (777.9 kt CO_2eq). The reason is an overall decrease in the amount of F gases imported to Ireland. Also, a significant decrease was noted in the import of gases R404A (GWP 3922), R410A (GWP 2088) and R134a (GWP 1430) in recent years. This would appear to be a result of the implementation of the F-gas regulations EU 517/2014 which limits the amount of the most important F-gases that can be sold from 2015 onwards and phases down in steps the higher GWP gases as well as banning the use of F-gases in many new types of equipment where less harmful alternatives are available. The decrease in CO_2eq of 38.3 per cent is in agreement with a report from the European Commission on the availability of hydrofluorocarbons in the Union Market (EC, 2020). This report found according to data reported under the F-gas Regulation, the total amount of HFCs supplied to the EU market (including in equipment such as air conditioners) dropped by 37 per cent in CO_2 equivalent between 2018 and 2015, whereas the drop measured in volume was only 25 per cent. This shows a clear shift in the supply towards lower GWP HFCs and other alternatives. A decrease of 15.7 per cent was seen in emissions of HFCs in 2.F.1 Refrigeration and Air conditioning in 2020.

The assumptions used to calculate the emissions from these categories are included in Table 4.5 of Annex 3.2.

Emissions of HFCs from sub-category *2.F.1.e Mobile Air-Conditioning* are estimated using a Tier 3b bottom-up analysis which uses national vehicle fleet statistics (Table 3.1.13, Annex 3.1.B) and assumed rates of air-conditioning unit penetration in the national vehicle fleet (AEA, 2011). The methodology used takes account of vehicle lifetime (12 years), the percentage of vehicles having HFC in their air-conditioning systems, average charge per unit, product manufacturing emissions (AEA, 2011), effective lifetime leakage rates (incorporating emissions from normal operating losses and accidental releases arising from collision damage) and decommissioning losses (EP and CEU, 2006). In 2020, the inventory team carried out two surveys to assess the rate of change over of mobile air conditioning to low global warming potential (GWP) gases as a result of the MAC Directive. This prohibits the use of F-gases with GWP of more than 150 times greater than CO_2 in new types of cars and vans produced from 2017. One survey was circulated to EPA staff nationwide with a 27 per cent response rate and the other was circulated by the End-of-Life Vehicles compliance scheme (ELVES) to their members in vehicle distribution and sales in Ireland. This had over 60 per cent response rate. The results of these surveys gave a clearer picture of when low GWP gases were phased in and what percentage of cars and vans use them for years 2014-2022.

The assumed recovery factor for Mobile Air conditioning is 0 per cent as information was received that recovery is not occurring for End-of-life vehicles in Ireland.

According to the 2006 guidelines, Chapter 7 Box 7.4, *"In actuality, a given MAC will probably leak over several years before being serviced. Rather than attempting to account for this, for this example we apply Equation 7.13 which assumes all MACs are serviced each year such that the estimated charge of each MAC is the same as the nominal charge. The annual emission rate is averaged to account for this assumption...Hence the bank in any given year is the sum of the Refrigerant Charged into New Equipment each year from the current year back to the assumed average lifetime of the equipment"*.

The assumed lifetime is 12 years and therefore the amount in operating stocks is calculated;

If Bt= bank for a certain year and refrigerant charged into new equipment;

Mt B2020 = M2020+M2019+M2018……...+ M2011+M2010+M2009

4.7.1.3 Uncertainties and Time-series Consistency

The uncertainties applicable to this category can be found in Annex 2.

An uncertainty analysis was performed for the aggregated emissions derived from a specific consideration of the individual sector uncertainty estimates (Adams et al., 2005) and reviewed in 2013 (Goodwin et al., 2013). An iterative Monte Carlo simulation procedure was used to estimate uncertainties in total and aggregated HFC, PFC and SF_6 emissions. The uncertainty of the activity data is 20 per cent and the uncertainty of the emission factor is 10 per cent were obtained from these studies.

4.7.1.4 Category-specific QA/QC and verification

The QA/QC approach for this category was reviewed and modified in 2013 (Goodwin et al., 2013). This includes checks on cell references and detailed calculation and checks to ensure that the sectoral emissions total in calculation sheets are the same as that in the final inventory dataset that is reported to the UNFCCC. This revised approach has been used in this submission.

4.7.1.5 Category-specific Recalculations

A revision to HFC in 2.F.1 Refrigeration and air conditioning, for the years 2001 to 2021 due to revised activity data on gas usage by installers. The average change is -0.1 per cent per annum. All recalculations are presented in table 4.4.

4.7.1.6 Category-specific Planned Improvements

There are ongoing discussions with the F-gas team in the Office of Environmental Enforcement in the EPA and the inventory team is attempting to find actual recovery rates for mobile air conditioning in the country from end-of-life vehicles.

4.7.2 Foam Blowing Agents (2.F.2)

4.7.2.1 Category Description

No manufacturing of open-cell foams (2.F.2.a) occurs in Ireland, and the production of closed-cell foams (2.F.2.b) takes place in Ireland by one company that used HCFC-141b but now uses pentane. Emissions from foam blowing agents were previously estimated using global data provided by the Alternative Fluorocarbons Environmental Acceptability Study (AFEAS) and weighted by GDP of all OECD countries. This method did not, therefore, take into account any country-specific information regarding the industry. Since then, two major production companies were consulted to understand the various manufacturing processes and the market in Ireland. Through this, it has been confirmed that the company which produces foams does not use F-gases, and due to the large market share of this company in Ireland it was determined that imports of products containing these gases are negligible if occurring at all, therefore emissions from use and disposal are not occurring in Ireland. Emissions from this category are reported as not occurring (NO) for manufacturing, use and disposal.

4.7.3 Fire Protection (2.F.3)

4.7.3.1 Category Description

There are two general types of fire protection (fire suppression) equipment that use HFCs and/or PFCs: portable (streaming) equipment, and fixed (flooding) equipment. HFCs, PFCs and more recently a fluoroketone are mainly used as substitutes for halons, typically halon 1301, in flooding equipment.

HFCs are most commonly used in fixed flooding systems in the protection of electronic and telecommunications equipment, in data centres, military applications, records offices, bank vaults and oil production facilities. There are several companies operating these systems in Ireland.

Although HFC-23 can be used in some systems, Goodwin et al., (2013) identified none within Ireland so the only HFC used is HFC-227ea. Most emissions occur when fire protection systems are triggered either accidentally or due to the occurrence of a fire. Smaller emissions occur during maintenance and filling.

4.7.3.2 Methodological Issues

Activity data on the use of HFCs in this sector has been provided by industry. From this information the number of systems and the quantity of HFCs present in the market has been estimated for the time series.

These systems were first introduced into the Irish market in 1996 so emissions are not occurring (NO) prior to 1996. The emission calculation methodology used for this category is a Tier 2 emission model. The model estimates emissions from three situations where emissions may occur:

- The first situation is from discharge (intentional and accidental). Although a major company within this sector has not recorded any discharges, they do apply the assumption that each system will discharge once over a ten-year period. This conservative assumption has been applied within the model.

- The second source covers leakage emissions and is estimated as 1 per cent of the total charge for all systems present.
- The third source is from the decommissioning of systems which began in 2010 assuming a 15-year lifetime of these systems.

4.7.3.3 Uncertainties and Time-series Consistency

The uncertainties applicable to this category can be found in Annex 2.

An uncertainty analysis was performed for the aggregated emissions derived from a specific consideration of the individual sector uncertainty estimates (Adams et al., 2005) and reviewed in 2013 (Goodwin et al., 2013). An iterative Monte Carlo simulation procedure was used to estimate uncertainties in total and aggregated HFC, PFC and SF_6 emissions. The uncertainty of the activity data is 20 per cent and the uncertainty of the emission factor is 10 per cent, which were obtained from these studies.

4.7.3.4 Category-specific QA/QC and verification

The QA/QC approach for this category was reviewed and modified in 2013 (Goodwin et al., 2013). This includes checks on cell references and detailed calculation and checks to ensure that the sectoral emissions total in calculation sheets is the same as that in the final inventory dataset that is reported to the UNFCCC. This revised approach has been used in this submission.

4.7.3.5 Category-specific Recalculations

There are no recalculations in this source category in this submission.

4.7.3.6 Category-specific Planned Improvements

There are no planned improvements for this category.

4.7.4 Aerosols (2.F.4)

4.7.4.1 Category Description

For the purposes of estimating emissions, Aerosols and Metered Dose Inhalers are treated separately. This category includes the following sub-categories;

- Metered dose inhalers 2.F.4.a,
- Other-Aerosols 2.F.4.b.

Most aerosol packages contain hydrocarbon (HC) as propellants but, in a small fraction of the total, HFCs and PFCs may be used as propellants or solvents. Emissions from aerosols usually occur shortly after production, on average six months after sale.

4.7.4.2 Methodological Issues

Emission estimates for Metered Dose Inhalers (MDI) 2.F.4.a are made based on data received from industry for manufacturing emissions, and population data coupled with emission factors for emissions from use. The HFCs used in MDI’s in Ireland are HFC-134a and HFC-227ea.

Process losses are based on an analysis of gross stock minus closing stock and usage data of the gases. The MDI market in Ireland is supplied by both Irish manufactured products and imported products. Irish manufactured products only contain HFC-134a based on annual industry returns and Adams et al. (2005). Imported products on the other hand can contain HFC-134a and HFC-227ea. As a result, there is no emissions from manufacture for HFC-227ea in CRF Table2(II)B-Hs2. Total emissions are calculated based on reported manufacturing losses (for HFC-134a) in conjunction with in-life emissions.

Ireland has a high prevalence of asthma and in order to reflect this country-specific circumstance, a bottom-up approach to estimating in-life emissions is applied. Approximately 10 per cent of the Irish population are suffering from asthma (Goodwin et al., 2013) and about 80 per cent of the asthma medication sold relates to MDIs (Asthma Support Team of a large pharmacy chain) with the remaining 20 per cent relating to Dry Powder Inhalers.

A calculation based on population and these data was undertaken in order to establish an estimate for the total annual demand. This demand is catered for by imported products from a number of manufacturers as well as those manufacturing in Ireland.

Information on the amount of HFCs contained in MDIs per patient was determined empirically at approximately 0.074kg per user per annum (Schwarz et al., 2012). Furthermore, it was estimated that of the HFCs used in MDIs in Ireland, HFC-134a accounted for 90 per cent and HFC-227ea for 10 per cent. HFC-227ea is mainly used by a non-Irish, European MDI producer. These data were used for the estimation of lifetime emissions. Company data on MDIs produced in Ireland show that the assumptions made in estimating emissions correspond quite closely and are a source of emission verification.

The category Other-Aerosols 2.F.4.b, is one which can cover a large number of products, however HFC's are generally only used as propellants where the use of HFCs is considered critical. The two HFCs of interest are HFC-134a and HFC-152a and the assumed species ratio of 90 per cent: 10 per cent, respectively for HFC-134a and HFC-152a (Schwarz et al., 2012) was used until Submission 2022. This species ratio is now revised in this submission to reflect the ration in the UK, which is used as a proxy. The new ratio ranges from 97.6 per cent in 1993 to 25.1 per cent in 2020 for HFC-134a and 2.4 per cent in 1993 to 74.9 per cent in 2020 for HFC-152a.

There is no trade association for aerosol manufacturers or importers in Ireland. Furthermore, Adams *et al* (2005) found that importation of HFC containing aerosols is carried out independently by retailers. As a result, little information exists in relation to the Irish market for these products (Goodwin et al., 2013).

Following consultations with the British Trade Association (BAMA), O'Leary *et al*. (2002) and Adams *et al*. (2005) recommended the use of a population-based proxy to estimate Irish emissions from those for the UK, which are based on trade data for the UK, on the assumption that the market for aerosols would be similar in Ireland. Emissions of HFC-134a and HFC-152a from aerosols are therefore derived using the UK estimates for lifetime and decommissioning emissions (as used in the UK national GHG inventory) and the ratio of the Irish population (CSO) to the UK population (Office of National Statistics, UK) in each year. The estimate for potential emissions is calculated using the UK trade data and the population ratio.

4.7.4.3 Uncertainties and Time-series Consistency

The uncertainties applicable to this category can be found in Annex 2.

An uncertainty analysis was performed for the aggregated emissions derived from a specific consideration of the individual sector uncertainty estimates (Adams et al., 2005) and reviewed in 2013 (Goodwin et al., 2013). An iterative Monte Carlo simulation procedure was used to estimate uncertainties in total and aggregated HFC, PFC and SF_6 emissions. The uncertainty of the activity data and the uncertainty of the emission factor were obtained from these studies.

4.7.4.4 Category-specific QA/QC and verification

The QA/QC approach for this category was reviewed and modified in 2013 (Goodwin et al., 2013). This includes checks on cell references and detailed calculation and checks to ensure that the sectoral emissions total in calculation sheets is the same as that in the final inventory dataset that is reported to the UNFCCC. This revised approach has been used in this submission. MDI emissions estimates are checked against confidential data received from a manufacturer in Ireland.

4.7.4.5 Category-specific Recalculations

There was a recalculation in subcategory Other-Aerosols 2.F.4.b for the years 1993 to 2021 to reflect the change in the UK inventory to take into the account of the ban on HFC with a GWP >150 and the revised species ration described above. The average change was a decrease in HFC emissions from this sub-category of -0.9 per cent or between 0.0 kt CO_2 eq in 1993 to -11.8 kt CO_2 eq in 2021. All recalculations are presented in table 4.4.

4.7.4.6 Category-specific Planned Improvements

There are no planned improvements for this category.

4.7.5 Solvents (2.F.5)

There are no known emissions from this category in Ireland. This category is reported as Not Occurring (NO).

4.7.6 Other Product Uses as Substitutes for ODS (2.F.6)

No activities have been identified for inclusion under this category. This category is reported as Not Occurring (NO).

4.8 Emissions from Other Product Manufacture and Use (2.G)

Emission estimates for category 2.G are presented in Table 4.3. This category includes the following sub-categories;

- Electric equipment 2.G.1,
- SF_6 and PFCs from other product use 2.G.2,
    1. Soundproof windows 2.G.2.c,
    2. Adiabatic properties: shoes and tyres 2.G.2.d,
    3. Other-Medical Applications and Tracer in Leak Detection 2.G.2.e,

- N_2O from Product Uses,
    1. Medical Application 2.G.3.a,
    2. Propellant for pressure and aerosol products 2.G.3.b

4.8.1 Electrical Equipment (2.G.1)

4.8.1.1 Category Description

SF_6 is used for electrical insulation, arc quenching, and for current interruption in equipment used in the transmission and distribution of electricity. The Electricity Supply Board (ESB) is the owner of both the high and low voltage distribution systems and the owner and operator of the medium and lower voltage distribution systems in Ireland. SF_6 is used in equipment across all voltage ranges on both the Distribution and Transmission systems owned by ESB Networks.

Electrical equipment containing SF_6 is imported into Ireland and at time of purchase, is added to the SF_6 installed inventory database. Quantities of SF_6 are needed for servicing and repair of existing equipment. There are no manufacturing emissions. As of 2019 ESB Networks requested equipment manufacturers of non-hermetically sealed switchgear to only supply a low level of SF_6 for safe transport to Ireland. Once installed on site the remaining amount of SF_6 required is used from ESB Networks internal stock.

Significant reduction in emissions in the years 2008 to 2010 are attributed to the network operator's investment in staff training, leak detection equipment and closed cycle SF_6 handling equipment. The increase in 2011 is due the highest installed inventory stock levels occurring in the period 2009 to 2011, but losses remain low around 0.5 per cent.

4.8.1.2 Methodological Issues

Emissions are estimated using a Tier 3 approach based on an analysis of opening and closing stocks of SF_6. The inventory estimates assume that the usage of SF_6 in equipment maintenance for one year is equal to the leakage emissions from electrical equipment in the same year. This method was reviewed by the project team and deemed to be acceptable and in line with 2006 IPCC Guidelines Tier 3 utility level pure mass-balance approach (IPCC, 2006).

The company supplies an estimate of SF_6 emissions from their equipment maintenance operations to the inventory agency on a yearly basis. The volume of SF_6 used for maintenance is calculated using the following methodology:

- Maintenance orders for SF_6 top ups are tracked using ESB Network's Enterprise Asset Management system. These are compared against SF_6 related plant outages from both Distribution and Transmission system operators.
- Each ESB Networks business area collates annual figures from locally held records and reports to ESB Networks Assets team who finalise the annual figures.
- Annual figures are then submitted to ESB Networks Environmental team for onward reporting to the EPA.

4.8.1.3 Uncertainties and Time-series Consistency

The uncertainties applicable to this category can be found in Annex 2.

An uncertainty analysis was performed for the aggregated emissions derived from a specific consideration of the individual sector uncertainty estimates (Adams et al., 2005) and reviewed in 2013 (Goodwin et al., 2013). An iterative Monte Carlo simulation procedure was used to estimate uncertainties in total and aggregated HFC, PFC and SF_6 emissions. The uncertainty of the activity and the emission factor were obtained from these studies.

4.8.1.4 Category-specific QA/QC and verification

The QA/QC approach for this category was reviewed and modified in 2013 (Goodwin et al., 2013). This includes checks on cell references and detailed calculation and checks to ensure that the sectoral emissions total in calculation sheets is the same as that in the final inventory dataset that is reported to the UNFCCC. This revised approach is used in this submission.

4.8.1.5 Category-specific Recalculations

There are no significant recalculations in this source category in this submission.

4.8.1.6 Category-specific Planned Improvements

There are no planned improvements for this category.

4.8.2 SF_6 and PFCs from Other Product Uses (2.G.2)

4.8.2.1 Category Description

Emissions of SF_6 are included in this category from the following activities:

- **Soundproof windows 2.G.2.c** – SF_6 was previously used as an insulation gas in double-glazing; however, its use has been phased out in response to F-gas regulations and is assumed not to have occurred since 2000. Emissions occur from remaining stock only.
- **Adiabatic properties 2.G.2.d** – SF_6 was used as a cushioning agent in sports shoes due to its chemically and biologically inert properties and its high molecular weight, which means that it does not diffuse across membranes; thus, the gas is not released until the sports shoe is destroyed at the end of its useful life. Emissions occur from remaining stock only.
- **Medical applications 2.G.2.e** – SF_6 is used in certain medical applications such as eye surgery where it is used to seal retinal holes internally and to hold reattached retina in place.
- **Tracer in Leak Detection 2.G.2.e** –SF_6 has been used as a tracer gas for leak detection and in agricultural research as a tracer gas to determine the rates of methane emissions from enteric fermentation in cattle.

4.8.2.2 Methodological Issues

Emission estimations from *Soundproof windows 2.G.2.*c account for opening and closing stock of the gas, assembly losses for Irish manufactured products, stocks in imported windows, leakage once installed and disposal emissions. Even though the use of SF_6 was discontinued in window insulation after 2000, the bank of gas in installed units is an emission source and is therefore accounted for in emission estimates.

A lifetime of 25 years was applied; therefore, emissions at disposal are calculated as 100 per cent of the remaining charge after 25 years of leakage at a rate of 1 per cent per annum. The entire quantity of SF_6 remaining inside the window at the end of life is emitted, because to-date no recovery process exists.

There is no specific information available in relation to the use of SF_6 in *Adiabatic properties 2.G.2.d* (sports goods, shoes) in Ireland, so a population-proxy is used to estimate emissions based on UK inventory data for the release of SF_6 upon disposal of sporting goods, as the market share of such products is assumed to be similar to that in the UK. Emissions are reported for all years from 1998 to 2011 and are considered not occurring from 2012 to 2022 as SF_6 use was phased out in 2003/2004. Emissions are reported together with SF_6 emissions from *Electrical equipment* in category *2.G.1*, as the UK proxy data is considered confidential.

Use of SF_6 in *Medical applications 2.G.2.e* is small with one hospital reporting the use of one 10-litre cylinder every three years. Based on this data, it is assumed that a similar quantity is used in a total of 10 hospitals, which undertake similar procedures. It is assumed that actual and potential emissions are equal on the basis that in each of the 10 hospitals once a cylinder is used (over a three-year period) it is replaced.

The use of SF_6 as a Tracer in *Leak Detection 2.G.2.e* was previously a relatively large source in the period 1990-2004. However, the company who used SF_6 for the purpose of leak detection has since ceased trading.

A number of Agricultural research projects, conducted in 2009, were identified and included in the inventory: maize experiment – emission rate of 1.8 mg SF_6/day from 60 capsules (1/animal) for 105 days; whole-crop wheat experiment – emission rate of 3.14 mg SF_6/day from 90 capsules (1/animal) for 154 days. Calculated emissions from these two experiments were used to estimate emissions from a third research project similar to these two. No projects since have been identified, so this sub-category is no longer a source of emissions of SF_6 in the Irish inventory.

4.8.2.3 Uncertainties and Time-series Consistency

The uncertainties applicable to this category can be found in Annex 2.

An uncertainty analysis was performed for the aggregated emissions derived from a specific consideration of the individual sector uncertainty estimates (Adams et al., 2005) and reviewed in 2013 (Goodwin et al., 2013). An iterative Monte Carlo simulation procedure was used to estimate uncertainties in total and aggregated HFC, PFC and SF_6 emissions. The uncertainty of the activity data and the emission factor were obtained from these studies.

4.8.2.4 Category-specific QA/QC and verification

The QA/QC approach for this category was reviewed and modified in 2013 (Goodwin et al., 2013). This includes checks on cell references and detailed calculation and checks to ensure that the sectoral emissions total in calculation sheets is the same as that in the final inventory dataset that is reported to the UNFCCC. This revised approach is used in this submission.

4.8.2.5 Category-specific Recalculations

Emissions from SF_6 use in shoes have been removed for all years from 2012 to 2021 as recommended during the UNFCCC review in 2023. See table 4.4.

4.8.2.6 Category-specific Planned Improvements

The inventory agency is considering all potential new sources including SF_6 use, including particle accelerators and the results of an EPA funded research project, FUSE 4i.

4.8.3 N_2O from Product Use (2.G.3)

4.8.3.1 Category Description

Evaporative/fugitive emissions of nitrous oxide (N_2O) can arise from various types of product use, including;

- Medical applications (anaesthetic use, analgesic use and veterinary use);
- Use as a propellant in aerosol products, primarily in food industry (pressure-packaged whipped cream, etc.);
- Oxidising agent and etchant used in semiconductor manufacturing;
- Oxidising agent used, with acetylene, in atomic absorption spectrometry;
- Production of sodium azide, which is used to inflate airbags;
- Fuel oxidant in auto racing; and
- Oxidising agent in blowtorches used by jewellers and others.

In general, medical applications and use as a propellant in aerosol products are likely to be larger sources than others.

The use of N_2O as an anaesthetic in hospitals is a source of emissions and has been estimated in this submission. Emission estimates for *Medical applications 2.G.3.*a are presented in Table 4.2 and are based on emissions of 30g of N_2O per capita.

4.8.3.2 Methodological Issues

Ireland is unable to estimate emissions for 2.G.3.b due to the lack of data on N_2O from propellant use in aerosol products. No data could be found on whipped spray cream consumption by Ireland's Central Statistics Office.

In absence of methodologies or emission factors in the existing guidelines, Ireland used population-based activity data and assumed a usage of 10 grams of N_2O per capita per year and emission factor of 1 (as all used gas is emitted into the atmosphere). This assumption is similar to that of other Annex I Parties that estimate emissions from this category. The Danish inventory approach was also used to assess the possible emission levels of this category for Ireland. Both approaches resulted in emissions below the threshold of 0.05 per cent of national total emissions. The inventory team considers that a disproportionate effort would be required to collect country specific data on whipped cream sales therefore, Ireland does not estimate N_2O emissions from propellant use for pressure and aerosol products and reports this category as not estimated (NE), considered insignificant.

4.8.3.3 Uncertainties and Time-series Consistency

The uncertainties applicable to category N_2O from Product Use are provided in Annex 2. The emission time series for 1990–2022 is consistent. Key activity data such as Ireland's population statistics are available for all applicable years and are used in a consistent manner.

4.8.3.4 Category-specific QA/QC and verification

Standard QA/QC procedures have been applied to this category. Details of Ireland's QA/QC process can be found in Chapter 1 of this report.

4.8.3.5 Category-specific Recalculations

There were no significant recalculations in this source category in this submission.

4.8.3.6 Category-specific Planned Improvements

There are no planned improvements for this category.

4.8.4 Other – Other Product Manufacture and Use (2.G.4)

Emissions of NMVOCs are reported in this category and are indirect greenhouse gases which result from the use of tobacco. The indirect CO_2 emissions associated with these NMVOC emissions are reported under this category. Previously, these estimates were reported in CRF Table 6 and included in Ireland's national total, without LULUCF with indirect.

4.8.4.1 Methodological Issues

Methodologies for estimating these NMVOC emissions can be found in the EMEP/EEA Emission Inventory Guidebook (EEA, 2019). Further information on emissions of NMVOCs and indirect CO_2 emissions can be found in Chapter 9 of this report. Estimates of indirect CO_2 emissions are derived from NMVOCs by assuming that 60 per cent of the mass of NMVOCs is converted to CO_2.

4.8.4.2 Uncertainties and Time-series Consistency

The uncertainties applicable to this category can be found in Annex 2.

4.8.4.3 Category-specific QA/QC and verification

Quality control checks have been installed to ensure that the emission estimates calculated in the data processing sheets are the same as those in the inventory dataset that is used for reporting purposes.

4.8.4.4 Category-specific Recalculations

There are no recalculations in this source category in this submission.

4.8.4.5 Category-specific Planned Improvements

There are no planned improvements for this category.

4.9 Other –Food and Beverage Industry (2.H.2)

Emissions of NMVOCs are reported here are indirect greenhouse gases which result from various activities in the food and beverage industry including;

- Bread baking
- Beer production
- Spirit production
- Meat, fish etc, frying and curing

- Coffee roasting
- Animal Feedstock

The indirect CO_2 emissions associated with these NMVOC emissions are reported under this category.

4.9.1.1 Methodological Issues

Methodologies for estimating these NMVOC emissions can be found in the EMEP/EEA Emission Inventory Guidebook (EEA, 2019). Further information on emissions of NMVOCs and indirect CO_2 emissions can be found in Chapter 9 of this report. Estimates of indirect CO_2 emissions are derived from NMVOCs by assuming that 60 per cent of the mass of NMVOCs is converted to CO_2.

The sources of activity data for these estimations varies, for bread baking data is sourced from Eurostat and is cross checked with data from the national statistics office (CSO); for beer production data is sourced from the Irish Beer market report which is published annually; spirit production data is sourced from the CSO; for coffee roasting data is based on activity data for unroasted coffee imports obtained from the UN Comtrade Database; for meat, fish frying and curing the activity data was obtained from the CSO, tonnes of animal slaughterings in Ireland which is taken to be the equivalent of meat rendered in Ireland, and for animal feedstock the tonnage of animal feed produced was sourced from the CSO.

The sources of these data are described and given in Ireland's Informative Inventory Report 2024.

4.9.1.2 Uncertainties and Time-series Consistency

The uncertainties applicable to this category can be found in Annex 2.

4.9.1.3 Category-specific QA/QC and verification

Quality control checks have been installed to ensure that the emission estimates calculated in the data processing sheets are the same as those in the inventory dataset that is used for reporting purposes.

4.9.1.4 Category-specific Recalculations

There were minor recalculations in this source category in this submission due to population revisions. See table 4.4.

4.9.1.5 Category-specific Planned Improvements

Using a specific carbon content of NMVOC for spirit production will be considered in the next submission and reported consistently with the EEA/EMEP Guidebook 2023 used for reporting to the UNECE under the Convention on Long Range Transboundary Air Pollution (CLRTAP) (UNECE, 1999) and the National Emission reduction Commitments Directive (EP and CEU, 2016).

Table 4.4(a) Recalculations Previous and current emission estimates in the IPPU Sector (1990-2021)

	2023 Submission	Gases	Units	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021
2.A.1	Cement Production	CO_2	kt CO_2eq	884.00	879.00	1,700.90	2,357.06	1,105.11	1,111.75	1,461.12	1,652.01	1,793.52	1,839.61	1,916.04	1,892.60	1,769.64	2,102.81
2.A.2	Lime Production	CO_2	kt CO_2eq	214.08	187.51	190.43	183.48	192.41	189.64	188.98	177.35	173.90	198.94	177.28	163.65	135.51	148.01
2.A.3	Glass Production	CO_2	kt CO_2eq	13.33	11.97	10.71	0.48	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2.A.4	Other Process Uses of Carbonates	CO_2	kt CO_2eq	5.32	5.71	6.73	11.78	1.52	0.31	0.35	1.00	0.98	1.31	1.23	1.61	2.29	6.12
2.B.1	Ammonia Production	CO_2	kt CO_2eq	990.23	973.44	882.29	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2.B.2	Nitric Acid Production	N_2O	kt CO_2eq	885.10	694.51	694.51	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2.C.1	Iron and Steel Production	CO_2	kt CO_2eq	26.08	24.80	28.80	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2.D.1	Lubricant Use	CO_2	kt CO_2eq	35.97	11.78	70.08	59.54	16.82	19.08	19.84	20.35	20.09	22.22	21.50	23.63	24.91	27.63
2.D.2	Paraffin Wax Use	CO_2	kt CO_2eq	6.26	8.59	15.73	35.28	21.84	22.12	21.70	24.49	23.71	25.09	23.65	25.01	25.85	31.95
2.D.3	Other Solvent Use	Indirect CO_2	kt CO_2eq	52.40	53.41	48.49	51.99	44.10	41.30	43.17	42.05	41.86	42.28	44.53	42.65	39.77	40.39
2.D.3	Urea as Catalyst	CO_2	kt CO_2eq	0.00	0.00	0.00	0.00	5.33	6.60	7.19	8.87	11.24	12.03	13.27	13.82	12.26	13.78
2.E.1	Integrated Circuit or Semiconductor	HFCs, PFCS, SF_6, NF_3	kt CO_2eq	1.07	136.96	450.60	289.85	91.58	54.35	38.18	60.25	68.30	87.62	89.59	96.07	93.65	90.49
2.F.1	Refrigeration and Air Conditioning	HFCs	kt CO_2eq	NO	4.52	113.74	668.54	857.31	916.79	1,000.69	978.01	1,049.69	962.07	652.59	652.39	521.46	572.51
2.F.3	Fire Protection	HFCs	kt CO_2eq	NO	NO	7.62	14.87	33.67	33.72	33.73	33.75	33.76	33.78	33.79	33.81	33.82	33.83
2.F.4	Aerosols	HFCs	kt CO_2eq	NO	24.97	111.64	134.58	122.41	107.71	104.46	101.59	99.41	96.34	93.36	81.38	64.09	63.09
2.G.1	Electrical Equipment	SF_6	kt CO_2eq	21.15	25.85	7.66	23.12	12.71	19.18	19.74	20.30	19.65	20.48	16.62	7.45	3.24	2.97
2.G.2	SF_6 and PFCs from Other Product Uses	SF_6	kt CO_2eq	13.30	13.39	15.20	12.48	3.49	3.04	3.20	3.35	3.35	3.35	3.35	3.35	3.35	3.35
2.G.3	N_2O from Product Uses	N_2O	kt CO_2eq	27.87	28.63	30.13	32.86	36.21	36.69	36.93	37.27	37.68	38.10	38.61	39.13	39.57	39.84
2.G.4	Other Solvent and product use	Indirect CO_2	kt CO_2eq	0.07	0.08	0.09	0.07	0.05	0.04	0.04	0.04	0.04	0.05	0.02	0.04	0.04	0.04
2.H.2	Food and beverages industry	Indirect CO_2	kt CO_2eq	21.16	22.63	21.45	29.77	40.04	49.41	42.09	44.97	47.56	59.31	59.44	65.08	58.56	66.01
	Total IPPU (including Indirect CO_2)		**kt CO_2eq**	**3,197.40**	**3,107.74**	**4,406.82**	**3,905.75**	**2,584.61**	**2,611.72**	**3,021.40**	**3,205.65**	**3,424.74**	**3,442.59**	**3,184.88**	**3,141.66**	**2,828.02**	**3,242.83**
	2024 Submission																
2.A.1	Cement Production	CO_2	kt CO_2eq	884.00	879.00	1,700.90	2,357.06	1,105.11	1,111.75	1,461.12	1,652.01	1,793.52	1,839.61	1,916.04	1,892.60	1,769.64	2,102.81
2.A.2	Lime Production	CO_2	kt CO_2eq	214.08	187.51	190.43	183.48	192.41	189.64	188.98	177.35	173.90	198.94	177.28	163.65	135.51	148.01
2.A.3	Glass Production	CO_2	kt CO_2eq	13.33	11.97	10.71	0.48	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2.A.4	Other Process Uses of Carbonates	CO_2	kt CO_2eq	5.32	5.71	6.73	11.78	1.52	0.31	0.35	1.00	0.98	1.31	1.23	1.61	2.29	6.12
2.B.1	Ammonia Production	CO_2	kt CO_2eq	990.23	973.44	882.29	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2.B.2	Nitric Acid Production	N_2O	kt CO_2eq	885.10	694.51	694.51	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2.C.1	Iron and Steel Production	CO_2	kt CO_2eq	26.08	24.80	28.80	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2.D.1	Lubricant Use	CO_2	kt CO_2eq	35.97	11.78	70.08	59.54	16.82	19.08	19.84	20.35	20.09	22.22	21.50	23.63	24.91	25.43
2.D.2	Paraffin Wax Use	CO_2	kt CO_2eq	6.26	8.59	15.73	35.28	21.84	22.12	21.70	24.49	23.71	25.09	23.65	25.01	25.85	32.02
2.D.3	Other Solvent Use	Indirect CO_2	kt CO_2eq	53.28	53.78	48.90	48.49	42.58	38.50	40.22	39.56	39.20	39.55	41.18	39.37	38.14	37.54
2.D.3	Urea as Catalyst	CO_2	kt CO_2eq	0.00	0.00	0.00	0.00	5.21	6.46	7.03	8.68	11.02	11.95	13.18	13.73	12.31	13.84
2.E.1	Integrated Circuit or Semiconductor	HFCs, PFCS, SF_6, NF_3	kt CO_2eq	1.07	136.96	450.60	289.85	91.58	54.35	38.18	60.25	68.30	87.62	89.59	96.07	82.21	81.11
2.F.1	Refrigeration and Air Conditioning	HFCs	kt CO_2eq	0.00	4.52	113.74	666.40	857.10	916.65	1,000.54	977.78	1,049.45	961.83	652.35	652.16	521.23	572.31
2.F.3	Fire Protection	HFCs	kt CO_2eq	NO	NO	7.62	14.87	33.67	33.72	33.73	33.75	33.76	33.78	33.79	33.81	33.82	33.83
2.F.4	Aerosols	HFCs	kt CO_2eq	NO	24.97	111.63	134.57	122.41	107.65	104.26	101.26	98.95	95.74	92.59	80.16	62.06	51.33
2.G.1	Electrical Equipment	SF_6	kt CO_2eq	21.15	25.85	7.66	23.12	12.71	19.18	19.74	20.30	19.65	20.48	16.62	7.45	3.24	2.97
2.G.2	SF_6 and PFCs from Other Product Uses	SF_6	kt CO_2eq	13.30	13.39	15.20	12.48	3.49	2.62	2.78	2.93	2.93	2.93	2.93	2.92	2.92	2.92
2.G.3	N_2O from Product Uses	N_2O	kt CO_2eq	27.87	28.63	30.13	32.86	36.21	36.69	36.93	37.27	37.68	38.10	38.61	39.13	39.57	39.84
2.G.4	Other Solvent and product use	Indirect CO_2	kt CO_2eq	0.07	0.08	0.09	0.07	0.05	0.04	0.04	0.04	0.04	0.05	0.02	0.04	0.04	0.04
2.H.2	Food and beverages industry	Indirect CO_2	kt CO_2eq	21.16	22.63	21.45	29.77	40.04	49.41	42.09	44.98	47.56	59.31	59.48	65.11	58.73	66.19
	Total IPPU (including Indirect CO_2)		**kt CO_2eq**	**3,198.28**	**3,108.12**	**4,407.22**	**3,900.11**	**2,582.76**	**2,608.15**	**3,017.54**	**3,202.00**	**3,420.73**	**3,438.51**	**3,180.04**	**3,136.44**	**2,812.48**	**3,216.30**

Table 4.4(b) Absolute and relative recalculations in the IPPU Sector (1990-2021)

	2023 Submission	**Gases**	**Units**	**1990**	**1995**	**2000**	**2005**	**2010**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
2.A.1	Cement Production	CO_2	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.A.2	Lime Production	CO_2	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.A.3	Glass Production	CO_2	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.A.4	Other Process Uses of Carbonates	CO_2	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00
2.B.1	Ammonia Production	CO_2	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.B.2	Nitric Acid Production	N_2O	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.C.1	Iron and Steel Production	CO_2	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.D.1	Lubricant Use	CO_2	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-	-2.20
2.D.2	Paraffin Wax Use	CO_2	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-	0.06
2.D.3	Other Solvent Use	Indirect CO_2	kt CO_2eq	0.88	0.37	0.41	-3.50	-1.52	-2.80	-2.94	-2.49	-2.66	-2.73	-3.34	-3.28	-1.63	-2.85
2.D.3	Urea as Catalyst	CO_2	kt CO_2eq	-	-	-	-	-0.11	-0.14	-0.16	-0.18	-0.23	-0.08	-0.09	-0.09	0.05	0.06
2.E.1	Integrated Circuit or Semiconductor	HFCs, PFCS, SF_6, NF_3	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-11.44	-9.38
2.F.1	Refrigeration and Air Conditioning	HFCs	kt CO_2eq	-	-	-	-2.14	-0.22	-0.14	-0.15	-0.24	-0.24	-0.24	-0.24	-0.24	-0.23	-0.21
2.F.3	Fire Protection	HFCs	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.F.4	Aerosols	HFCs	kt CO_2eq	-	-0.00	-0.01	-0.00	-0.01	-0.07	-0.20	-0.33	-0.46	-0.60	-0.77	-1.22	-2.03	-11.76
2.G.1	Electrical Equipment	SF_6	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.G.2	SF_6 and PFCs from Other Product Uses	SF_6	kt CO_2eq	-	-	-	-	-	-0.42	-0.42	-0.42	-0.42	-0.42	-0.42	-0.43	-0.43	-0.43
2.G.3	N_2O from Product Uses	N_2O	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.G.4	Other Solvent and product use	Indirect CO_2	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.H.2	Food and beverages industry	Indirect CO_2	kt CO_2eq	-	-	-	-	-	-	-	0.00	0.00	0.00	0.04	0.04	0.17	0.18
	Total IPPU (including Indirect CO_2)		**kt CO_2eq**	**0.88**	**0.37**	**0.40**	**-5.65**	**-1.85**	**-3.57**	**-3.86**	**-3.66**	**-4.01**	**-4.07**	**-4.84**	**-5.22**	**-15.53**	**-26.52**
	2024 Submission																
2.A.1	Cement Production	CO_2	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.A.2	Lime Production	CO_2	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.A.3	Glass Production	CO_2	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.A.4	Other Process Uses of Carbonates	CO_2	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0%
2.B.1	Ammonia Production	CO_2	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.B.2	Nitric Acid Production	N_2O	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.C.1	Iron and Steel Production	CO_2	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.D.1	Lubricant Use	CO_2	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-	-8.0%
2.D.2	Paraffin Wax Use	CO_2	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-	0.2%
2.D.3	Other Solvent Use	Indirect CO_2	kt CO_2eq	1.7%	0.7%	0.8%	-6.7%	-3.4%	-6.8%	-6.8%	-5.9%	-6.4%	-6.5%	-7.5%	-7.7%	-4.1%	-7.1%
2.D.3	Urea as Catalyst	CO_2	kt CO_2eq	-	-	-	-	-2.1%	-2.2%	-2.2%	-2.1%	-2.0%	-0.7%	-0.7%	-0.6%	0.4%	0.4%
2.E.1	Integrated Circuit or Semiconductor	HFCs, PFCS, SF_6, NF_3	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-12.2%	-10.4%
2.F.1	Refrigeration and Air Conditioning	HFCs	kt CO_2eq	-	-	-	-0.3%	-0.0%	-0.0%	-0.0%	-0.0%	-0.0%	-0.0%	-0.0%	-0.0%	-0.0%	-0.0%
2.F.3	Fire Protection	HFCs	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.F.4	Aerosols	HFCs	kt CO_2eq	-	-0.0%	-0.0%	-0.0%	-0.0%	-0.1%	-0.2%	-0.3%	-0.5%	-0.6%	-0.8%	-1.5%	-3.2%	-18.6%
2.G.1	Electrical Equipment	SF_6	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.G.2	SF_6 and PFCs from Other Product Uses	SF_6	kt CO_2eq	-	-	-	-	-	-13.7%	-13.1%	-12.5%	-12.5%	-12.6%	-12.7%	-12.7%	-12.8%	-12.9%
2.G.3	N_2O from Product Uses	N_2O	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.G.4	Other Solvent and product use	Indirect CO_2	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.H.2	Food and beverages industry	Indirect CO_2	kt CO_2eq	-	-	-	-	-	-	-	0.0%	0.0%	0.0%	0.1%	0.1%	0.3%	0.3%
	Total IPPU (including Indirect CO_2)		**kt CO_2eq**	**0.0%**	**0.0%**	**0.0%**	**-0.1%**	**-0.1%**	**-0.1%**	**-0.1%**	**-0.1%**	**-0.1%**	**-0.1%**	**-0.2%**	**-0.2%**	**-0.5%**	**-0.8%**

Chapter 5 Agriculture

5.1 Overview of Agriculture Sector

The list of activities under Agriculture in the IPCC reporting format is given in Table 5.1 below. A summary of emissions from these activities are given in Table 5.2, Figure 5.1 and Figure 5.2 below.

Enteric fermentation, Manure Management, Agricultural Soils, Liming and Urea Application are the activities that give rise to greenhouse gas emissions in the Agricultural sector (Table 5.1).

Estimates are included for all emission sources that occur in the country and the required level of disaggregation is achieved for detailed completion of the CRF tables.

5.1.1 Emissions Overview

There are ten key categories in this sector:

- ***3.A.1 Enteric Fermentation, Dairy Cattle*** (Level and Trend)
- ***3.A.1 Enteric Fermentation, Non-Dairy Cattle*** (Level and Trend)
- ***3.A.2 Enteric Fermentation, Sheep*** (Level and Trend)
- ***3.B.1.1 Manure Management (CH_4), Dairy Cattle*** (Level)
- ***3.B.1.1 Manure Management (CH_4), Non-Dairy Cattle*** (Level)
- ***3.B.1.3 Manure Management (CH_4) Swine*** (Level)
- ***3.B.2.5 Manure Management (N2O), Indirect N_2O Emissions*** (Level)
- ***3.D.1 Direct Soil Emissions (N_2O)*** (Level and Trend)
- ***3.D.2 Indirect Soil Emissions (N_2O)*** (Level)
- ***3.G.1 Liming (CO_2)*** (Level and Trend)
-

Other categories present in this sector include:

- ***3.A.3 Enteric Fermentation, Swine***
- ***3.A.4 Enteric Fermentation, Other Livestock***
- ***3.B.1.2 Manure Management (CH4), Sheep***
- ***3.B.1.4 Manure Management (CH4), Other Livestock***
- ***3.B.2.1 Manure Management (N2O), Cattle***
- ***3.B.2.2 Manure Management (N2O), Sheep***
- ***3.B.2.3 Manure Management (N2O), Swine***
- ***3.B.2.4 Manure Management (N2O), Other Livestock***
- ***3.H Urea Application***

The greenhouse gases relevant to Agriculture are as follows:

- ***Carbon dioxide*** emissions originate from *3.G Liming* and *3.H Urea Application*. Carbon dioxide emissions account for 3.3 per cent of Agricultural emissions in 2022 and have increased by 66.2 per cent between 1990-2022.
- ***Nitrous Oxide*** emissions originate from *3.B Manure Management* and *3.D Agricultural Soils*. Nitrous oxide emissions account for 22.3 per cent of Agricultural emissions in 2022 and have increased by 4.0 per cent between 1990-2022.
- ***Methane*** emissions originate from *3.A Enteric Fermentation* and *3.B Manure Management*. Methane is the most significant GHG in agriculture, contributing 74.3 per cent of agricultural emissions in 2022 and have increased by 19.2 per cent between 1990-2022.

The 2024 submission shows total GHG emissions of 22,436.8 kt CO_2 equivalent in the Agriculture sector in 2022, of which *3.A Enteric Fermentation* accounts for 65.0 per cent, *3.D Agricultural Soils* 19.5per cent, *3.B Manure Management* 12.1 per cent, *3.G Liming* 2.8 per cent, and *3.H Urea Application* 0.6 per cent. The latest estimates show that emissions in the Agriculture sector have increased by 16.4 per cent from 1990 to 2022 mainly due to a 18.4 per cent increase in CH_4 emissions from *3.A Enteric Fermentation* and a 25.3 per cent increase in emissions from *3.B Manure Management*.

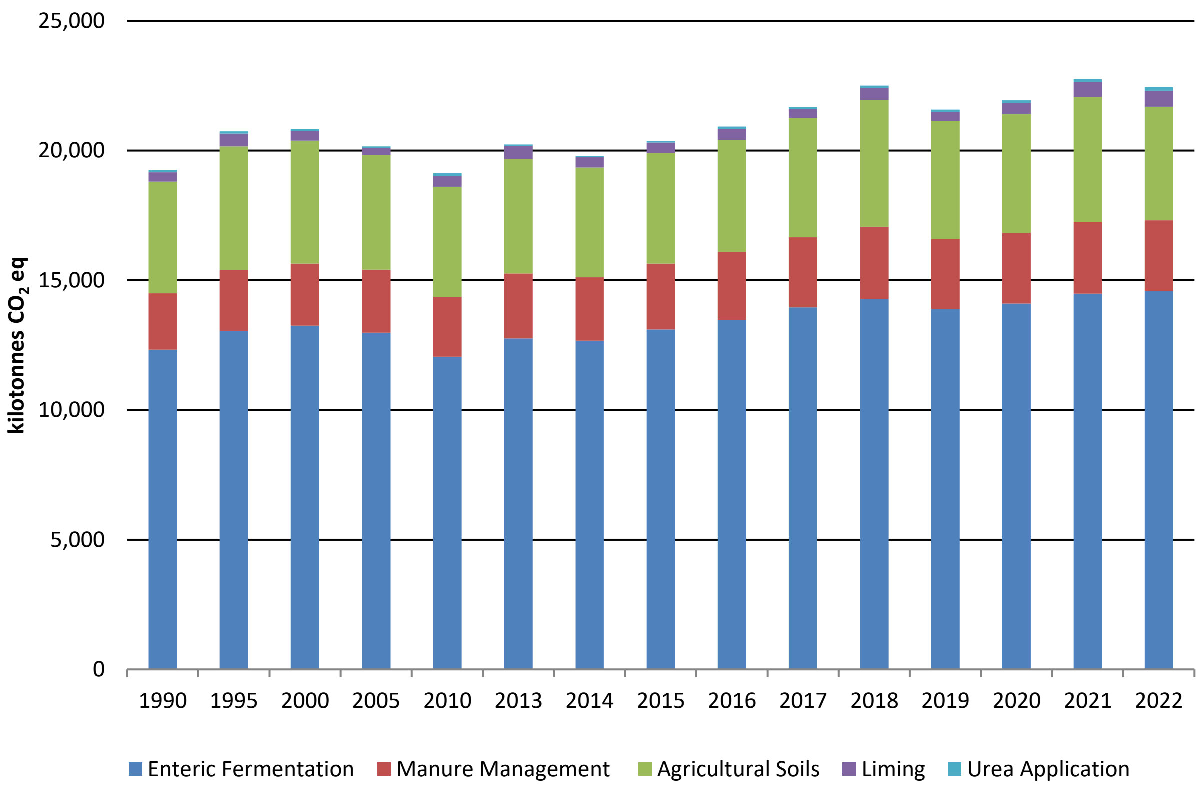


Figure 5.1 Total Emissions from Agriculture by Sector, 1990-2022

5.1.2 Methodology Overview

A summary of the Tier methods, consistent with the 2006 IPCC Guidelines, is provided in Table 5.1 below, along with a summary of the activities applicable to Ireland.

There is extensive and up-to-date statistical data on all aspects of the agriculture sector in Ireland. Most of this data (animal population statistics) is compiled and published by the Central Statistics Office and is the official source of the basic data for inventory purposes. The exception is for statistics on synthetic fertiliser use, poultry population statistics and information on cross border (with Northern Ireland) lamb slaughtering statistics which are obtained directly from the Department of Agriculture Food and the Marine (DAFM). The CSO and DAFM are key data providers whose annual statistical inputs to the inventory agency are covered by Memorandum of Understanding (MOU) in Ireland's national system (Section 1.4). The time-series of key agricultural statistics, as used for the various activity data (e.g. livestock populations and fertiliser use) are given in Table 3.3.A of Annex 3.3.

There is significant collaboration between inventory experts, agricultural production and agri-environmental researchers within Teagasc (Irish Agriculture and Food Development Authority), DAFM and CSO, which has grown out of the improved inventory methodologies developed for both CH_4 and N_2O. These collaborations have been maintained by the inventory agency and are an important part of the overall QA/QC procedures and improvements being undertaken on an annual basis.

Table 5.1 Level 3 Source Methodology for Agriculture

3. Agriculture	**CO_2**	**CH_4**	**N_2O**
A. Enteric Fermentation			
1. Cattle	NA	T2*	NA
2. Sheep	NA	T1*	NA
3. Swine	NA	T1	NA
4. Other Livestock	NA	T1	NA
B. Manure Management			
1. Cattle	NA	T2*	T1
2. Sheep	NA	T1	T2
3. Swine	NA	T1	T2
4. Other Livestock	NA	T1	T2
5. Indirect N_2O emissions*	NA	NA	T2*
C. Rice Cultivation	NO	NO	NO
D. Agricultural Soils			
1. Direct N_2O from Managed Soils*	NA	NA	T1*
2. Indirect N_2O from Managed Soils*	NA	NA	T1*
E. Prescribed Burning of Savannas	NO	NO	NO
F. Field Burning of Agricultural Residues	NO	NA	NA
G. Liming*	T1*	NO	NO
H. Urea Application	T1	NO	NO
I. Other Carbon-containing fertilisers	NA	NO	NO
J. Other	NO	NO	NO

***Key Category**

Table 5.2 Emissions from Agriculture 1990-2022

		Gas	Unit	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
3.A.1	Cattle	CH_4	kt CO_2eq	10185.1	10830.2	11149.3	11228.0	10787.2	11381.9	11291.7	11747.1	12100.5	12496.2	12845.3	12489.4	12609.2	12970.2	13023.3
3.A.2	Sheep	CH_4	kt CO_2eq	2048.0	2123.1	1997.7	1639.9	1159.7	1273.1	1280.2	1252.9	1263.2	1352.7	1331.9	1297.5	1391.3	1412.7	1460.1
3.A.3	Swine	CH_4	kt CO_2eq	43.9	54.4	59.1	57.1	52.3	51.0	51.8	51.0	52.9	53.9	53.9	54.2	55.2	57.1	54.1
3.A.4	Other livestock	CH_4	kt CO_2eq	42.4	47.3	44.5	48.6	59.9	55.6	52.6	51.5	51.1	47.6	47.0	46.0	49.2	46.6	46.5
3.B.1	Cattle	CH_4	kt CO_2eq	1203.9	1247.6	1254.9	1292.0	1273.7	1387.0	1359.4	1433.2	1478.7	1539.1	1581.6	1524.2	1539.3	1541.0	1541.9
3.B.1	Cattle	N_2O	kt CO_2eq	229.0	251.4	262.8	280.9	259.7	286.0	264.1	281.2	288.9	299.4	314.6	292.3	287.4	295.5	296.2
3.B.2	Sheep	CH_4	kt CO_2eq	105.4	110.4	104.5	84.7	57.5	64.7	65.9	63.9	63.5	68.6	67.4	65.8	70.1	70.2	72.8
3.B.2	Sheep	N_2O	kt CO_2eq	19.9	21.0	19.7	16.5	12.2	13.1	13.1	12.8	13.1	14.0	13.8	13.3	14.7	14.9	15.3
3.B.3	Swine	CH_4	kt CO_2eq	285.7	357.8	403.5	393.6	344.7	350.9	355.2	346.8	359.2	361.6	365.7	368.5	371.0	387.0	357.4
3.B.3	Swine	N_2O	kt CO_2eq	9.0	11.1	12.1	11.7	10.8	10.5	10.7	10.5	10.9	11.1	11.1	11.2	11.4	11.8	11.2
3.B.4	Other livestock	CH_4	kt CO_2eq	71.7	63.2	68.5	77.9	81.9	96.4	99.8	107.6	108.5	111.0	113.7	115.1	118.4	120.7	118.7
3.B.4	Other livestock	N_2O	kt CO_2eq	15.7	14.4	14.5	15.8	18.7	17.7	17.3	17.2	17.0	16.1	15.8	15.5	16.0	15.4	15.3
3.B.5	Indirect N_2O emissions	N_2O	kt CO_2eq	233.0	250.7	257.4	264.9	248.2	267.5	257.2	268.5	277.4	287.9	302.3	286.3	288.1	295.0	294.7
3.D.1	Direct N_2O Emissions From Managed Soils	N_2O	kt CO_2eq	3587.3	4007.7	3956.1	3692.5	3525.1	3702.1	3539.0	3547.0	3585.0	3823.3	4072.9	3806.1	3851.8	4050.7	3642.8
3.D.2	Indirect N_2O Emissions from Managed Soils	N_2O	kt CO_2eq	724.7	771.5	778.1	725.3	710.0	709.0	688.4	708.9	735.9	771.2	814.9	755.2	747.8	765.7	735.7
3.G.1	Limestone $CaCO_3$	CO_2	kt	355.0	494.6	366.4	266.7	427.9	515.7	391.1	401.1	433.6	332.7	461.1	343.9	399.5	597.4	624.0
3.H	Urea Application	CO_2	kt	96.7	86.3	91.8	60.8	98.2	47.1	54.5	64.3	79.1	84.0	88.8	92.0	109.4	102.0	126.8
3	**Total Agriculture**		**kt CO_2eq**	**19256.5**	**20742.7**	**20841.0**	**20157.0**	**19127.8**	**20229.1**	**19791.9**	**20365.7**	**20918.6**	**21670.5**	**22501.7**	**21576.4**	**21929.8**	**22754.0**	**22436.8**

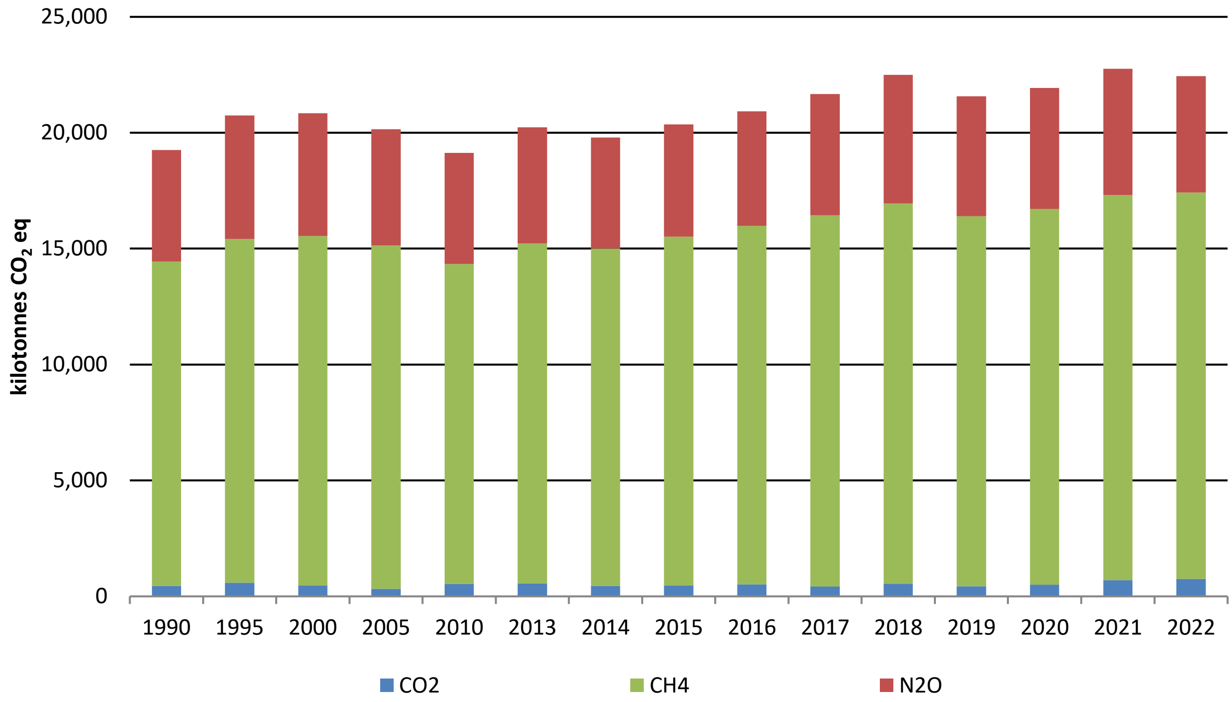


Figure 5.2 Total Emissions from Agriculture by Gas, 1990-2022

5.2 Emissions from livestock (3.1)

The two IPCC Level 2 emission source categories under *3.1 Livestock* in 2022 are *3.A Enteric Fermentation* and *3.B Manure Management*. Total emissions from these activities amounted to 17,307.5 kt CO_2eq in 2022.

Five project reports have greatly contributed to improving the estimation of emissions from enteric fermentation and manure management in Ireland:

- O'Mara (2006), Development of emission factors for the Irish Cattle Herd
- Hyde et al. (2008), an extensive Farm Facilities (Manure Management) Survey
- O' Brien and Shalloo (2019), A review of livestock methane emission factors
- Buckley et al. (2023), Teagasc National Farm Survey - A report on bovine manure management, application and storage practices in Ireland
- DAFM (2023), Industry survey on the crude protein content in compound animal feeds

This research, along with other relevant work related to the development of a nitrogen-flow approach to NH_3 emissions as outlined in the EMEP/EEA Emission Inventory Guidebook (EMEP/EEA, 2013, 2016,2019 and 2023), has facilitated the application of a large amount of country-specific information underlying the various estimates of emissions.

The livestock types relevant for Ireland are as follows;

- Dairy Cattle
- Non-Dairy Cattle
- Sheep
- Swine

- Other livestock;
- Deer
- Goats
- Horses, Mules and Asses
- Poultry (including ducks and geese)
- Fur-bearing Animals

5.2.1 Emissions from Enteric Fermentation (3.A)

The IPCC Level 3 emission source categories relevant under *3.A Enteric Fermentation* in 2022 are *3.A.1 Cattle*, *3.A.2 Sheep*, *3.A.3 Swine*, and *3.A.4 Other Livestock*. Total emissions from these activities amounted to 14,584.0 kt CO_2eq in 2022, 65.0 per cent of total Agricultural emissions.

5.2.1.1 Enteric Fermentation, Cattle (3.A.1)

5.2.1.1.1 Category Description

Methane is produced in herbivores as a by-product of enteric fermentation, a digestive process by which carbohydrates are broken down by micro-organisms into simple molecules for absorption into the bloodstream. The amount of methane that is released depends on the type of digestive tract, age, and weight of the animal, and the quality and quantity of the feed consumed. Ruminant livestock (e.g., cattle, sheep) are major sources of methane with moderate amounts produced from non-ruminant livestock (e.g., pigs, horses).

Enteric fermentation from cattle is both a trend and level key category of CH_4 in Ireland.

5.2.1.1.2 Methodological Issues

A Tier 2 approach is used for *Enteric Fermentation*, Cattle. The Tier 2 approach has been used for 1990 and for the years 2003 to 2022 inclusive. Interpolation has been used to complete the time series.

In the Tier 2 approach, the Irish cattle herd is characterised by 11 principal animal classifications as shown in Table 5.3 for which annual census data are provided by the CSO. In-depth analysis of production systems and the associated animal feed and energy requirements is conducted for all categories within the Irish cattle population to determine CH_4 production. Substantial further subdivision is incorporated for dairy and beef cattle to adequately describe the wide range of cattle rearing and finishing systems applicable in Ireland. In total, dairy cows are covered by 12 systems and 18 system types are analysed for suckler (beef) cows, while up to 30 systems are examined for both male and female beef cattle (O'Mara, 2006 and O'Brien and Shalloo, 2019).

Table 5.3 Animal Classifications for Cattle Population

Cattle Type	Classification		
Breeding cattle	Dairy cows	Suckler (Beef) cows	
Beef cattle	Male < 1 year	Male 1 – 2 years	Male > 2 years
	Female < 1 year	Female 1 – 2 years	Female > 2 years
Other cattle	Breeding bulls	Dairy in-calf heifers	Beef in-calf heifers

For both **dairy cows** and **suckler cows**, the country is divided into three regions: (1) south and east, (2) west and midlands, and (3) north-west, coinciding with the regions used for the implementation of regulations on Good Agricultural Practices for Protection of Waters:

- SI 788 of 2005 (DEHLG, 2005)
- SI 378 of 2006 (DEHLG, 2006)
- SI 101 of 2009 (DEHLG, 2009)
- SI 610 of 2010 (DEHLG, 2010)
- SI 31 of 2014 (DECLG, 2014)
- SI 134 of 2014 (DECLG, 2014)
- SI 605 of 2017 (DHPLG, 2017)
- SI 65 of 2018 (DHPLG, 2018)

This division facilitates in-depth analysis of separate regions with different lengths of winter housing and takes account of different animal feeding practices. The cattle production systems in each region are defined in terms of calving date, the dates of winter housing and spring turn-out to grass, milk yield and composition, forage and concentrate feeding level, cow live-weight and live-weight change and lactation period. The number of cows in each category, given by CSO statistics, is allocated to the three regions identified above using the Cattle Movement Monitoring System (CMMS) and Animal Identification and Movement (AIM) system reports published by the Department of Agriculture, Fisheries and Food (DAFF, 2004-2010) and the Department of Agriculture Food and the Marine (DAFM, 2011-2022). The CSO produces two censuses of animal numbers per year, one reflecting the number of animals nationally in June and the other referring to populations in December. For the purposes of calculating emissions from breeding cattle (dairy cows and suckler cows), an average of the number in each category of breeding animals present in the national herd in June and December is used[4].

In the approach outlined by O'Mara (2006), the daily energy requirement of cows in each region is calculated by month or part thereof based on maintenance requirements, milk yield and composition, requirements for foetal growth and gain or loss of body weight using the French energy system (INRA, 1989). In this system, net energy requirement is defined in terms of *unité fourragère lait* (UFL), where 1 UFL is the net energy value of 1 kg of barley at 86 per cent dry matter and is equal to 7.11 MJ net energy for lactation (NE_l). This international energy system, which is well established and used locally in Ireland, is considered more appropriate to the local conditions than the system and equations used by the 2006 IPCC guidelines. The energy gains and losses refer to intra-annual changes for the animal and do not mean that average body weight for animals in the dairy herd is increasing from year to year. The live-weight of 535 kg for dairy cows is an indicative weight supplied by the DAFM, as dairy cow live-weights are not in general monitored on farms. The live weight is adopted as the reference point for the annual emission factor derivation for the herd and is chosen to be consistent with other parameters relevant to the estimation of emissions from cattle, e.g. manure production.

The important equations contained within the approach are:

Maintenance NEl requirements (MJ) = 9.96 + (0.6 x LW/100), where LW is live weight. A 10 per cent activity allowance was added for the housed period and a 20 per cent allowance was added for the grazing period as outlined by INRA (1989);

[4] The publication of separate census data for June and December annually, and the application of these statistics in order to achieve the most representative annual average population related to cattle, explains the differences that are often seen between national and FAO statistics for agriculture. Ireland has high quality agricultural statistics and differences with FAO are to be expected, but they are of no consequence to the emissions estimates.

NE_l (MJ) required per kg milk = 0.376 * fat content + 0.209 * protein content + 0.948;

Pregnancy: mean of 12.1 MJ NE_l /day for the last 3 months of pregnancy;

Live-weight change: each kg live-weight lost contributed 24.9 MJ NE_l to energy requirements, while each kg of live-weight gained required 32 MJ NE_l.

The composition of the diet of cows in each region is described by month or part thereof and daily intake is calculated by reference to the daily energy requirement. The concentrate allowance is fixed while forage intake varied according to energy requirements. Daily methane emissions (MJ/day) are calculated from digestible energy intake using the equation of Yan et al. (2000).

$CH_4 = DEI * [0.096 + (0.035 \times S_{DMI}/T_{DMI})] – 2.298 * (FL – 1)$

where DEI is digestible energy intake (MJ/day), S_{DMI} and T_{DMI} are silage and total dry matter intakes (kg/day), respectively, and FL is feeding level (multiples of the maintenance energy requirement).

In this submission for enteric fermentation the methane conversion rate (Y_m) for cattle now varies based on animal diet and level of productivity. In line with the 2019 refinement to the 2006 IPCC Guidelines, the Y_m values now employed for the national cattle herd is lower than that used previous to the 2023 submission (6.3 vs 6.5), reducing emissions of CH_4 from enteric fermentation for most years. In the early part of the time series the Y_m value of 6.5 is maintained for dairy cows where milk production was less than 5,000 kg per year with a Y_m value of 6.3 applied for the remaining years where average milk production per cow is over 5,000 kgs annually. A Y_m value of 6.3 is applied to all other cattle categories (Y_m value of 6.5 used previous to the 2023 submission). Daily CH_4 emissions are summed to give annual emissions for cows in each region, and a weighted national average emission factor is then calculated.

Emission factors for the **beef cattle** categories, given in Table 5.3, are determined by calculating lifetime emissions for the animal and by partitioning between the first, second and third years of the animal's life. This approach allows the published CSO animal population census for June to be used directly as the activity data most representative of the inventory year for enteric fermentation while taking into account the movement of cattle from one age category to another (i.e. from 0-1 year old to 1-2 year old to over 2 years old), as enumerated by the June census, up to two times in their almost three-year lifetime (O'Mara 2006 and O'Brien and Shalloo, 2019).

Important parameters such as housing period (O'Mara, 2006; Hyde et al., 2008; Buckley et al, 2023), grazing period (O'Mara, 2006; Hyde et al., 2008; Buckley et al, 2023) and live-weight gains (O'Mara, 2006 reconciled with actual national carcass weights) during winter housing periods and grazing seasons are defined for each system (O'Mara, 2006; Hyde et al., 2008; Buckley et al, 2023). The most important parameter for beef cattle is live-weight gain, as it directly affects the energy requirement and thus the feed intake. There is little statistical information on the live-weight gain of the different types of cattle in the cattle herd, but the weight of carcasses of all slaughtered cattle is recorded by the DAFM. Using data for the average carcass weight of male and female cattle, appropriate live-weight gains are applied to the various life stages of each animal category, such that when all categories are combined, that data is consistent with the national statistics for carcass weight (plus or minus 10 kg difference).

Given these data for live-weight and live-weight gain, O'Mara, (2006) estimated the energy requirements of animals during the winter housing periods and grazing seasons of the animal's lifetime using the INRAtion computer programme, version 3.0. This programme was devised by the French research organisation Institut National de la Recherche Agronomique (INRA) and is based on the net energy system for cattle. In version 3 of INRAtion, some adaptation for Irish conditions was made to the equations for estimating the energy requirements of growing and finishing animals (O'Mara, 1997, Crowley, 2001 and Crowley et al, 2002). Net energy requirements of growing beef cattle are defined in terms of UFL, as in the case of dairy cattle, while for finishing cattle, net energy requirements are defined in terms of UFV (from the French *unité fourragère viande*) where 1 UFV is the net energy value of 1 kg of barley for meat production and is equal to 7.61 MJ NE_{mg}.

The composition of the diet in each system is described by grazing season and winter housing period and daily intake is calculated by reference to the daily energy requirement. The concentrate allowance is fixed while forage intake is varied according to energy requirements. The Irish modifications to the INRAtion programme were predominantly for animals at weanling and finishing stages (i.e. at times that concentrates were likely to be fed). No modifications were made for 'heavy' growing animals, (typically animals in their second grazing season or later that were not being finished). For animals in these stages, intakes were adjusted as appropriate (O' Mara, 2006). Daily methane emissions were calculated using the equation of Yan et al. (2000), however a constant of 0.063 of gross energy intake was applied in line with the 2019 refinement to the 2006 IPCC Guidelines when the diet was grazed grass plus 3 kg or less of concentrate supplement/day. Daily emissions are aggregated to give annual emissions per system and a weighted national average emission factor is then calculated.

Bulls for breeding and **in-calf heifers** account for on average 6 per cent of the national cattle herd. Separate production systems are not defined for these categories because of the lack of published data on their feed intake and the small number of animals involved (O'Mara, 2006; O'Brien and Shalloo, 2019). Bulls for breeding are mostly of continental breeds, and their emission factors are based on those for late maturing male beef cattle of suckler origin in their second year. The emission factor for animals in this category is determined by an applicable period of 310 days in their second year, which is adjusted upwards to the full period of 365 days in the case of breeding bulls.

In-calf heifers are assigned the same emission factors as female beef cattle in their second year (i.e. corresponding to the category 1–2 years old). In-calf heifers only require emissions associated with the period March – December of their second year to be accounted for, as they are subsequently enumerated as dairy or suckler cows in the CSO animal census and AIM (previously CMMS) data thereafter. Female beef cattle in the category 1-2 years old are assumed to be slaughtered in early spring of their third year (O'Mara, 2006; O'Brien and Shalloo, 2019). Adjustment for the slightly longer period is not made in respect of in-calf heifers, as they are carrying a calf in addition to normal growth which is reflected in the calculation methodology.

Table 5.4 Tier 2 CH_4 Enteric Fermentation Emission Factors for cattle 1990 to 2022

	Enteric Fermentation (kg/head/year)														
	1990	**1995**	**2000**	**2005**	**2010**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Dairy cows	101.31	104.42	107.53	110.24	112.02	111.28	111.25	114.17	113.28	116.05	117.40	119.35	119.92	121.12	121.43
Suckler cows	73.81	73.77	73.74	74.79	71.64	71.47	71.92	72.79	72.41	72.22	72.00	72.20	72.57	73.56	73.67
Male cattle < 1 year	25.19	27.66	30.13	32.27	33.12	36.29	33.48	35.28	35.02	35.95	39.07	35.30	34.61	36.52	36.62
Male cattle 1 - 2 years	57.61	59.11	60.61	59.68	60.96	58.49	58.92	59.47	57.77	58.42	59.22	57.16	58.09	57.42	56.99
Male cattle > 2 years	32.87	33.29	33.70	37.76	40.26	37.95	36.41	36.83	35.48	33.58	34.81	36.84	34.01	32.63	32.73
Female cattle < 1 year	23.68	26.13	28.58	30.28	31.45	33.65	31.06	32.82	32.24	33.06	35.94	32.34	31.80	33.23	33.27
Female cattle 1 - 2 years	41.86	43.06	44.26	48.71	50.21	50.56	50.73	51.21	50.76	51.45	52.62	50.97	51.42	51.22	51.18
Female cattle > 2 years	22.35	22.35	22.35	22.32	21.93	21.56	21.40	20.89	20.63	20.49	20.42	20.36	20.28	20.22	20.18
Bulls for breeding	71.23	77.46	83.70	88.23	91.38	96.10	89.80	93.74	92.17	93.74	101.28	92.17	91.38	96.26	96.26
Dairy in-calf heifers	45.87	48.41	50.95	52.79	53.91	55.65	53.12	54.55	53.92	54.55	57.58	53.92	53.61	55.57	55.57
Beef in-calf heifers	49.24	51.83	54.42	56.30	57.41	59.16	56.62	58.05	57.41	58.04	61.08	57.41	57.10	59.08	59.08

5.2.1.1.3 Uncertainties and Time-series Consistency

The uncertainties applicable to Enteric Fermentation are provided in Annex 2. The emission time series for agriculture 1990–2022 is consistent. Key activity data such as disaggregated animal numbers are available for all years and are used in a consistent manner.

5.2.1.1.4 Category-specific QA/QC and verification

Standard QA/QC procedures have been applied to *Enteric Fermentation, Cattle*. Details of Ireland's QA/QC process can be found in Chapter 1 of this report.

5.2.1.1.5 Category-specific Recalculations

There are no recalculations to emission estimates from in 3.A.1 *Enteric Fermentation, Cattle* in this submission.

5.2.1.1.6 Category-specific Planned Improvements

The inventory agency previously incorporated the results of a study aimed at reviewing the Tier 2 methodology used for the estimation of CH_4 emissions from enteric fermentation and manure management in cattle (O'Brien and Shalloo, 2019). Further refinements may be undertaken for future submissions as part of ongoing QA/QC processes.

5.2.1.2 Enteric Fermentation, All Other Livestock (3.A.2-3.A.4)

5.2.1.2.1 Category Description

This grouping includes **sheep (3.A.2)**, **swine (3.A.3)**, and **other livestock (3.A.4)**. Enteric fermentation from other livestock in Ireland consists of **deer**, **goats**, **horses**, **mules and asses**, and **fur-bearing animals**. Enteric Fermentation emissions of CH_4 are not estimated for poultry and fur-bearing animals, as there is no methodology in the 2006 IPCC Guidelines, therefore the notation key "NE" is reported in CRF Table 3.As1. *Enteric fermentation, sheep 3.A.2* is a key category (Trend and Level) in Ireland.

5.2.1.2.2 Methodological Issues

The Tier 1 approach in the 2006 IPCC guidelines is used for *Enteric Fermentation; Sheep, Swine, and Other Livestock*.

The type of information used to derive the Tier 2 emission factors for cattle is not available for other important livestock categories in Ireland, such as **sheep** and **swine**. However, the inventory agency is investigating the development of a Tier 2 estimate for sheep as outlined in section 5.2.1.2.6. Therefore, the inventory agency continues to use the Tier 1 approach for enteric fermentation for all livestock categories other than cattle. The emission factors used are generally those for Western Europe given in Table 10.10 of the 2006 IPCC guidelines. However, in order to fully utilise Irish national statistics and the detailed CSO breakdown in respect of sheep and swine populations, the base emission factors from the IPCC are adjusted as shown in Table 3.3.B of Annex 3.3.

For sheep, the emission factor for lambs is calculated on the basis that lambs have an assumed lifetime of 180 days before slaughter and a CH_4 conversion rate (Y_m) of 6.7 per cent as per 2019 refinement of 2006 guidelines Table 10.10 using liveweights from Irelands sheep methane models to give approximate emission factors. The Y_m value for all categories of sheep is 6.7 For swine, the default emission factor of 1.5 kg CH_4 per head (Table 10.10 of 2019 refinement to 2006 IPCC guidelines) per year is adjusted for each subcategory of swine on the basis of a default swine weight (in table 10.10 of the 2019 refinement to the 2006 IPCC guidelines) of 72 kg (high productivity systems) and the known average weight of each subcategory of swine in Ireland as per equation 10.2.4 of the 2019 refinement. As a result, the implied emission factors produced by the CRF related to total populations of sheep and swine in Ireland are relative to the proportions of animal sub-categories within these major animal categories.

5.2.1.2.3 Uncertainties and Time-series Consistency

The uncertainties applicable to Enteric Fermentation are provided in Annex 2. The emission time series for agriculture 1990–2022 is consistent. Key activity data such as disaggregated animal numbers are available for all years and are used in a consistent manner.

5.2.1.2.4 Category-specific QA/QC and verification

Standard QA/QC procedures have been applied to *Enteric Fermentation, All Other Livestock*. Details of Ireland's QA/QC process can be found in Chapter 1 of this report.

5.2.1.2.5 Category-specific Recalculations

There are no recalculations to emission estimates from all other livestock (3.A.2 – 3.A.4) in this submission.

5.2.1.2.6 Category-specific Planned Improvements

The inventory agency continues to investigate the applicability of developing Tier 2 estimates of CH_4 from enteric fermentation and manure management from sheep as recommended in previous annual inventory review reports. However, implementation of a Tier 2 approach for sheep is currently difficult given the paucity of detailed information on representative feeding practice and manure management data for sheep. The inventory agency continues to engage with national bodies to improve relevant data collection.

5.2.2 Emissions from Manure Management (3.B)

The IPCC Level 3 emission source categories relevant under *3.B Manure Management* in 2022 are *3.B.1 Cattle*, *3.B.2 Sheep*, *3.B.3 Swine*, *3.B.4 Other Livestock*, and *3.B.5 Indirect N_2O Emissions*. Total emissions of CH_4 and N_2O from these activities amounted to 2,723.5 kt CO_2eq in 2022.

5.2.2.1 Manure Management, Cattle (3.B.1)

5.2.2.1.1 Category Description

This category describes how to estimate CH_4 produced during the storage and treatment of manure, and from manure deposited on pasture. The term 'manure' is used here collectively to include both dung and urine (both the solids and the liquids) produced by livestock. The main factors affecting CH_4 emissions are the amount of manure produced and the portion of the manure that decomposes anaerobically. The former depends on the rate of manure production per animal and the number of animals, and the latter on how the manure is managed. When manure is stored or treated as a liquid (e.g., in lagoons, ponds, tanks, or pits), it decomposes anaerobically and can produce a significant quantity of CH_4. The temperature and the retention time of the storage unit greatly affect the amount of methane produced. When manure is handled as a solid (e.g., in stacks or piles) or when it is deposited on pastures and rangelands, it tends to decompose under more aerobic conditions and less CH_4 is produced. The decomposition of the organic material in cattle manures is both a level and trend key category of CH_4 emissions in Ireland.

This category also includes N_2O produced, directly and indirectly, during the storage and treatment of manure before it is applied to land. The N_2O emissions generated by manure in the system 'pasture, range, and paddock' occur directly and indirectly from the soil and are therefore reported under the category *N_2O Emissions from Managed Soils*.

Direct N_2O emissions occur via combined nitrification and denitrification of nitrogen contained in the manure. The emission of N_2O from manure during storage and treatment depends on the nitrogen and carbon content of manure, and on the duration of the storage and type of treatment.

Indirect emissions result from volatile nitrogen losses that occur primarily in the forms of ammonia (NH_3) and nitrogen oxides (NO_x). The fraction of excreted organic nitrogen that is mineralised to ammoniacal nitrogen during manure collection and storage depends primarily on time, and to a lesser degree temperature.

5.2.2.1.2 Methodological Issues

Manure management practice surveys (Hyde et al., 2008; Buckley et al., 2023) provide detailed data on manure management practices to support the adoption of a higher tier method. The manure management surveys are carried on out on a representative sample of farms, the results of which are available at both national level and for each of the three designated Nitrates Directive regions (as described in SI 605 of 2017, for example). The proportioning of Manure Management Systems (MMS) within the model is undertaken on an individual subsystem basis. The partitioning of the year into pasture and housing periods is based on the results of the manure management surveys for each particular subsystem. Having derived the time spent at pasture and the time spent in housing for cattle, the manure management surveys (Hyde et al, 2008; Buckley et al, 2023) are then used to determine the partitioning of liquid and solid manures to MMS within the housing period, and the estimation of the number of animals that are out-wintered (i.e. at pasture all year round).

Information obtained from the manure management surveys (Hyde et al., 2008; Buckley et al., 2023) and the work on emission factors for enteric fermentation in cattle (O' Mara., 2006; O'Brien and Shalloo, 2019) described in section 5.2.1 above is the basis of the CH_4 emission factors for manure management. The results from the manure management surveys provide a representation of manure allocation among the relevant animal manure management systems in the country while the excretion of organic matter by cattle is fully characterised as part of the analysis of their feed and energy requirements relating to enteric fermentation (O'Mara, 2006). The main results of the manure management surveys pertinent to inventory calculations are outlined in Tables 3.3.D.1 and 3.3.D.2 of Annex 3.3.

The analysis of the feeding regime for cattle (O'Mara, 2006; O'Brien and Shalloo, 2019) includes a full evaluation of the organic matter content of the feeds applicable to the 11 classifications that characterise the national herd (Table 5.2), which facilitates the estimation of their respective levels of organic matter excretion. The emission factors for manure management are derived using the quantified organic matter excretion as volatile solids (VS), the methane production potential (B_O) of manure, the allocation to manure management systems based on the manure management surveys (Hyde et al., 2008; Buckley et al., 2023) and the methane conversion factor (MCF) values for manure, which are now presented on a climatic region basis in the 2019 refinement, rather than temperature regimes previously. Additionally, MCF values are presented in terms of the length of the storage period. Where the storage period is not known a default of 6 months is applied. Current estimates use the 6-month default values, while Teagasc undertake further analysis of the period of storage of manures from National Farm Survey Statistics. The values used are 21 per cent Table 10.17, 2019 refinement for both liquid and solid manure. Additionally, the MCF value at grazing is 0.47 per cent (Table 10.17, 2019 Refinement).

Volatile solids values for dairy cows and non-dairy cattle are estimated using the information provided in O'Mara (2006) and O'Brien and Shalloo (2019). These values differ from the default values provided in the 2006 IPCC Guidelines due to the higher digestibility of feeds in Ireland. The default digestibility presented in the 2006 IPCC Guidelines of 60 per cent is very low in comparison to the digestibility of silage (70 per cent), grazed grass (80 per cent) and concentrates (80 per cent). Grazed grass and silage make up the majority of feed intake of cattle in Ireland due to Ireland's grass-based production systems. The emission factors for cattle are given in Table 5.5.

Nitrogen excretion rates have been adopted in Ireland for all animal categories for which annual census data are published by the CSO. In 2011, the inventory agency reviewed the applicability of the nitrogen excretion rates used in the inventory in collaboration with the Department of Agriculture, Food and the Marine, agricultural researchers and animal nutritionists for dairy cows. Subsequent reviews, the most recent in 2020 (based on O'Brien and Shalloo, 2019; DAFM, 2020) have revised nitrogen excretion rates for all cattle categories. Nitrogen excretion rates for all livestock are provided in Table 3.3.E of Annex 3.3 and, except for cattle (both dairy and non-dairy) categories, are sourced from SI 605 of 2017 (DHPLG, 2017), the 2006 IPCC guidelines and the 2023 EMEP/EEA Inventory Guidebook. In the case of cattle, the excretion rates are consistent with the nitrogen content of cattle feed intake as analysed in conjunction with the determination of Tier 2 CH_4 emission factors for enteric fermentation and manure management for cattle.

The nitrogen excretion rates are used by the inventory agency, along with the information on the allocation of animal manures to each applicable manure management system (MMS) from manure management surveys (Hyde et al., 2008; Buckley et al., 2023) as the basis of CRF Table 3.B (b) and data provided in Annex 3.3. Nitrogen excretion rates for all cattle categories are estimated using the information contained with the Tier 2 estimates of CH_4 from enteric fermentation and manure management and the Tier 2 approach to estimating nitrogen excretion by cattle in section 10.5.2, Volume 4 of the 2006 IPCC guidelines. Furthermore, to allow for the application of disaggregated emission factors to the dung and urine deposited on pasture by cattle, the nitrogen excreted by cattle has been partitioned into that contained in urine and the nitrogen contained in dung. Further discussion on the derivation of these values is presented in Annex 3.3.E.

In relation to those animal categories for which nitrogen excretion rates are based on those presented in SI 605 of 2017 (DHPLG, 2017) and associated underlying calculations and reproduced in Annex 3.3, it must be noted that the values shown are corrected for gaseous losses. In some cases, the nitrogen excretion associated with offspring are included in the adult female total (e.g. lowland ewes and lambs) which is explained in Annex 3.3. The values presented in Table 6 of SI 605 of 2017 (DHPLG, 2017) for livestock are for crop available nitrogen post gaseous losses (i.e. total nitrogen excreted minus gaseous losses). For ducks, mink and fox, the default nitrogen excretion values presented in Table 10.19 Volume 4 of the 2006 IPCC Guidelines are adopted. The nitrogen excretion value for geese is that presented in the 2023 EMEP/EEA Inventory Guidebook (EMEP/EEA, 2023).

Approximately two-thirds of animal manure nitrogen is excreted at pasture annually, reflecting the relatively short period that cattle are housed in Ireland. Animal manures excreted at pasture and the associated emissions are accounted for under N_2O emissions from managed agricultural soils (Section 5.4.1). In 2022 the bulk of cattle manures in housing were managed in pit storage systems (93.8 per cent and 71.5 per cent for dairy cattle and other cattle respectively) for eventual spreading on agricultural lands. The remainder of animal manures produced in-house are in deep bedding systems. The emission factors given by the 2006 IPCC guidelines, Table 10.21, 0.002 kg N_2O-N/N excreted for pit storage and 0.01 kg N_2O-N/N excreted for deep bedding manure management systems are used for cattle manures. The emission factor presented in the 2019 refinement to the 2006 IPCC guidelines, Table 11.3 of 0.014 kg N_2O-N (kg NH_3-N + NOx-N volatised) is used to estimate indirect N_2O emissions from manure management.

Table 5.5 Tier 2 CH_4 Manure Management Emission Factors for cattle 1990 to 2022

	Manure Management (kg/head/year)														
	1990	**1995**	**2000**	**2005**	**2010**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Dairy cows	12.98	12.92	12.86	12.99	12.88	12.63	12.66	12.76	12.62	12.73	12.94	13.52	13.63	13.19	13.17
Suckler cows	7.59	7.35	7.11	7.39	7.79	8.29	8.47	8.79	8.77	9.17	8.88	8.91	8.78	8.47	8.48
Male cattle < 1 year	4.46	4.76	5.05	5.33	5.82	6.23	5.71	6.03	6.00	6.26	6.73	6.06	5.86	5.96	5.97
Male cattle 1 - 2 years	7.30	7.35	7.40	7.30	7.72	7.34	7.48	7.61	7.28	7.41	7.58	7.20	7.50	7.20	7.14
Male cattle > 2 years	0.97	1.01	1.04	1.49	1.79	1.63	1.44	1.52	1.37	1.20	1.40	1.57	1.24	1.07	1.08
Female cattle < 1 year	4.30	4.60	4.90	5.15	5.44	5.85	5.41	5.73	5.64	5.90	6.34	5.69	5.55	5.61	5.61
Female cattle 1 - 2 years	4.68	4.79	4.91	5.18	5.97	6.12	6.24	6.28	6.18	6.40	6.59	6.26	6.43	6.33	6.29
Female cattle > 2 years	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
Bulls for breeding	9.08	9.93	10.78	11.43	12.00	12.84	11.71	12.42	12.14	12.42	13.77	12.14	12.00	12.87	12.87
Dairy in-calf heifers	4.04	4.37	4.71	4.97	5.19	5.53	5.08	5.36	5.25	5.36	5.91	5.25	5.19	5.54	5.54
Beef in-calf heifers	4.87	5.19	5.50	5.75	5.98	6.32	5.86	6.14	6.03	6.14	6.69	6.03	5.97	6.33	6.33

5.2.2.1.3 Uncertainties and Time-series Consistency

The uncertainties applicable to Manure Management are provided in Annex 2. The emission time series for agriculture 1990–2022 is consistent. Key activity data such as disaggregated animal numbers are available for all years and are used in a consistent manner.

5.2.2.1.4 Category-specific QA/QC and verification

Standard QA/QC procedures have been applied to *Manure Management, Cattle*. Details of Ireland's QA/QC process can be found in Chapter 1 of this report.

5.2.2.1.5 Category-specific Recalculations

Recalculations in 3.B.1 resulted in an increase of 74.8 kt CO_2 eq on average across the timeseries in subcategory 3.B.1.2 Sheep and an average decrease of 7.0 kt of CO_2 eq for 3.B.1.4 Other livestock was due to the correction of the pasture manure management methane conversion factor for sheep, horses and goats following a transcription error in the previous submission. CH_4 from manure management across the time series increased by an average of 3.8 per cent annually. A correction to a transcription error for sheep manure management N excretion rates resulted in a decrease of 4.3 kt CO_2 eq emissions on average across the timeseries for 3.B.2.2 Sheep and also an average decrease of 1.5 kt CO_2 eq emissions on average across the timeseries for 3.B.2.5 Indirect N2O emissions. N2O from manure management across the time series decreased by an average of 1.0 per cent annually.

5.2.2.1.6 Category-specific Planned Improvements

The inventory agency previously incorporated the results of study (O'Brien and Shalloo, 2019) aimed at reviewing the Tier 2 methodology used for the estimation of CH_4 emissions from enteric fermentation and manure management in cattle. Further refinements may be undertaken for the next submission as part of ongoing QA/QC processes.

The inventory agency continues to investigate the use of anaerobic digestion in Ireland, which is still in its infancy, with only a small number of plants (fewer than 10) in operation. There is a lack of information of the effective capacity and actual throughput of these plants in terms of quantity and type of feedstock and digestate produced that may be spread on land, as there is no system in place at the national level to accurately track the data owing to the relatively small scale of this industry in Ireland. There are however plans to develop anaerobic digestion at a much larger scale. The inventory agency has engaged with a number of agencies with regard to collection of appropriate data to fill data gaps and create robust systems to track the use of anaerobic digester systems to manage animal manure and other materials in Ireland as the industry grows. However, the development of the industry has stalled. The inventory agency will continue to engage with the relevant agencies so that an appropriate system is put in place. Information on the use of anaerobic digestion for the management of animal manures will be included in emission estimates as it becomes available. In this submission data relating to anaerobic digestion is reported as IE included in manure management.

5.2.2.2 Manure Management, All Other Livestock (3.B.2-3.B.4)

5.2.2.2.1 Category Description

This grouping includes **sheep**, **swine**, and **other livestock**. Manure management from other livestock in Ireland consists of **deer**, **goats**, **horses**, **mules and asses**, **poultry** and **fur animals**.

5.2.2.2.2 Methodological Issues

The Tier 1 approach in the 2006 IPCC Guidelines is used to estimate CH_4 emissions from Manure Management from *Sheep*, *Goats*, *Horses*, *Mules and Asses*, *Poultry*, *Deer* and *Fur-bearing animals*. The allocations to manure management systems are based on the national farm facilities survey (Hyde et al., 2008) and appropriate values of B_O and VS from Table 10.16 of the 2019 Refinement to the 2006 IPCC guidelines while MCFs are derived from Table 10.17. The Tier 2 approach used for *Swine* utilizes country-specific information on GE intake, DE and ash fraction of manure. The B_o values used for swine are those presented in Tables 10.16 and MCF values from Table 10.17 of the 2019 Refinement. Section 10.2.4 Chapter 10 of the 2019 Refinement allows for the adjustment of default emission factors according to the differentiation of country specific liveweights from those presented in the guidelines. This approach is adopted for emissions of CH_4 from enteric fermentation from pigs. Additionally, Table 10.13 provides default values for volatile solids excretion (part of manure management factor equation) on a 1000 kg mass basis, which is used to estimate volatile solid excretion for the poultry flock and thus revised manure management emission factors for CH_4.

The Tier 2 approach in the 2019 Refinement to the 2006 IPCC Guidelines is used to estimate N_2O emissions from *Manure Management* for *Sheep*, *Swine*, *Horses*, *Mules and Asses*, *Poultry*, *Deer* and *Fur-bearing animals*. Country specific N excretion rates and manure management system usage data are utilised.

In 2022, 91.1 per cent of sheep manure is on pasture with the remainder in deep bedding system. All swine manure is in pit storage systems. The remainder of animal manures produced in-house are in different MMS as outlined with CH_4 emission factors for manure management in Table 3.3.D.2, Annex 3.3.

The emission factors given by the 2019 refinement to the 2006 IPCC guidelines, Table 10.21, 0.002 kg N_2O-N/N excreted for pit storage and 0.01 kg N_2O-N/N excreted for deep bedding, 0.005 kg N_2O-N/N excreted for liquid system, 0.01 kg N_2O-N/N excreted for solid storage and dry lot, 0.001 kg N_2O-N/N excreted for litter manure management systems are used for all other livestock categories as presented in Annex 3.3. The emission factor presented in the 2006 IPCC guidelines, Table 11.3 0.014 kg N_2O-N (kg NH_3-N + NO_x-N volatised) is used to estimate indirect N_2O emissions from manure management.

5.2.2.2.3 Uncertainties and Time-series Consistency

The uncertainties applicable to *Manure Management* are provided in Annex 2. The emission time series for agriculture 1990–2022 is consistent. Key activity data such as disaggregated animal numbers are available for all years and are used in a consistent manner.

5.2.2.2.4 Category-specific QA/QC and verification

Standard QA/QC procedures have been applied to *Manure Management, Other Livestock*. Details of Ireland's QA/QC process can be found in Chapter 1 of this report.

5.2.2.2.5 Category-specific Recalculations

A correction to a transcription error for sheep manure management N excretion rates resulted in a decrease of 4.3 kt CO_2 eq emissions or -20.0 per cent on average across the timeseries for 3.B.2.2 Sheep and also an average decrease of 1.5 kt CO_2 eq emissions or -0.6 per cent on average across the timeseries for 3.B.2.5 Indirect N_2O emissions.

5.2.2.2.6 Category-specific Planned Improvements

The inventory agency continues to investigate the applicability of developing Tier 2 estimates of CH_4 from enteric fermentation and manure management from sheep as recommended in previous annual inventory review reports. However, implementation of a Tier 2 approach for sheep is currently difficult given the paucity of detailed information on representative feeding practice and manure management data for sheep. The inventory agency continues to engage with national bodies to improve relevant data collection. The inventory agency has engaged with a number of agencies with regard to collection of appropriate data to fill data gaps and create robust systems to track the use of anaerobic digester systems to manage animal manure and other materials in Ireland. Information on the use of anaerobic digestion for the management of animal manures will be included in emission estimates as it becomes available.

5.3 Emissions from Rice Cultivation (3.C)

No activities have been identified in Ireland for inclusion under this category. This category is reported as Not Occurring (NO).

5.4 Emissions from Agricultural Soils (3.D)

The IPCC Level 3 emission source categories relevant under *3.D Agricultural Soils* in 2022 are *3.D.1 Direct N_2O Emissions from Managed Soils* and *3.D.2 Indirect N_2O Emissions from Managed Soils*. Total emissions from these activities amounted to 4,378.5 kt CO_2eq in 2022.

The emissions of N_2O that result from anthropogenic N inputs or N mineralisation occur through both a direct pathway (i.e., directly from the soils to which the N is added/released), and through two indirect pathways: (i) following volatilisation of NH_3 and NO_x from managed soils and the subsequent redeposition of these gases and their products NH_4^+ and NO_3^- to soils and waters; and (ii) after leaching and runoff of N, mainly as NO_3^-, from managed soils.

5.4.1 Direct N_2O Emissions from Managed Soils (3.D.1)

5.4.1.1 Category Description

Direct N_2O Emissions from Managed Soils is a key category (Trend and Level) in Ireland. This category includes emissions from **inorganic N fertilisers**, **organic N fertilisers**, **urine and dung deposited by grazing**, **crop residues**, **mineralisation/immobilization associated with loss/gain of soil organic matter** and **cultivation of organic soils**.

The following N sources are included in the methodology for estimating direct N_2O emissions from managed soils:

- synthetic N fertilisers (FS_N);
- organic N applied as fertiliser (F_{ON}) (both animal manures and sewage sludge);
- urine and dung N deposited on pasture, range and paddock by grazing animals (F_{PRP});
- N in crop residues (above-ground and below-ground), including from N-fixing crops and from forages during pasture renewal (F_{CR});
- N mineralisation associated with loss of soil organic matter resulting from change of land use or management of mineral soils (F_{SOM}); and

- drainage/management of organic soils (i.e., Histosols) (F_{OS}).

5.4.1.2 Methodological Issues

The Tier 1 approach in the 2019 Refinement to the 2006 IPCC Guidelines is used for *Direct N2O Emissions from Managed Soils*.

The estimates of direct N_2O emissions from agricultural soils take into account the nitrogen inputs from all of these sources. The overarching equation used for estimating Direct N_2O Emissions from Managed Soils is equation 11.1 in Volume 4, Chapter 11 of the 2006 IPCC Guidelines, customised to Ireland's circumstances as follows:

$$N_2O_{Direct} - N = N_2O - N_{Ninputs} + N_2O - N_{OS} + N_2O - N_{PRP}$$

where:

$$N_2O - N_{Ninputs} = [(F_{SN} + F_{ON} + F_{CR} + F_{SOM}) \times EF_1]$$

$$N_2O - N_{OS} = \left[\left(F_{OS,G,Temp,NP}\right) \times EF_2\right]$$

$$N_O - N_{PRP} = \left[\left(F_{PRP,CPP} \times EF_{3PRP,CPP}\right) + \left(F_{PRP,SO} \times EF_{3PRP,SO}\right)\right]$$

where:

F_{SN} = annual amount of synthetic fertiliser N applied to soils, kg N yr^{-1}

F_{ON} = annual amount of animal manure (FAM) and sewage sludge (FSEW) applied to soils kg N yr^{-1}

F_{CR} = annual amount of N in crop residues returned to soils, kg N yr^{-1}

F_{SOM} = annual amount of N in mineral soils that is mineralised, in association with loss of soil C from soil organic matter as a result of changes to land use or management, kg N yr^{-1}

F_{PRP} = annual amount of urine and dung N deposited by grazing animals, kg N yr^{-1} (Note: the subscripts CPP and SO refer to Cattle, Poultry and Pigs, and Sheep and Other animals, respectively)

F_{OS} = annual area of managed/drained organic soils, ha (Note: the subscripts G, Temp, and NP refer to Grassland, Temperate and Nutrient Poor, respectively)

EF_1 = emission factor for N_2O emissions from N inputs, kg N_2O–N (kg N input)$^{-1}$

EF_2 = emission factor for N_2O emissions from drained/managed organic soils, kg N_2O–N ha-1 yr^{-1}

EF_{3PRP} = emission factor for N_2O emissions from urine and dung N deposited on pasture, range and paddock by grazing animals, kg N_2O–N (kg N input)$^{-1}$; (Note: the subscripts CPP and SO refer to Cattle, Poultry and Pigs, and Sheep and Other animals, respectively)

Emissions from **inorganic fertilisers** (F_{SN}) are estimated using country specific emission factors for the three types of nitrogen fertiliser on the Irish market, calcium ammonium nitrate, urea and urea with inhibitor. Further information on derivation of fertiliser type specific emission factors are presented in Annex 3.3.F based on the work of Harty et al. (2016) and Roche et al. (2016). The annual statistics on nitrogen fertiliser use (F_{SN}) by type are obtained from the Department of Agriculture, Food and the Marine. The emission factors applied are 0.0140, 0.0025 and 0.0040 kg N_2O-N/kg N applied, respectively for CAN, urea and urea + n-butyl thiophosphoric triamide.

The implied emission factor for EF_1 is on average 107 per cent (0.0124 kg N_2O-N/kg N) higher than the default value (0.006 kg N_2O-N/kg N) presented in the 2019 Refinement to the 2006 IPCC guidelines. Disaggregated emission factors are presented in Table 5.6.

Organic fertilisers (F_{ON}) consist of animal manure applied to soils (F_{AM}) and sewage sludge applied to soils (F_{SEW}). Through calculations made for Indirect N_2O emissions from Managed Soils (3.D.2) the quantity of these fertilisers which are volatilised as NH_3 and NO_x are subtracted. Published estimates of sludge production (O'Leary et al, 1997; O'Leary and Carty, 1998; O'Leary et al, 2000; Smith et al, 2003; Smith et, 2004; Smith et al, 2007; Monaghan et al, 2009; Monaghan et al, 2012; Shannon et al, 2014a; Shannon et al 2014b; Environmental Protection Agency, 2016) and the proportion applied on agricultural lands are used to estimate F_{SEW} on the basis of 5 per cent nitrogen content in sewage sludge (Pakhnenkoa et al, 2009) with typical dry solids content of 25 per cent (Fehily Timoney, 1985). Although the amount of sludge spreading on land is increasing, it contributed only 1.0 per cent of the organic nitrogen input to agricultural soils in 2022. Table 3.3.G of Annex 3.3 shows the total quantity of nitrogen applied each year to agricultural soils through sewage sludge for the time series 1990-2022.

In the 2019 Refinement to the 2006 IPCC guidelines emissions from urine and dung deposited by grazing (F_{PRP}) consist of emissions from cattle and poultry, utilising the emission factor of 0.006 kg N_2O-N/N kg ($EF_{3PRP,CPP}$), and emissions from sheep and other livestock (horses, mules, goats and deer), which utilize the emission factor of 0.003 kg N_2O-N/N kg ($EF_{3PRP,SO}$). In this submission emissions associated with urine and dung deposition on pasture by cattle are calculated using country-specific disaggregated emission factors for dung (F~PRP cattle-dung~) and urine (F~PRP cattle – urine~). Further information on the derivation of the country specific emission factors for the nitrogen contained in the dung and urine of cattle deposited on pasture is presented in Annex 3.3.F based on the work of Krol et al. (2016). The implied emission factor for EF_3 as a result of use the disaggregated emission factors described is 44 per cent higher than the default value (0.006 kg N_2O-N/ kg N) presented in the 2019 Refinement to thee 2006 IPCC guidelines. Disaggregated emission factors are presented in Table 5.6.

Emissions from **crop residues** (F_{CR}) are estimated using equation 11.6 in Volume 4, Chapter 11 of the 2019 Refinement to the 2006 IPCC Guidelines and uses annual crop production statistics provided by the CSO. The crops considered in Ireland are maize, wheat, oats, barley, beans and peas, potatoes, turnips, oilseed rape, sugar beet, and fodder beet. The contribution from crops in Ireland is small relative to other nitrogen sources and it fluctuates significantly in response to the production level of the relevant crops. Additional information on data used to estimate N_2O emissions from crop residues returned to soils is provided in Tables 3.3.H of Annex 3.3.

Emissions from **mineralisation/immobilization associated with loss/gain of soil organic** matter (F_{SOM}) are estimated using equation 11.8 in Volume 4, Chapter 11 of the 2019 Refinement to the 2006 IPCC Guidelines. The default C:N ratio of the soil organic matter of 10 is used. The Tier 1 approach is used so a single value for all land-uses is applied. The activity data utilised is the carbon loss associated with the cultivation of croplands as reported in 4.B Croplands.

Emissions from **drainage/management of organic soils** (i.e., Histosols) (F_{OS}) are estimated using the area of drained/managed organic soils utilised in the estimation of emissions and removals from 4.C Grasslands (Section 6.5.2.4) and the default EF_2 values for nutrient poor and nutrient rich (4.3 kg N_2O-N ha^{-1} yr^{-1} and 8.2 kg N_2O-N ha^{-1} yr^{-1}) organic soils from Table 2.5 of the 2013 IPCC Wetland Supplement.

Table 5.6 Information related to Direct N_2O Emissions from Managed Soils (3.D.1)

Parameter	Emission Factor	Emission Factor Reference
EF_{1CAN}	0.0140 kg N_2O-N/kg N	Harty et al. (2016) and Roche et al (2016).
EF_{1Urea}	0.0025 kg N_2O-N/kg N	Harty et al. (2016)
$EF_{1Urea+NBPT}$	0.0040 kg N_2O-N/kg N	Harty et al. (2016)
EF_2	4.3 kg N_2O-N/ha	Table 11.1, Volume 4, Chapter 11 of the 2006 IPCC Guidelines & Table 2.5, 2013 IPCC Wetland Supplement
$EF_{3\ PRP,CPP}$	0.006 kg N_2O-N/kg N	Table 11.1, Volume 4, Chapter 11 of the 2019 refinement to the 2006 IPCC Guidelines
$EF_{3\ cattle\text{-}dung}$	0.0031 kg N_2O-N/kg N	Krol et al. (2016)
$EF_{3\ cattle\ -\ urine}$	0.012 kg N_2O-N/kg N	Krol et al. (2016()
$EF_{3PRP,SO}$	0.012kg N_2O-N/kg N	Table 11.1, Volume 4, Chapter 11 of the 2019 refinement to the 2006 IPCC Guidelines

5.4.1.3 Uncertainties and Time-series Consistency

The uncertainties applicable to *Direct N_2O Emissions from Managed Soils* are provided in Annex 2. The emission time series for agriculture 1990–2022 is consistent. Key activity data such as disaggregated animal numbers are available for all years and are used in a consistent manner.

5.4.1.4 Category-specific QA/QC and verification

Standard QA/QC procedures have been applied to *Direct N_2O Emissions from Managed Soils*. Details of Ireland's QA/QC process can be found in Chapter 1 of this report.

5.4.1.5 Category-specific Recalculations

3.D.1.2.a Animal manures applied to soils had a recalculation decrease of 1.8 kt CO_2 eq or 0.5 per cent on average across the time series and 3.D.1.3 Urine and dung deposited by grazing animals decreased on average 14.9 kt CO_2 eq or 1.4 per cent, due to the correction to a transcription error for sheep manure management N excretion rates.

3.D.1.5 Mineralisation/Immobilisation Associated with loss/gain of Soil Organic matter increased on average 0.5 per cent or 0.1 kt CO_2 eq across the time series due to revisions of cropland carbon stocks.

3.D.1.6 Cultivation of organic soils decreased 379.9 kt CO_2 eq or 58.3 per cent on average across the time series This was a result of recently published activity data relating to the area of grasslands on organic soils drained and the assignment of nutrient status (nutrient rich and nutrient poor status) of these soils in Ireland. Previous submission estimates for this category utilised the default approach which assumed that all grasslands on organic soil were drained and nutrient poor status was assigned.

5.4.1.6 Category-specific Planned Improvements

A much more in-depth model approach is needed to take account of all the factors that determine soil emissions and to capture the inter-annual variation in the national emission rate. The inventory agency continues to engage with researchers working on N_2O emissions from soils, with a view to adopting a methodology that systematically accounts for the influences of soil type, fertiliser type and application rates, temperature and rainfall, which are not captured by the current IPCC methodology. However, the lack of reliable data in relation to the key soil properties including bulk density and organic carbon content has delayed the application of such a methodology at national level. Other countries are in similar positions, in that they are using relatively sophisticated methods for estimating emissions from enteric fermentation and manure management, but do not have the data to use a Tier 2 or Tier 3 approach for estimating emissions of N_2O from soils. Notwithstanding the above, Ireland has integrated country-specific research results into emissions calculations in this submission.

Teagasc (Agriculture and Food Development Authority) have a number of projects initiated aimed at refining and testing mitigation measures for reducing N_2O emissions from soil. An emission factor for N_2O emissions from sheep dung and urine under the PRP MMS is being refined for both upland and lowland sheep on contrasting soils. An EU funded ERA-NET project is investigating the effect of soil pH on N_2O emissions from grassland soils across Europe with one site in Ireland. A large DAFM funded project is investigating the effect of a range of soil properties on N_2O emissions to identify mitigation measures, with an initial focus on the effect of soil phosphorus on N_2O emissions. Additionally, a Global Research Alliance funded project investigating mitigation measures associated with dairy cow urine on N_2O emissions commenced in 2019. Finally, the effect of multispecies grasslands for reducing N_2O emissions, enhancing carbon sequestration and stabilising yields is also due to be investigated.

5.4.2 Indirect N_2O Emissions from Managed Soils (3.D.2)

5.4.2.1 Category Description

Indirect N_2O Emissions from Managed Soils is a key category (Level) in Ireland. This category includes emissions from **atmospheric deposition** and **nitrogen leaching and run-off** from two indirect pathways: (i) following volatilisation of NH_3 and NO_x from managed soils and the subsequent redeposition of these gases and their products NH_4^+ and NO_3^- to soils and waters; and (ii) after leaching and runoff of N, mainly as NO_3^-, from managed soils.

5.4.2.2 Methodological Issues

The Tier 1 approach in the 2019 Refinement to the 2006 IPCC Guidelines is used for *Indirect N_2O Emissions from Managed Soils*.

The IPCC methodology for indirect emissions is based on a simple approach that allocates emissions of N_2O due to nitrogen deposition resulting from NH_3 and NO_X emissions in agriculture and from nitrogen leaching to the country that generated the source nitrogen. The contributions from NH_3 and NO_X emission sources in other sectors, such as transport and stationary combustion, are excluded and the import of nitrogen from other countries through atmospheric transport and runoff is not considered.

Emissions from **atmospheric deposition** ($N_2O_{(ATD)}$) arise due to the volatilisation of nitrogen applied to soils in synthetic fertilisers and animal manures. The proportions of these fertilisers that are volatised are $Frac_{GASF}$ and $Frac_{GASM}$ respectively. The volatilisation rates for Ireland are determined in an elaborate NH_3 inventory for agriculture (Hyde et al, 2024). It is assumed that nitrogen lost as NO_X is negligible in comparison to NH_3. $Frac_{GASM}$ is split into $Frac_{GASM1}$ and $Frac_{GASM2}$ with $Frac_{GASM1}$ referring to NH_3-N losses from animal manures in housing, storage and landspreading and $Frac_{GASM2}$ being the proportion of nitrogen from sewage sludge applied to soils that is volatilised as NH_3. These values are presented in Table 5.7. Equation 11.9 in Volume 4, Chapter 11 of the 2019 Refinement to the 2006 IPCC Guidelines which is used to estimate the emissions:

$$N_2O_{(ATD)} - N = [(F_{SN} \times Frac_{GASF}) + ((F_{AM} + F_{PRP} \times Frac_{GASM1}) + (F_{SEW} \times Fraac_{GASM2})] \times EF_4$$

where:

$N_2O_{(ATD)}$–N = annual amount of N_2O–N produced from atmospheric deposition of N volatilised from managed soils, kg N_2O–N yr^{-1}

$Frac_{GASF}$ = fraction of synthetic fertiliser N that volatilises as NH3 and NOx, kg N volatilised (kg of N applied)$^{-1}$

$Frac_{GASM1}$ = fraction of applied animal manure N (F_{AM}) and of urine and dung N deposited by grazing animals (FPRP) that volatilises as NH_3 and NO_x, kg N volatilised (kg of N applied or deposited)$^{-1}$

$Frac_{GASM2}$ = fraction of applied sewage sludge N (F_{SEW}) that volatilises as NH3 and NOx, kg N volatilised (kg of N applied or deposited)$^{-1}$

EF_4 = emission factor for N_2O emissions from atmospheric deposition of N on soils and water surfaces, [0.014 kg N–N_2O (kg NH_3–N + NO_x–N volatilised)$^{-1}$] for wet climate

Conversion of $N_2O_{(ATD)}$-N emissions to N_2O emissions for reporting purposes is performed by using the following equation:

$$N_2O_{(ATD)} = N_2O_{(ATD)} - N \times 44/28$$

Emissions from leaching and run-off are estimated using equation 11.10 in Volume 4, Chapter 11 of the 2019 Refinement to the 2006 IPCC Guidelines:

$$N_2O_{(L)} - N = (F_{SN} + F_{ON} + F_{CR} + F_{SOM} + F_{PRP}) \times Frac_{LEACH-(H)} \times EF_5$$

where:

$N_2O_{(L)}$-N = annual amount of N_2O–N produced from leaching and runoff of N additions to managed

soils in regions where leaching/runoff occurs, kg N_2O–N yr^{-1}

$Frac_{LEACH-(H)}$ = fraction of all N added to/mineralised in managed soils in regions where leaching/runoff occurs that is lost through leaching and runoff, kg N (kg of N additions)$^{-1}$

EF_5 = emission factor for N_2O emissions from N leaching and runoff, 0.011 kg N_2O–N (kg N leached and runoff)$^{-1}$

F_{SN}, F_{ON}, F_{CR}, F_{SOM} and F_{PRP} are as described in section 5.5.1.2.

Estimates of the nitrogen loads in Irish rivers reported under the OSPAR Convention (NEUT, 1999) suggest that approximately 10 per cent of all applied nitrogen in Irish agriculture is lost through leaching. More recent research (Ryan et al., 2006; Del Prado et al., 2006 and Richards et al., 2009) also suggest an average value of 10 per cent. The value of 0.1 is thus considered to be a more realistic estimate of $Frac_{LEACH-(H)}$ for Irish conditions than the default value of 0.24 and it is used in this submission.

Table 5.7 Information related to Indirect N_2O Emissions from Managed Soils (3.D.2)

Parameter	Emission Factor	Emission Factor Reference
$Frac_{GASF}$	0.043	Calculated value for 2022
$Frac_{GASM1}$	0.076	Calculated value for 2022
$Frac_{GASM2}$	0.130	Table 3.1 & Annex 1.1 Chapter 3D of the 2016 EMEP/EEA Emission Inventory Guidebook
$Frac_{LEACH-(H)}$	0.100	OSPAR Convention (NEUT, 1999); Ryan et al., 2006; Del Prado et al., 2006 and Richards et al., 2009

5.4.2.3 Uncertainties and Time-series Consistency

The uncertainties applicable to *Indirect N_2O Emissions from Managed Soils* are provided in Annex 2. The emission time series for agriculture 1990–2022 is consistent.

5.4.2.4 Category-specific QA/QC and verification

Standard QA/QC procedures have been applied to *Indirect N_2O Emissions from Managed Soils*. Details of Ireland's QA/QC process can be found in Chapter 1 of this report.

5.4.2.5 Category-specific Recalculations

3.D.2.1 Atmospheric deposition emissions increased 26.4 kt CO_2 eq or 8.7 per cent on average across the time series due to updates to synthetic fertiliser ammonia emission factors in the EEA/EMEP guidebook 2023 and the correction of a transcription error for sheep manure management N excretion rates.

3.D.2.2 Nitrogen Leaching and Runoff emissions decreased 5.8 kt CO_2 eq or 1.4 per cent on average across the time series due to the correction of a transcription error for sheep manure management N excretion rates, revisions of cropland carbon stocks and the correction of a transcription error associated with the quantity of nitrogen contained in crop residues.

5.4.2.6 Category-specific Planned Improvements

There are no planned improvements for this category at this stage.

5.5 Emissions from Prescribed Burning of Savannas (3.E)

No activities have been identified in Ireland for inclusion under this category. This category is reported as Not Occurring (NO).

5.6 Emissions from Field Burning of Agricultural Residues (3.F)

The practice of field burning of agricultural residues does not occur in Ireland. This is as a result of requirements imposed on farmers who are in receipt of payments under the Common Agricultural Policy and national agri-environmental schemes. This category is reported as Not Occurring (NO).

5.7 Emissions from Liming (3.G)

5.7.1 Category Description

Liming is used to reduce soil acidity and improve plant growth in managed systems and is applied to **cropland** and **grassland** in Ireland. Liming is a key category (Level and Trend) in Ireland. In Ireland, emissions from liming only occur from **Limestone $CaCO_3$**, with no activities identified for **Dolomite $CaMg(CO_3)_2$** which is reported as Not Occurring (NO). Total emissions from Liming amounted to 624.0 kt CO_2eq in 2022.

5.7.2 Methodological Issues

The Tier 1 approach in the 2006 IPCC Guidelines is used for Liming. Annual sales of lime are used to infer the quantity applied to soils, assuming that all lime sold to farmers is applied during the same year. In Ireland, lime is applied to both grassland and cropland. The default emission factor of 0.12 is used for the proportion of carbon in lime. All lime sold in Ireland for application to agricultural soils is required to have a Total Neutralizing Value (TNV) of greater than 90 per cent to conform to Department of Agriculture, Food and the Marine specifications as prescribed in Statutory Instrument 248 of 1978 S.I. No. 248/1978 - Marketing of Non-EEC Fertilisers Regulations, 1978. (irishstatutebook.ie) . Typical test results from the state lab indicates TNV values greater than 95 per cent. Calcium and calcium carbonate contents are also measured by the state laboratory so that quarries meet the specifications required. The state Agricultural Research body Teagasc has initiated a project aimed at developing Tier 2 emission estimates for this category. Relevant updates will be provided as they become available in future submissions. The inventory agency has undertaken some initial discussions with agri-environmental researchers and funding agencies with a view to exploring the development of more refined estimates from this category.

5.7.2.1 Uncertainties and Time-series Consistency

The uncertainties applicable to *Liming* are provided in Annex 2. The emission time series for agriculture 1990–2022 is consistent. Key activity data are available for all years and are used in a consistent manner.

5.7.2.2 Category-specific QA/QC and verification

Standard QA/QC procedures have been applied to *Liming*. Details of Ireland's QA/QC process can be found in Chapter 1 of this report.

5.7.2.3 Category-specific Recalculations

No recalculations have been undertaken in this category in this submission.

5.7.2.4 Category-specific Planned Improvements

A research study was initiated in 2022 aimed at developing Tier 2 emission factors for this category. The study in being undertaken by Teagasc and is funded by the Department of Agriculture, Food and the Marine. The results of this study will be included in emission estimates as they become available.

5.8 Emissions from Urea Application (3.H)

5.8.1 Category Description

Adding urea to soils during fertilisation leads to a loss of CO_2 that was fixed in the industrial production process. Total emissions from these activities amounted to 126.8 kt CO_2eq in 2022.

5.8.2 Methodological Issues

The Tier 1 approach in the 2006 IPCC Guidelines is used for *Urea Application*. The amount of Urea based fertilisers is available from national fertiliser statistics provided to the inventory agency by DAFM.

The default emission factor of 0.20 is used for the proportion of carbon in the urea applied to land.

5.8.2.1 Uncertainties and Time-series Consistency

The uncertainties applicable to *Urea Application* are provided in Annex 2. The emission time series for agriculture 1990–2022 is consistent. Key activity data such as fertiliser use statistics are available for all years and are used in a consistent manner.

5.8.2.2 Category-specific QA/QC and verification

Standard QA/QC procedures have been applied to *Urea Application*. Details of Ireland's QA/QC process can be found in Chapter 1 of this report.

5.8.2.3 Category-specific Recalculations

No recalculations have been undertaken in this category in this submission.

5.8.2.4 Category-specific Planned Improvements

There are no planned improvements for this category at this stage.

5.9 Emissions from Other Carbon-Containing Fertilisers (3.I)

No activities have been identified in Ireland for inclusion under this category. This category is reported as Not Occurring (NO).

5.10 Emissions from Other Agricultural Sources (3.J)

No activities have been identified in Ireland for inclusion under this category. This category is reported as Not Occurring (NO).

Table 5.8 Recalculations in Agriculture 1990-2021

			1990	1995	2000	2005	2010	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
										Estimates in 2023 Submission (kt)							
3.A	Enteric Fermentation	CH_4	439.98	466.25	473.24	463.34	430.68	451.55	455.77	452.72	467.95	480.99	498.23	509.93	495.97	503.75	517.44
3.B	Manure Management	CH_4	56.43	60.29	62.34	63.60	61.31	65.72	66.10	65.38	67.98	70.08	72.41	74.16	72.25	73.03	73.78
3.B	Manure Management	N_2O	1.94	2.10	2.17	2.25	2.09	2.28	2.26	2.14	2.24	2.31	2.39	2.50	2.35	2.35	2.40
3.D.1	Direct em. from Managed Soils	N_2O	15.46	16.92	16.60	15.49	14.67	13.92	15.25	14.59	14.59	14.69	15.55	16.47	15.43	15.57	16.30
3.D.2	Indirect em. From Managed Soils	N_2O	2.66	2.83	2.85	2.66	2.58	2.47	2.60	2.53	2.60	2.70	2.83	2.98	2.77	2.74	2.80
3.G	Liming	CO_2	355.04	494.60	366.38	266.73	427.93	229.40	515.69	391.07	401.15	433.60	332.75	461.06	343.90	399.48	597.41
3.H	Urea Application	CO_2	96.68	86.27	91.84	60.81	98.24	46.35	47.09	54.55	64.27	79.11	83.99	88.76	91.98	109.40	102.04
3	Total Carbon dioxide	CO_2	451.71	580.86	458.23	327.55	526.18	275.75	562.78	445.62	465.41	512.70	416.74	549.82	435.88	508.89	699.45
3	Total Methane	CH_4	496.41	526.54	535.58	526.94	491.99	517.27	521.87	518.10	535.92	551.06	570.63	584.09	568.21	576.78	591.21
3	Total Nitrous oxide	N_2O	20.07	21.84	21.62	20.40	19.34	18.67	20.11	19.26	19.43	19.69	20.77	21.94	20.54	20.66	21.51
3	Total (CO_2 eq)	CO_2 eq	**19,668.6**	**21,112.8**	**21,182.8**	**20,487.5**	**19,428.0**	**19,706.4**	**20,504.1**	**20,056.2**	**20,620.3**	**21,161.5**	**21,897.7**	**22,719.2**	**21,789.8**	**22,133.3**	**22,953.5**
										Recalculated Estimates in 2024 Submission (kt)							
3.A	Enteric Fermentation	CH_4	439.98	466.25	473.24	463.34	430.68	451.55	455.77	452.72	467.95	480.99	498.23	509.93	495.97	503.75	517.38
3.B	Manure Management	CH_4	59.52	63.54	65.41	66.01	62.78	67.37	67.82	67.16	69.70	71.78	74.30	76.01	74.06	74.96	75.68
3.B	Manure Management	N_2O	1.91	2.07	2.14	2.23	2.07	2.26	2.24	2.12	2.23	2.29	2.37	2.48	2.33	2.33	2.39
3.D.1	Direct em. from Managed Soils	N_2O	13.54	15.12	14.93	13.93	13.30	12.61	13.97	13.35	13.39	13.53	14.43	15.37	14.36	14.54	15.29
3.D.2	Indirect em. From Managed Soils	N_2O	2.73	2.91	2.94	2.74	2.68	2.53	2.68	2.60	2.68	2.78	2.91	3.08	2.85	2.82	2.89
3.G	Liming	CO_2	355.04	494.60	366.38	266.73	427.93	229.40	515.69	391.07	401.15	433.60	332.75	461.06	343.90	399.48	597.41
3.H	Urea Application	CO_2	96.68	86.27	91.84	60.81	98.24	46.35	47.09	54.55	64.27	79.11	83.99	88.76	91.98	109.40	102.04
3	Total Carbon dioxide	CO_2	451.71	580.86	458.23	327.55	526.18	275.75	562.78	445.62	465.41	512.70	416.74	549.82	435.88	508.89	699.45
3	Total Methane	CH_4	499.50	529.78	538.65	529.35	493.46	518.92	523.59	519.88	537.65	552.77	572.53	585.94	570.02	578.70	593.05
3	Total Nitrous oxide	N_2O	18.18	20.10	20.00	18.90	18.06	17.40	18.89	18.07	18.29	18.60	19.71	20.93	19.55	19.69	20.56
3	Total (CO_2 eq)	CO_2 eq	**19,256.5**	**20,742.7**	**20,841.0**	**20,157.0**	**19,127.8**	**19,417.2**	**20,229.1**	**19,791.9**	**20,365.7**	**20,918.6**	**21,670.5**	**22,501.7**	**21,576.4**	**21,929.8**	**22,754.0**
										Percentage Change in Total Emissions due to Recalculations							
3.A	Enteric Fermentation	CH_4	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	-0.01%
3.B	Manure Management	CH_4	5.48%	5.38%	4.91%	3.79%	2.39%	2.51%	2.60%	2.72%	2.53%	2.44%	2.61%	2.50%	2.51%	2.64%	2.57%
3.B	Manure Management	N_2O	-1.56%	-1.44%	-1.29%	-0.96%	-0.64%	-0.68%	-0.68%	-0.73%	-0.68%	-0.62%	-0.66%	-0.60%	-0.65%	-0.65%	-0.66%
3.D.1	Direct em. from Managed Soils	N_2O	-12.44%	-10.59%	-10.06%	-10.03%	-9.35%	-9.42%	-8.37%	-8.49%	-8.23%	-7.90%	-7.24%	-6.65%	-6.89%	-6.66%	-6.24%
3.D.2	Indirect em. From Managed Soils	N_2O	2.71%	2.91%	2.98%	2.73%	3.79%	2.46%	2.75%	2.75%	2.80%	2.90%	3.00%	3.16%	2.95%	2.93%	3.08%
3.G	Liming	CO_2	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
3.H	Urea Application	CO_2	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
3	Total Carbon dioxide	CO_2	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
3	Total Methane	CH_4	0.62%	0.62%	0.57%	0.46%	0.30%	0.32%	0.33%	0.34%	0.32%	0.31%	0.33%	0.32%	0.32%	0.33%	0.31%
3	Total Nitrous oxide	N_2O	-9.38%	-7.96%	-7.46%	-7.36%	-6.66%	-6.78%	-6.06%	-6.16%	-5.88%	-5.57%	-5.09%	-4.63%	-4.85%	-4.70%	-4.40%
3	Total (CO_2 eq)	CO_2 eq	**-2.10%**	**-1.75%**	**-1.61%**	**-1.61%**	**-1.55%**	**-1.47%**	**-1.34%**	**-1.32%**	**-1.23%**	**-1.15%**	**-1.04%**	**-0.96%**	**-0.98%**	**-0.92%**	**-0.87%**

Chapter 6 Land-Use, Land-Use Change and Forestry

6.1 Introduction

The source category classification for reporting on the LULUCF sector was revised by Decision 24/CP.19 to that given in Table 6. 1. The six top-level categories are used to represent managed land areas and they are broadly defined to accommodate all land areas in most countries, taking into account possible differences in national classification systems. Each category is split into two sub-categories, which are, in some cases, further sub-divided to reflect national circumstances and the level of detail considered most appropriate for the estimation of relevant emissions and removals. The two sub-categories are 1): lands remaining within the initial land, and 2): lands converted from other land uses using a transition period of 30 years for forest land and 20 years for all other land use categories. The approach ensures consistency and comparability of activities reported under the UNFCCC (herein referred to Convention reporting) and those reported to the EU under the EU LULUCF regulations ((EU) 2018/841 and (EU) 2023/839). The area-based approach is intended to make the best use of the various types of data likely to be available for the given categories of land and reduce possible overlaps and omissions in reporting for national total land areas.

The net CO_2 emissions to, or removals from, the atmosphere are to be reported with respect to overall carbon gain or loss for up to five relevant carbon pools for the defined land categories. These pools are above-ground biomass, below-ground biomass, dead organic matter (litter and dead wood) and soils. For Convention reporting above-ground biomass and below-ground biomass are reported together as living biomass, and litter and deadwood are reported together as dead organic matter (DOM). The 2006 IPCC guidelines and the 2019 refinement provides methodologies for calculating changes in carbon pools where land areas form the basic activity data and carbon stock change is determined from a number of other parameters. Various levels of land sub-division may be used to capture differences due to climate, management system, vegetation type or other factors influencing carbon exchange. As for other sectors of the inventory, the 2006 IPCC guidelines provides higher tiered methods for estimating emissions and removals, where higher tiers may be used if the necessary data are available. The estimation of emissions and removals also utilises the 2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol and 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands, where appropriate. Those emissions of N_2O and CH_4 associated with land management not reported under Agriculture are reported in the LULUCF sector including such activities as soil disturbance, and the drainage and rewetting of mineral and organic soils. Emissions of N_2O and CH_4 are reported for biomass burning (and CO_2 emissions from biomass burning in Wetlands).

6.2 Overview of LULUCF Sector

6.2.1 Sector Coverage

Complete coverage of the relevant gases has been achieved for the years 1990-2022 in all IPCC land categories, as indicated in Table 6.1. This chapter presents a broad description of data treatment and the methodologies used to estimate emissions and removals for the relevant land categories in the time-series 1990-2022. The estimates for *4.A Forest Land* are prepared under the responsibility of the Department of Agriculture Food and the Marine (DAFM) and submitted to the Inventory agency in accordance with a memorandum of understanding (MOU) between DAFM and the EPA (see section 1.3 of this report). All other emissions and removals estimates are prepared by a member of the national inventory team. A detailed report on the work undertaken to report for the 2006 inventory submission on the LULUCF sector is available (O'Brien, 2007), with subsequent revisions to methodologies reported in National Inventory Reports where necessary.

Table 6.1 Level 3 Source Category Coverage for Land Use, Land Use Change and Forestry

4 Land Use Land-Use Change and Forestry	Carbon Stock Change Emissions of CO_2				CH_4	N_2O
	Biomass	DOM	Soils	Wood products		
A. Forest Land						
1. Forest Land remaining Forest Land	All	All	All		All	Part, IE
2. Land converted to Forest Land	All	All	All		All	Part, IE
B. Cropland						
1. Cropland remaining Cropland	All	NO	All		NA	IE
2. Land converted to Cropland	NO	NO	NO		NA	NO
C. Grassland						
1. Grassland remaining Grassland	NO	NO	All, NO*		NO	All. IE
2. Land converted to Grassland	All	All	All		All	Part, IE
D. Wetlands						
1. Wetlands remaining Wetlands	All	NO	All		NO	IE
2. Land converted to Wetlands	All	All	All		All	All
E. Settlements						
1. Settlements remaining Settlements	NO	NO	NA		NO	IE, NE
2. Land converted to Settlements	All	All	All		All	Part, IE
F. Other Land						
1. Other Land remaining Other Land	NO	NO	NO*		NO	NO
2. Land converted to Other Land	All	All	All		All	All
G. Harvested wood products				All**		

Biomass - includes above and below ground biomass
DOM - dead organic matter (deadwood and litter)
All - all emission sources covered; NE - emissions not estimated; NO - activity not occurring; NA - not applicable (no emissions of the gas occur in the pool/source category); IE - emissions included elsewhere.
* Under the Tier 1 method, there is no carbon stock change in soil for these land categories, if there is no change in management
** HWP reported based on domestic production approach and excluding Harvest form deforested lands

The 1990-2022 inventory for LULUCF follows the same general approach and methodologies as those used for the 2023 submission for the 1990-2021 inventory and ensures transparent and consistent reporting of activities and land use transition under the Convention. The current approach reports all land areas converted to another land use using a 20 or 30-year transition period. The 20- year period is chosen as the default IPCC approach and is applied to all land uses other than Forest land. For Forest land, a transition period of 30 years is used to ensure compliance with Regulation (EU) 2018/841 and 2023/839 (NFAP, 2020).

The estimates of emissions and removals from LULUCF over the period 1990-2022 are presented in Table 6.2 for all land-use categories. The LULUCF sector is a net source of emissions in all years, with the losses of carbon dominated by the impact of drainage of organic soils in Grasslands and Wetlands, and gains in biomass carbon increasingly evident in Forest Land.

6.2.2 Land Use Definitions and Land Use Change Matrices

Table 6.3 summarises the definitions and coverage of the IPCC land-use categories in the LULUCF sector as they relate to Ireland along with the data sources that are used for estimating the respective areas remaining in the categories, the areas converted to the categories and their associated greenhouse gas emissions and removals. The IPCC Wetlands category has been sub divided into unexploited wetlands (unmanaged), and exploited peatlands, the latter being managed wetland areas that are drained for the purpose of commercial and domestic harvesting of peat for combustion (in 1.A.1.a, 1.A.1.c and 1.A.4.b) and/or horticultural use.

Annex 3.4.D gives a more detailed breakdown of the annual exchange of land between land use types and the cumulative change over time. The matrices of land use are intended to show the dynamism of changes in land use in Ireland and to identify the conversions that are most significant in terms of their potential to contribute to either emissions or removals of greenhouse gases over the inventory time-series.

6.2.2.1 Land use classification hierarchy

The flow diagram in Figure 6.1 illustrates how different data sources are used to derive land use categories in a hierarchal manner. Forest lands are initially derived using forest datasets and statistics. This is primarily based on the Forest Information and Planning System which used 1995 as the baseline (FIPS 95) afforestation and deforestation data (see section 6.3.1). The areas under forest land include open areas within forest boundaries. This submission includes biomass carbon stock change (CSC) for these areas using information obtained from the 2006, 2012, 2017 and 2021 national forest inventories (NFI) and a reconstruction of historical age class distributions (see section 6.3.2). Emissions from soils are reported for all areas besides open areas within forest boundaries (e.g. forest roads, biodiversity areas not covered by trees) where no drainage occurs. Identification of land cover type converted to forest land (L-F) is based on an analysis of the CORINE land cover data set. Deforestation in identified forests areas is assessed using a combination of CORINE, NFI, maps and aerial photography datasets to obtain information on transitions to other land use categories (see section 6.3.1).

Other land use categories (i.e. non-forest land) are then allocated to other land uses using other data sources such as annual publication of agricultural statistics from the CSO, the Land Parcel Information System (LPIS) from the DAFM, or specific information from industry experts, as in the case for some areas of drained peatland for exploitation. Additional spatial databases such as CORINE, and the Indicative Soils Map of Ireland (Fealy and Green, 2009), are used to estimate the soil types associated with each land use. Table 6.3 details the data sources used to estimate land use areas and soil types typical of each land use type.

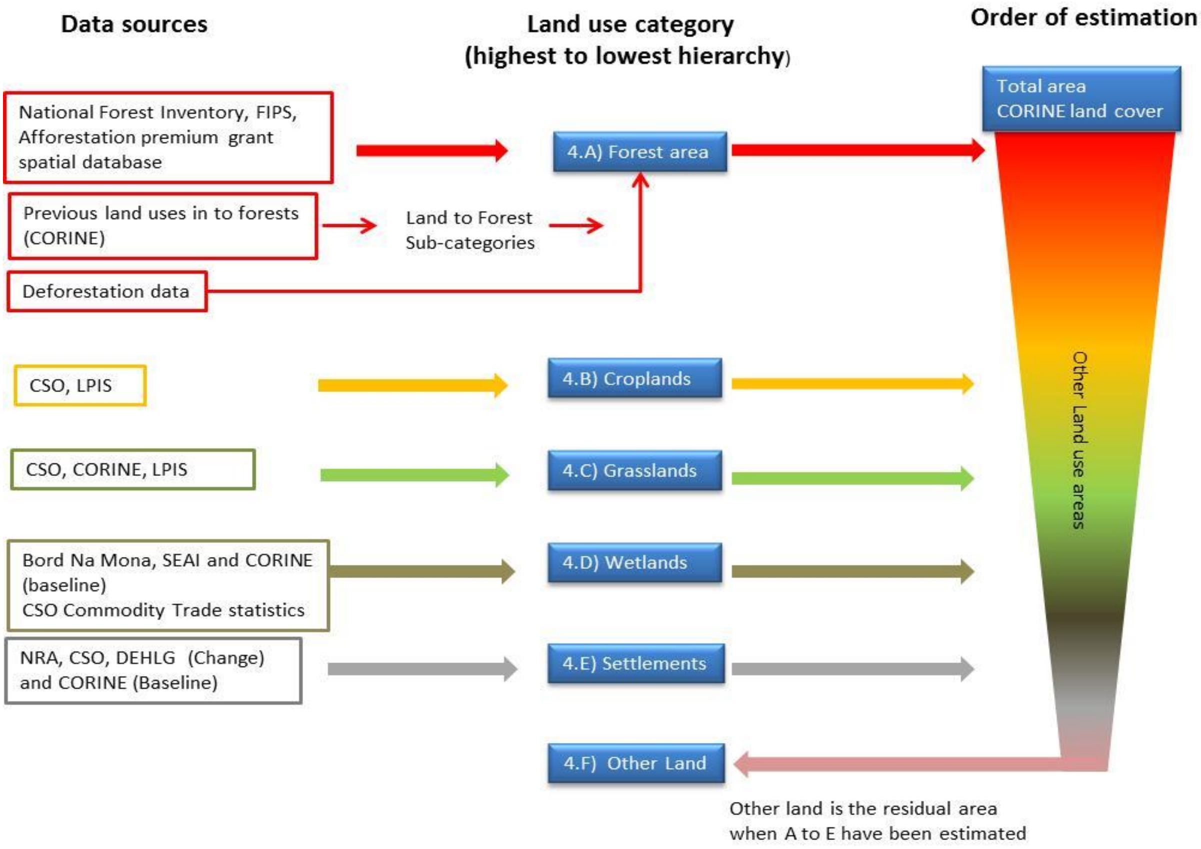


Figure 6.1 Methodologies and hierarchy of determining land use areas and transitions

See Table 6.3 for a detailed outline of data sources. Other Land is derived from the land not included in the forest, cropland, grassland, wetland and settlement areas and as such is the residual land area not included in the other land categories.

6.2.3 Land use change trends

Figure 6.2 shows the presents a summary of land use change across all categories between 1990 and 2022. Grassland is the dominant land-use category in all years, accounting for 62.1 per cent of total area in 1990, followed by Wetland accounting for 19.1 per cent. Forest Land covered 6.8 per cent, followed by Cropland at 10.5 per cent and Settlements at 1.5 per cent. Other Land is the residual land use at 0.1 per cent. The major land-use changes since 1990 have been the conversion of Grassland and Wetland to Forest Land. In 2022, Grassland accounted for 59.4 per cent of land area, Wetland 17.2 per cent, Forest Land 11.0 per cent, Cropland at 10.5 per cent, with Settlement and Other Land accounting for 1.8 per cent and 0.1 per cent, respectively.

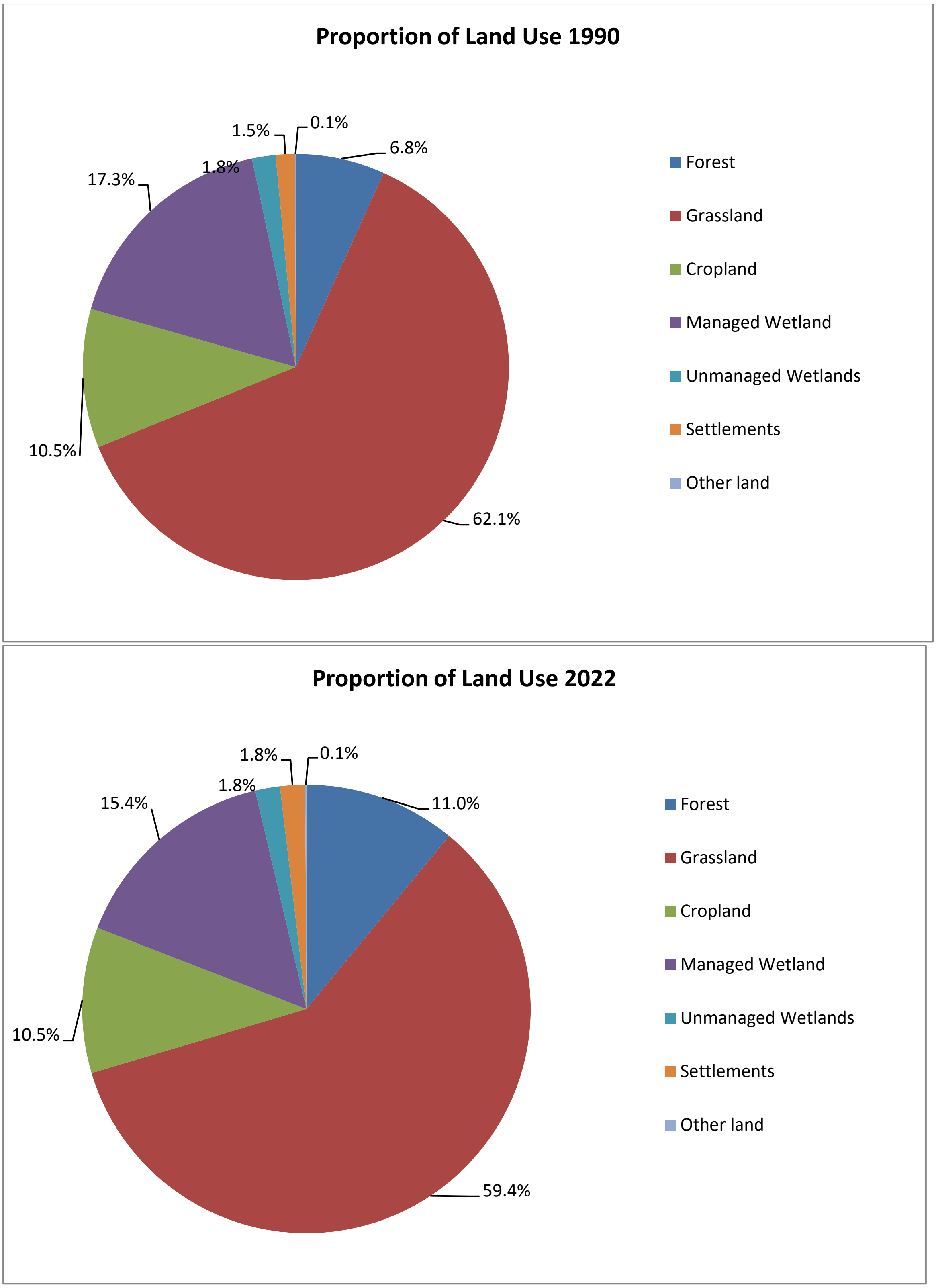


Figure 6.2 Overview of land use change between 1990 and 2022

Table 6.2 Emissions[a] and Removals[a] from Land Use Land-Use Change and Forestry 1990-2022 (kt CO_2 eq)

LULUCF	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
4A Forestland	-2723.21	-1554.16	-428.49	-1238.01	-2790.49	-3757.18	-3449.80	-4080.84	-4151.00	-2556.45	-2462.64	-2008.88	-1768.93	-1134.58	-1574.99
A. Forest Land CO_2	-2924.88	-1797.49	-688.88	-1515.80	-3118.98	-4061.35	-3753.62	-4383.71	-4451.97	-2912.90	-2782.05	-2318.48	-2082.32	-1440.38	-1878.56
A. Forest Land CH_4	57.24	71.85	70.99	71.35	107.45	80.90	79.84	76.66	73.40	123.74	86.75	75.81	80.95	74.82	73.87
A. Forest Land N_2O	144.43	171.48	189.40	206.44	221.04	223.27	223.98	226.21	227.56	232.72	232.66	233.79	232.44	230.98	229.70
4B Cropland	-48.09	-44.66	1.35	42.77	-113.16	-4.85	-51.20	-71.34	-92.59	-92.02	-154.79	-142.38	-125.21	-101.29	-83.38
B. Cropland CO_2	-48.15	-44.74	1.30	42.65	-113.18	-4.85	-51.20	-71.34	-92.59	-92.02	-154.82	-142.39	-125.21	-101.31	-83.41
B. Cropland CH_4	0.05	0.07	0.05	0.09	0.02	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.02	0.02
B. CroplandN_2O	0.01	0.02	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
4C Grassland	3928.29	3682.81	3220.73	3121.41	2817.99	3271.75	2724.69	2733.87	2729.95	2645.58	2452.12	2481.69	2829.33	2511.64	2484.88
C. Grassland CO_2	2260.94	2059.08	1648.46	1565.97	1250.17	1784.46	1248.65	1293.68	1314.12	1218.36	1063.73	1118.42	1480.36	1175.04	1160.62
C. Grassland CH_4	1659.29	1611.57	1566.45	1545.06	1500.12	1419.29	1408.45	1375.00	1351.40	1359.48	1327.36	1306.21	1295.28	1286.86	1278.87
C. Grassland N_2O	8.06	12.16	5.82	10.38	67.70	68.00	67.60	65.20	64.44	67.74	61.03	57.05	53.68	49.75	45.39
4D Wetlands	4203.32	4637.90	3971.69	5039.78	5839.22	5125.77	5096.47	6041.20	4922.67	5820.33	4633.82	4567.33	4784.64	4080.91	3757.65
D. Wetlands CO_2	1780.24	2284.61	1719.84	2746.14	3310.62	2844.81	2779.40	3805.07	2722.73	3330.57	2294.44	2193.05	2409.57	1596.73	1153.19
D. Wetlands CH_4	2383.51	2308.77	2215.92	2251.48	2448.08	2244.04	2275.74	2208.89	2179.39	2422.78	2311.03	2352.11	2354.36	2468.69	2590.97
D. Wetlands N_2O	39.57	44.53	35.92	42.16	80.52	36.93	41.32	27.24	20.54	66.98	28.35	22.18	20.71	15.49	13.48
4E Settlements	62.66	85.60	172.32	305.96	250.75	126.76	119.10	128.76	535.79	161.88	491.01	200.17	193.67	187.76	221.29
E. Settlements CO_2	60.03	80.72	161.50	262.02	182.69	64.50	58.21	67.27	474.30	98.57	403.54	111.78	110.54	109.85	143.62
E. Settlements CH_4	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
E. Settlements N_2O	2.63	4.88	10.82	43.93	68.06	62.26	60.88	61.49	61.49	63.30	87.47	88.39	83.14	77.90	77.67
4F Other Land	0.90	23.65	53.75	69.82	62.63	62.14	61.81	59.51	57.20	54.90	52.63	50.37	47.97	46.03	43.62
F. Other Land CO_2	0.83	21.28	41.49	48.79	17.25	16.96	16.69	16.42	16.15	15.88	15.65	15.42	14.77	14.58	13.93
F. Other Land CH_4	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
F. Other Land N_2O	0.07	2.37	12.26	21.02	45.39	45.18	45.12	43.08	41.05	39.02	36.98	34.95	33.19	31.44	29.69
4G Harvested Wood Products	-413.04	-679.70	-1123.25	-1129.67	-818.73	-662.33	-763.17	-728.72	-803.70	-868.83	-825.65	-866.32	-809.02	-962.68	-865.73
G. HWP CO_2	-413.04	-679.70	-1123.25	-1129.67	-818.73	-662.33	-763.17	-728.72	-803.70	-868.83	-825.65	-866.32	-809.02	-962.68	-865.73
G. HWP CH_4	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
G. HWP CH_4	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Total LULUCF kt CO_2 eq	**5010.82**	**6151.44**	**5868.1**	**6212.05**	**5248.21**	**4162.07**	**3737.89**	**4082.44**	**3198.31**	**5165.40**	**4186.49**	**4281.98**	**5152.45**	**4627.79**	**3983.34**

[a] positive values indicate emissions and negative values indicate removals

Table 6.3 Description of Land Use Categories

Land Use Category	Definition and Coverage	Area 1990 (ha)	Area 2022 (ha)	Percentage change 1990-2020	Sources of Information	Principal Conversions	
						To	From
Forest Land	All public and private plantation forests. Forest land is an area of land where tree crown cover is greater than 20% of the total area occupied. It has a minimum width of 20m and a minimum area of 0.1ha and includes all trees with a potential to reach 5m in height in situ. Trees grown for fruit or horticulture are excluded (included in cropland), as are non-tree woody species such as furze and rhododendron. The forest area includes open areas within forest boundaries, assumed to be 10% based on NFI statistics.	481,074	780,536	+62.2%	National Forest Inventory (NFI) 2006, 2012, 2017 and 2021 FIPS (Forest Inventory and Planning System) 1995 COILLTE inventory database Forest Service Premiums GIS database 1995-2022 CORINE Land Cover General Soil Map Deforestation statistics CSO statistics on harvest and HWP	Grassland Wetland Settlement Other land	Grassland Wetland
Cropland	Spatial location of cropland and temporary grasslands are identified from the history of parcels used for crops in the period 2000-2016 from the Land Parcel Information System. The parcels are the gross boundary of the parcels; actual utilised areas are based on the aggregate figures from the CSO annual statistics.	749,075	747,634	-0.2%	Central Statistics Office (CSO), NFI Land Parcel Information System Indicative Soil Map of Ireland	Settlement	Not occurring
Grassland	Areas of improved grassland (pasture and areas used for the harvesting of hay and silage) and unimproved grassland in use (rough grazing) as recorded by CSO annual statistics. Semi-natural grassland is estimated using CORINE Land Cover.	4,416,808	4,224,631	-4.4%	CSO, CORINE Land Cover, NFI LPIS (Land Parcels Information System) Indicative Soil Map for Ireland	Forest land, Settlement	Forest land
Unmanaged Wetlands	Unexploited wetlands	126,780	126,780	NA	CORINE Land Cover, NFI Indicative Soil Map for Ireland	NA	NA
Managed Wetland	Wetland areas commercially exploited for public and private extraction of peat and areas used for domestic harvesting of peat. The quantity of peat extracted for horticultural use is estimated from export trade data.	1,230,083	1,097,716	-10.8%	Bord na Mona (BNM) area statistics; NFI, Expert opinion Central Statistics Office	Unmanaged Wetlands, Forestry	Forest, land managed wetland
Settlements	Urban areas, roads, airports and the footprint of industrial, commercial/institutional and residential buildings	103,739	128,179	+23.6%	CORINE Land Cover; National Roads Authority (NRA) road construction statistics; CSO housing stock, house completions and other construction floor area statistics; General Soil Map, NFI	Not occurring	Grassland, Cropland, Forest land
Other Land	Residual when all other land use areas have been determined	4,227	6,310	+49.3%	CORINE, (includes, water bodies, bare rock etc.), NFI	Forest land	Forest land
Total Land	National territorial area	7,111,785	7,111,785		CORINE Land Cover, Indicative Soil Map of Ireland		

6.3 Forest Land (Category 4.A)

6.3.1 Overall approach and data sources

Ireland adopts the gains and losses approach for reporting biomass carbon stock changes (CSC) using tier 3 models. The reporting of C pools is done using the Carbon Budget Model of the Canadian Forest Sector framework (CBM-CFS3, Kurz et al., 2009). The activity data for identification of changes in forest area is based on a combination of different approaches using the following data sources (also see section 6.2.2);

- The 1995 forest information parcel data (FIPS95);
- The grant and premiums application system (GPAS) and spatial database (iFORIS) for identification of afforested lands since 1990. Information on identification of land uses converted to forest is derived from the CORINE land cover change 1990 to 2006 data set;
- Deforestation data is derived from a combination of sources including CORINE 1990 and 2000, FIPS95, National Forest Inventory (NFI) data, felling licence information and aerial photography;
- The forest fires database;
- Stratification of forest areas into different soil strata is done using NFI information and the EPA indicative soil map (IFS map).

The activity data used to derive state variables for the modelling framework is primarily derived from the FIPS95 data, harvest statistics and the NFI. The first Irish NFI was completed in 2006 with a second NFI inventory was completed in 2012, a third in 2017 and the most recent in 2021. The NFI data is the primary activity data used to provide initial state variables within different forest strata for calculation of carbon stock changes (CSC) from 2006 onwards using the CBM-CFS3 model (Kurz et la., 2009; section 6.3.3.1 and Annex 3.4.A.5). The CBM-CFS3 was used for the first time in the 2019 submission (1990-2017 inventory) and it replaces the CARBWARE model that was used in submissions prior to that. Estimation of CSC in the forest lands remaining forest lands before 2006 cannot be determined using the CBM-CFS3 model due to limited historical activity data on stand variables. Therefore, a more generalised stand model (FORCARB), based on British Forestry commission yield tables, is used to provide CSC estimates prior to 2006 (Edwards and Christy, 1981; Black et al., 2012).

Activity data and models used to derive CSC for forest lands are shown in a schematic overview in figure 6.3. It includes the activity data used by the different models and the different time series the model outputs represent. The CBM-CFS3 model was used for the EU LULUCF Regulation ((EU) 2018/841) Forest Reference Level (FRL) submissions in 2018 and 2019. The model has been parameterised for Irish conditions. The FORCARB model is based on static management interventions (i.e. set clear-felling at maximum mean annual increment and thinning's at a 5-year marginal thinning intensity cycle), which do not reflect management interventions in Ireland (Broad and Lynch, 2006; Black et al., 2008, 2012). In addition, it is well documented that the productivity index or yield class of the major species in Ireland, Sitka spruce, is higher than those in the UK, exceeding the highest documented BFC yield class (YC 24) table (Farrelly et al., 2011). The use of two different models for the historic (pre 2006) and post 2006 time series does offer the potential of introducing a time series bias or inconsistency. However, this is addressed by re-scaling (in line with Chapter 5 Volume 1 of the 2006 IPCC guidelines) the historic (FORCARB) time series by interpolation against the CBM-CFS3 model outputs as indicated in Figure 6.3.1 (also see section 6.3.4.1 and section 6.3.4.1).

Figure 6.3 shows how the data sources used for different forest activities (clear boxes) are represented in relation to the time series. For example, FIPS95 was collected in 1995 and is used to derive information of species and forest areas in forest land from 1990 to 2006 as indicated by the black arrows. For all afforested lands since 1990, all CSCs are estimated using the CBM-CFS3 model (see CRF 4A2 box). For forest land remaining forest land two models are used (see CRF 4A1 box). The vertical brackets show which activity data is used by the different modelling frameworks FORCARB and CBM-CFS3. The red open box and yellow box in Figure 6.3 indicate interpolation and adjustment of the historic data against FORCARB outputs to ensure a consistent representation of the entire time series.

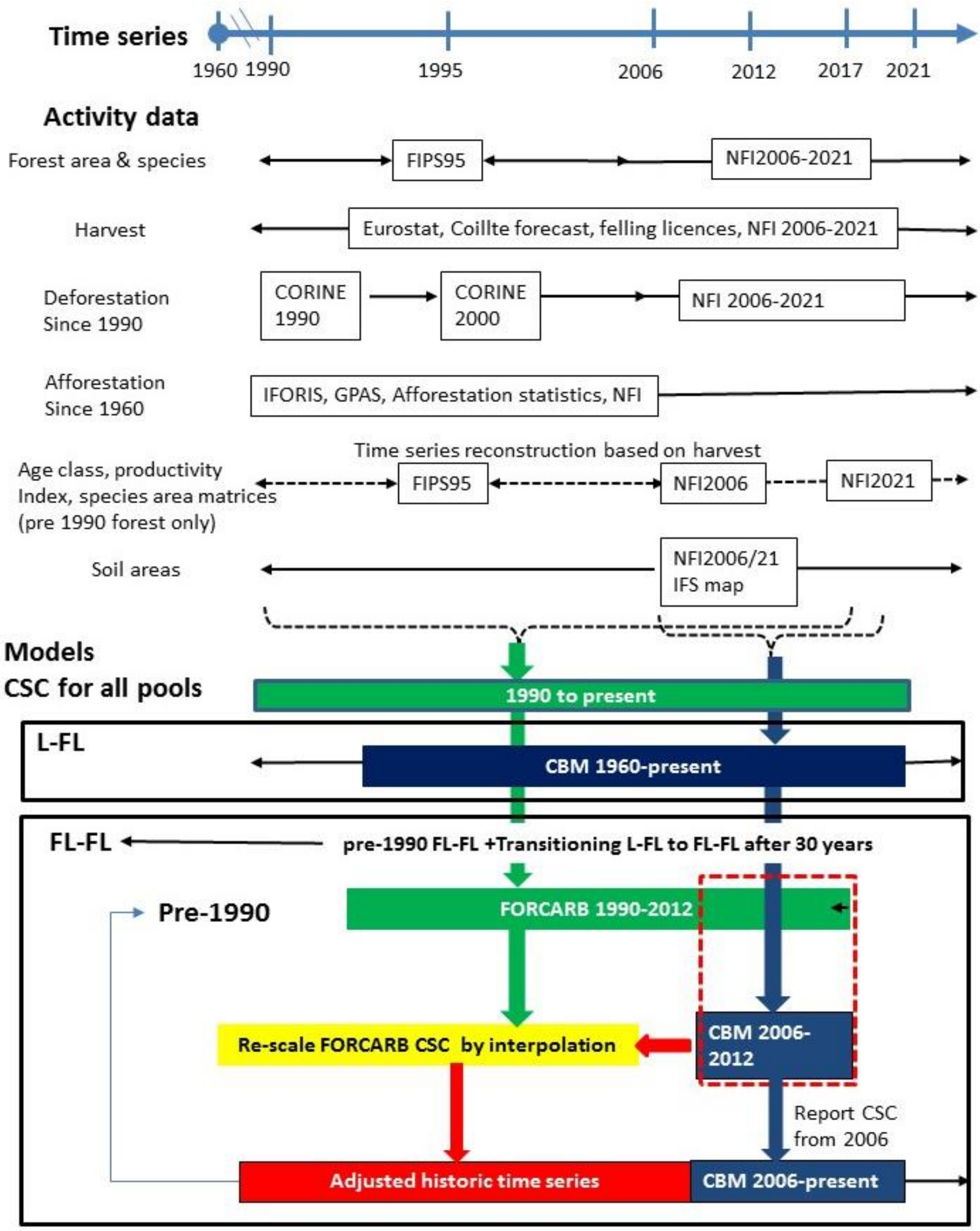


Figure 6.3 Activity data and models used to derive carbon stock changes for forest land

In order to construct a time series land converted to forest land (L-FL) using a 30-year transition, afforestation statistics and NFI was used to identify soil types of areas afforested since 1960. The relationships between afforested land, deforested land and transitions between L-FL and FL-FL is shown in detail in Annex 3.4 D.2. After 30-years from the initial transition to L-FL, remaining forest areas and associated emissions and removals area carried over to the FL-FL category (see Figure 6.3). This is done within the CFS-CBM framework where CSC and areas associated with L-FL transitioning to FL-FL are added to CSC profiles for forest lands planted before 1990 to calculate the areas and CSC for FL-FL for the time series 1990-2021 (see section 6.3.3.1 and Annex 3.4 C).

6.3.1.1 Justification for using a 30-year transition period

The default transition period of 20 years as presented in Chapter 2, Volume 4 of the 2006 IPCC guidelinesis based on assumptions relating to SOC stock changes following transition to other land uses. The default assumption is that SOC stock take 20 years to reach a steady sate after land use transitions. However, the IPCC guidelines state that the actual length of transition period depends on "natural and ecological circumstances of a particular country or region and may differ from 20 years". Irish studies show that C dynamics in soils, litter and biomass following transition to forest land may take significantly longer than 20 years (Wellock et al., 2011, Black et al., 2014, NFAP, 2020). According to paragraph 2 of article 6 of the EU LULUCF regulation ((EU) 2018/841) "a Member State may change the categorisation of transitioning land from land converted to forest land to forest land remaining forest land, 30 years after the date of that conversion, if duly justified based on the IPCC Guidelines". The CBM simulations demonstrate that the ecological circumstances for the transition period for SOC, litter and deadwood pools are longer than 30 years (NFAP, 2020). However, since the EU LULUCF regulation does not allow transition periods longer than 30 years, the 30-year transition period is adopted for reporting lands converted to forest land.

6.3.2 Detailed description of activity data

6.3.2.1 FIPS95

A full survey of the private and state forests was completed in 1996 under the Forest Service's Forest Planning and Inventory System (FIPS 95). It provides information on areas by species as identified by remote sensing (Fogarty et al 1999). This activity data is used for the determination of forest areas, species and broad age class categories for 1995 used in the FORCARB model for forest land remaining forest land category (Gallagher et al., 2004). The forest area going back to 1990 and projected forward to 2005 are derived from FIPS95 minus afforestation since 1990 (iFORIS data) and deforestation since 1990. The age class structure and yield class distribution for each year was reconstructed based on felling and replanting statistics and annual harvest data (see section 6.3). The FIPS 95 data provides no information on volume, stocking density or management of forest lands and cannot be used by the CBM-CFS3 model. However, it is used to provide historic CSC estimates for the period 1990 to 2006 using the FORCARB model, which are then subject to re-scaling using the CBM-CFS3 model estimates (Figure 6.3 and section 6.3.4.1).

6.3.2.2 IFORIS

The IFORIS database is used to derive the total area of forests established before 1990 and afforestation areas of lands converted to forests since 1990. Afforestation areas from 1960 to 1990 are provided by Forest Service statistics. Ireland adopts combined approaches 2 and 3 as set out in

Chapter 3, Volume 4 of the 2006 IPCC guidelines. Spatially explicit GIS polygons, representing all forest areas in 1995, were derived from the available FIPS 95 spatial layer. Digitised maps of afforested areas since 1990 were derived using the Grants and Premiums Administration System (GPAS), archived in the iFORIS database (Figure 6.4). After attributing the species information with the unique ID from the Species Data table, the spatial and attribute data were joined in the Premiums layer, representing all afforested land since 1990. The data was quality controlled and the reasons for records not meeting the data validation criteria were recorded by the Forest Service. There were four separate stages in the data validation process, which occurred in successive iterations. The validated data were appended together and then reformatted and quality controlled. The FIPS95 afforested areas was then erased from the resulting Premiums table to produce the Forestry07 layer. These data sources are then updated for the new grant aided afforestation scheme areas. For example, the Forestry08 layer is derived from the GPAS08 data and the Forestry07 layer (Figure 6.4). The IFORIS database is updated every year using the GPAS data. Finally, the total forest areas and afforestation area is derived directly from the GPAS and IFORIS database after removal of areas identified as deforested (see deforestation data section 6.3.2.4).

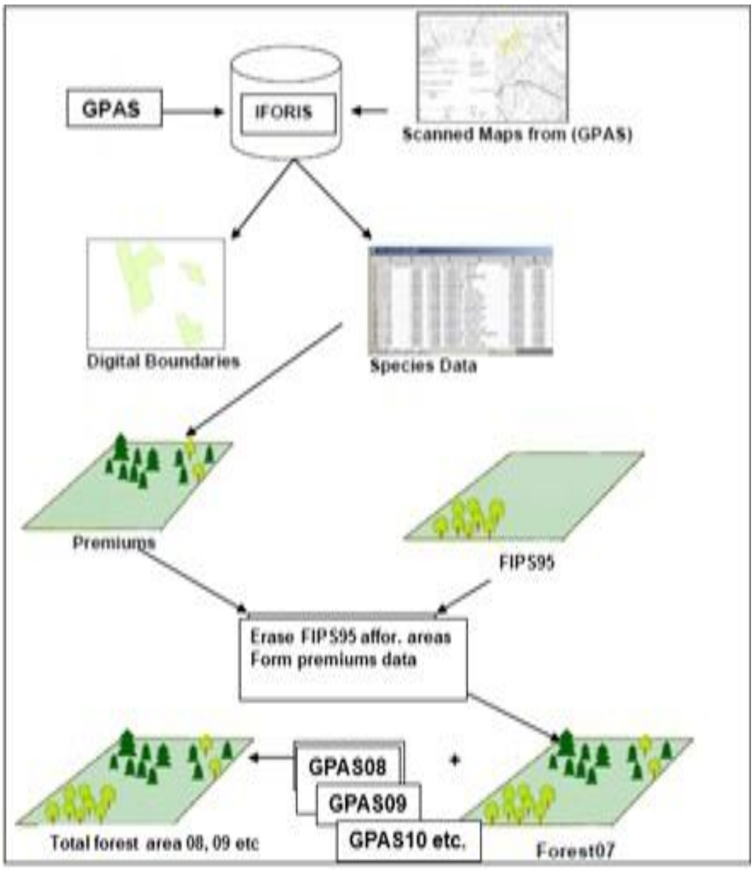


Figure 6.4 The process involved in deriving the total forest area and afforestation areas since 1990 using the IFORIS database

6.3.2.3 The National Forest Inventory

Ireland's first National Forest Inventory (NFI) was completed in 2006 using a sampling approach, based on a randomised systematic grid sample design. The second and subsequent NFIs were completed in 2012, 2017 and 2021, respectively. This system is also designed to track land use change trends. A pilot study in Co. Wexford showed that a grid resolution of 2 km x 2 km was required to provide the density of plots needed to achieve a national estimate of timber volume with a precision of 95 per cent at the 95 per cent confidence level. This grid resolution equates to 17,423 points nationally, each representing approximately 400 ha.

There are three stages of land-use classification undertaken in the NFI, primarily to identify forest areas according to the forest definition. These stages are land-use type, land-use category and land-use class (Figure 6.5). They form the basis of the NFI, as the classification process dictates whether the sample points are included in the NFI or not, and also the range of attributes to be collected at the individual sample points.

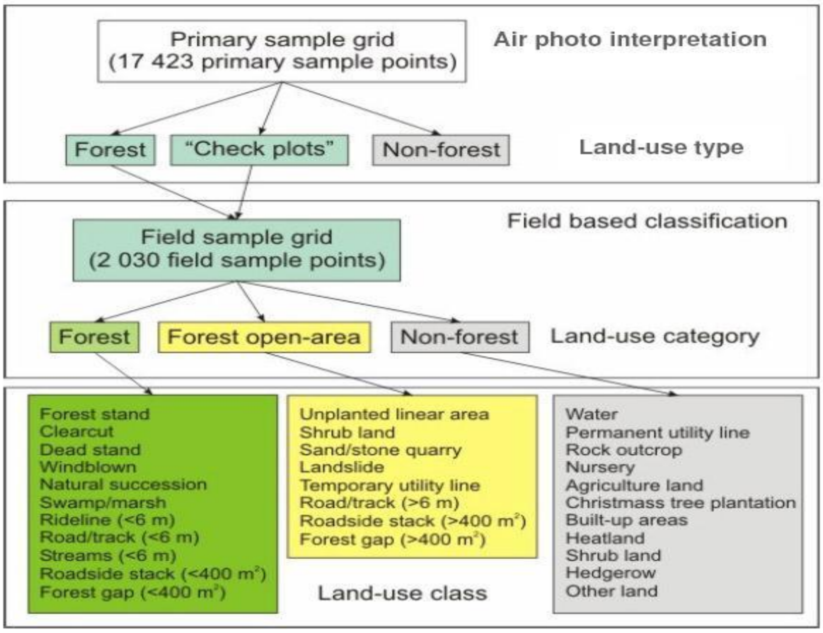
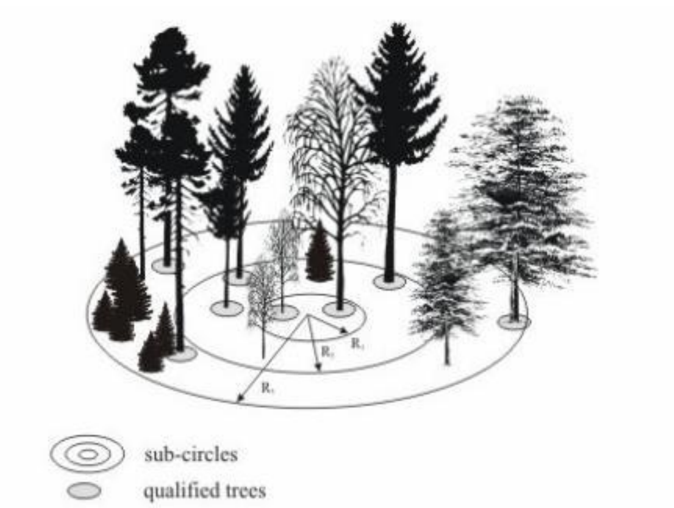


Figure 6.5 Overview of the National Forest Inventory classification system (taken from NFI, 2007a)

The 2 km x 2 km grid is overlaid on the total land base map of the Republic of Ireland to facilitate land-use type (LUT) interpretation using colour aerial photographs (OSI, 2005, Bing 2011/12 and Global viewer). The primary focus of the interpretation is to identify forest land transitions. In tandem with this, other land-use types are identified for LULUCF reporting under the Convention. The grid is permanent, and this allows for the re-assessment of primary sample points at future dates to monitor forest and other land-use change (i.e. afforestation and deforestation) when Ordnance Survey Ireland (OSI) produces the next range of ortho-rectified aerial photos (NFI, 2007).

Once a forest plot has been identified, field measurements are undertaken in established permanent plots. The exact location of the centre of ground survey plots is identified in the field by navigating to a six-digit Irish national grid co-ordinate using both GPS and electronic compass/laser technology. The total area of the circular sample plot is 500 m^2 (i.e. 25.24 m in diameter). Adjustments for slope are automatically made by the laser/range-finding equipment. The concentric circle approach, comprising three concentric circles with different radii is used for tree assessment. Trees of different dimensions are mapped and described on each plot (Figure 6.6). Individual trees in the plot are mapped and tree metrics are collected and archived in a GPS format. Forest mensuration measurements are made on selected individual trees within the plot based on the position within the plot and the threshold diameter (Figure 6.6). This information is used to estimate plot-level parameters and to scale up the measurements to 1 ha (section 6.3.3.1.3). The permanent plot data describing single tree dimensions, deadwood and plot level information is used to derive age-class, species and soil matrices to initiate the CBM-CFS3 model (see sections 6.3.4 and 6.3.5).

Soil surveys are also conducted in permanent sample plots. The soil group classification used in the NFI is a modification of the great soil groups employed in the National Soil Survey (Gardiner and Radford, 1980), with the addition of sand, making 11 great soil groups. These are brown earth, gley, regosol, grey brown podzolic, rendzina, sand, brown podzolic, basin peat, lithosol, podzol and blanket peat. For a soil to be classified as peat, the peat depth has to be greater than 30 cm (see section 6.3.5.2).



	R_1	R_2	R_3
Sub-circle radius (m)	3	7	12,62
Sub-circle area (m^2)	28,3	153,9	500
Treshold diameter (mm)	70	120	200

Figure 6.6 The concentric plot design and mapping of individual tress in the National Forest Inventory (NFI, 2007a)

Individual tree data is scaled to the plot level using proportional scaling factors (see Annex 3.4.B.3). Furthermore, since the IFORIS and other spatial data is measured at a different scale to NFI plots, scaling is done to derive area for a given strata data to the country level. For example, a PSP represents 400 ha based on a 2 x 2 km grid sample. Since the NFI only detects forest areas at a 400 ha resolution the adjustment is done using the spatial GPAS data. The same adjustment is done for all other categories and CRF reporting tables.

So for example, if the area of organic soils under forest land remaining forest land is estimated to be 4.8 kha based on NFI PSP (i.e. 12 plots out of 650 (representing a total of 260 kha plots for the afforestation categories) and the total IFORIS area is 260.47 kha, then the area is readjusted as follows:

New sub-category area (4.809 kha) = (12/650) × 260.47 (eq 6.3.1)

6.3.2.4 Harvests and Deforestation

Harvest before 2006

Harvests only occur on lands converted to forest land prior to 2006. EUROSTAT harvest data information is compiled by an external contractor on behalf of the DAFM. The EUROSTAT harvest is obtained from timber mills and information from the industry (e.g. Coillte and the private sector). Harvest data from 1961 to 2022 were compiled using national data submitted to the FAO and EUROSTAT. For the 1990-2022 time series the FAO/EUROSTAT harvested volume was used to simulate harvest in the FORECARB model (Figure 6.3). This was done by adjusting age class distributions using optimisation procedures based on the prescribed rotation age, thinning intervals and total harvest volume for each species cohort (see section 6.3.3.2). The simulated harvest was validated against the official FAO/EUROSTAT data as shown in section 6.3.4 (Table 6.7).

Harvests between 2006 and 2021

The 2006, 2012, 2017 and 2021 NFIs were used to derive harvest data for the periods after 2005. The 2012-2017 inventory cycle was chosen to represent the period up to the end of 2016 as it is the mid-point of the 3rd NFI measurement period The NFI records individual trees within permanent sample plots (PSP) that are harvested, and the indicative date of harvest based on:

I. The previous diameter at breast height (DBH) and height of the tree in the 2006/21 NFI;
II. The estimated year of harvest is based on assessment of condition of stumps and deadwood on site;
III. The volume at year of harvest is then estimated using the DBH and height in the corresponding NFIs and growth is interpolated between inventory years and extrapolated after the last available NFI using the CBM-CFS3 model (see section 6.3.3.1). Models are validated when a new inventory cycle is completed;
IV. The simulated harvest was validated against the official FAO/EUROSTAT data as shown in section 6.3.4 (Table 6.7).

Harvests from all forest land increased from 1.67 Mm^3 in 1990 to 4.33 Mm^3 in 2021 due to an increase in forest cover and changes in the age class structure and clear fell of more crops at rotation age. Most harvest occurred in forest land remaining forest land (CRF 4.A.1) which also increased from ca. 0.88 Mm^3 in 1990 to 3.59 Mm^3 by 2021 (Table 6.6). Harvest from lands converted to forest land were mainly associated with thinning's and some clear felling of highly productive rotation forests before stand age of 30 years. The total timber volumes harvested from the areas L-FL was 0.78 Mm^3 in 1990 increasing to 0.88 Mm^3 by 2014 and subsequently reducing to 1.33 Mm^3 in 2019 and subsequently decreasing to 0.74 Mm^3 in 2021 (Table 6.13). Harvests from the Coillte lands (state forest) represented ca. 71 per cent of the total timber harvest for the period 2017-2021 (NFI, 2021). Approximately 65 per cent of the afforestation area is privately owned, where thinnings are not commonly carried out because of limited road access to sites and the small fragmented nature of private forest, making it economically unviable to thin forest stands. NFI analysis suggests that 66 per cent of grant-aided stands, are not thinned.

Harvests after 2021

To derive harvest after 2021 from Coillte (State owned) forests, the NFI sample plot co-ordinates and Coillte sub-compartment polygons were intersected to produce a layer representing NFI-Coillte plots with harvest management statistics (Figure 6.7).

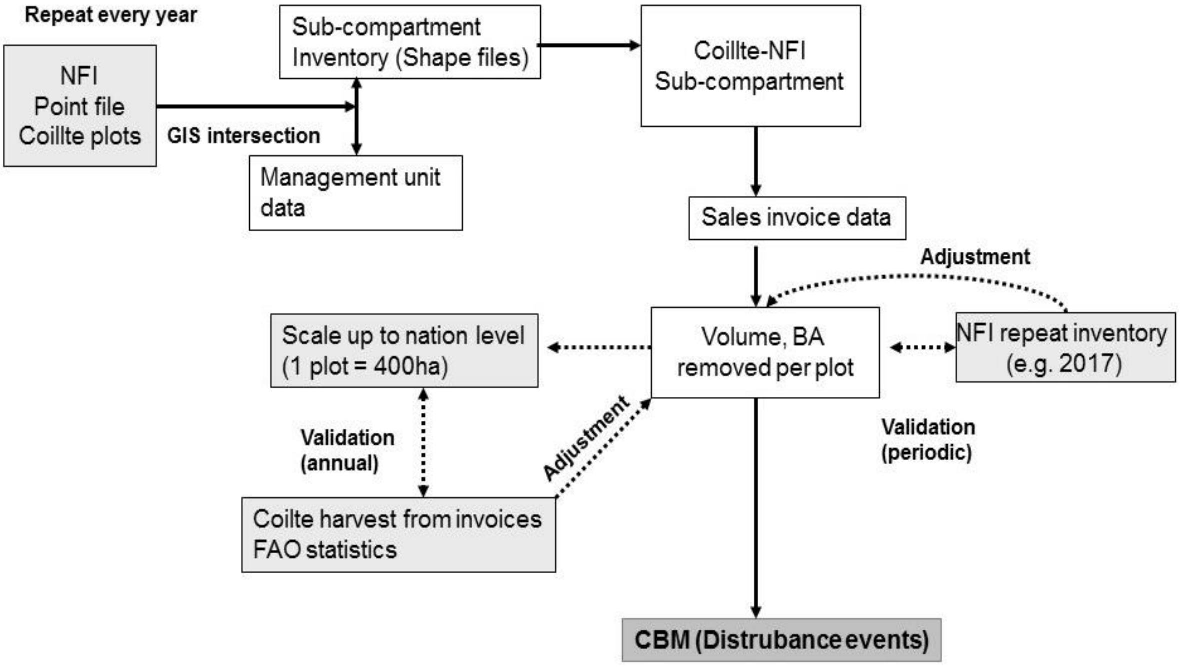


Figure 6.7 Methodology used to derive harvest information for post 1990 State Forest

Harvested volume and basal area removed during harvest was assigned to individual NFI plots, representing 400 ha, based on Coillte Forecast plans. The total volume removed in a given year was validated against independently derived FAO/Eurostat data and Coillte sales invoice information. The harvest data is used to populate the clearfell and thinnings in the 'Disturbance Events' table in the Archive Index Database (AIDB) in CBM-CFS3 model to simulate the harvesting of trees. A final validation is performed in CBM-CFS3 to ensure that the expected and simulated harvest rates are consistent (Figure 6.7). It will be possible in the future to re-evaluate 'ground truthed data' from repeat NFI inventories of harvested plots, where adjustment can be made to the harvest volumes based on new PSP information. To derive harvests from private forests, a GIS layer was created by intersection of Townland boundaries and names (OSI) and the GPAS layer compartments (Figure 6.8) that contain NFI plots. This layer contains attributes which identifies permanent sample plots which may be subjected to harvesting activities as supplied on felling licence application forms (Figure 6.8). Once this layer is updated every year the Forest Service carries out the following checks:

i. Forest inspectors open the GIS attribute table to check if the Townland in question (as specified on felling licence application) contains a sample compartment.
ii. If there is a sample compartment in the Townland, then an aerial photo layer is used to locate the compartment as indicated in the OSI map in the hardcopy of the felling licence application.
iii. Once the compartment is located, a shaded area within or covering the entire area should be identified once the GIS layer is switched on. The shaded area will contain a unique number which is used as a reference (name - FID number).
iv. The inspector can then contact the contractor or owner to obtain information on area, species, volume and basal area removed due to harvest.

The scaled up total volume removed in each year is compared against independently derived FAO/Eurostat information and adjusted if required. The harvest data is used to populate the clearfell and thinnings in the "Disturbance Events" table in the AIDB database in the CBM-CFS3 model to simulate the harvesting of tress. A final validation is performed in CBM-CFS3 model to ensure that the expected and simulated harvest rates are consistent (Figure 6.8).

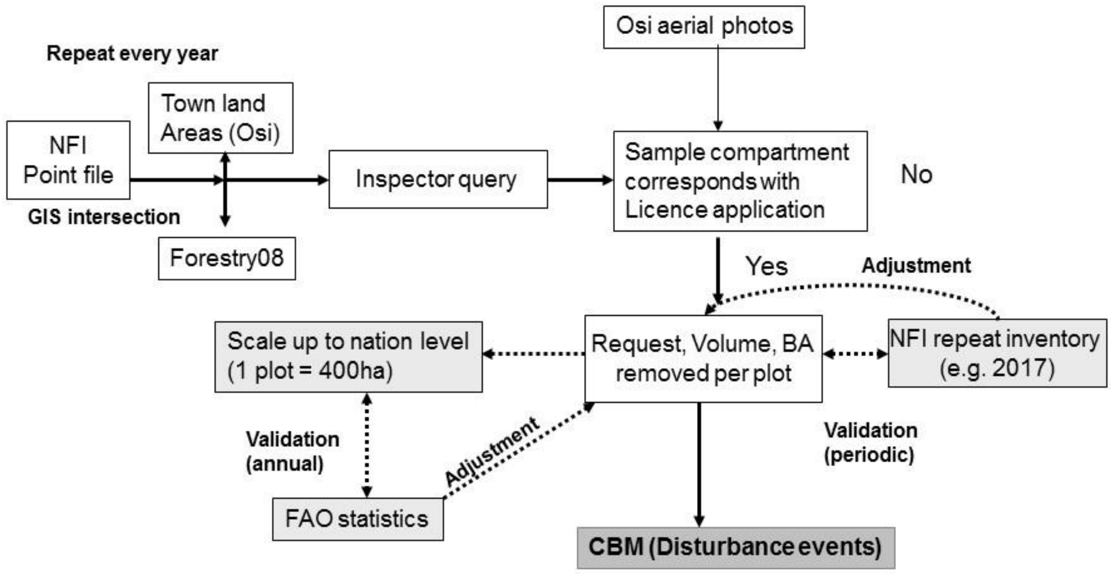


Figure 6.8 Procedure used to derive harvest activity data for private forested areas

Deforestation

Clear-felled areas, which were not restocked within 5 years between NFI's or if there was clear indication of land use change, were deemed to be deforested. The following approaches are used to determine deforestation areas. (see Annex 3.4.A):

1) Sampling approach: NFI grid points and aerial photography (see Annex 3.4.A.2)

This is a modification of 2006 IPCC guidelines approach 3, where the grids or centroids are sampled using a systematic sampling procedure adopted in the NFI. Assessment of 17,423 NFI point intersects with aerial photographs form 2000 and 2006 provides the opportunity to report deforestation for this period. This method identified 15 NFI PSP grid samples, which were deemed to be deforested between 2000 and 2006. The current land uses of these previously deforested lands were determined from photo interpretation using the 2006 images.

Assessments of deforestation from 1995 to 2000 were based on a GIS intersection of the 17,423 NFI plots with the FIPS 95 forest parcel polygon layer. This exercise produced 105 forest parcels, which were classified as forest in the FIPS 1995 dataset, but then re- classified as non-forest land in the NFI aerial photography 2000 interpretation. These 105 polygons were cross-checked with 1995 black and white aerial photographs to verify that they were forests in 1995. However, most of the sampled forest polygons were deemed to not be deforested or were originally other land uses in 1995. This was due to original FIPS 95 interpretation inconsistencies of photographs and mapping errors in the FIPS95 layer. Only 5 NFI sample points were identified to be deforested between 1995 and 2000. Although it is recognised that a grid-based sample introduces a high level of uncertainty due to the poor resolution of detecting highly fragmented deforestation, this is the only available data set for this time series. Importantly these uncertainties should not introduce bias, because deforestation could be both over and underestimated using this approach.

The final deforestation-land use change-soils matrices for 1995-2000 and 2000-2006 were obtained by intersecting identified deforested sample points with the national soils map database (Indicative Forest Soils (IFS), see Annex 3.4.A.2).

2) Tracking deforestation using CORINE Land cover (CLC) data sets (see Annex 3.4.A.1)

Although CORINE forms some of the activity data used to establish land use matrices, classification and resolution problems have been highlighted in comparative studies across Europe (Black et al., 2009; Hazeu and De Wit 2004, Cruickshank and Tomlinson 1996). Despite the abovementioned inappropriateness of CLC for reporting areas under LULUCF in a representative and accurate manner, this is the only data currently available to track historic deforestation prior to FIPS 95 (see method 1 above).

For this exercise, the CLC codes 311 (conifers), 312 (broadleaves) and 313 (mixed woodlands) were extracted to represent forest land area that were present in 1990. The transitional land cover classes were re-classified into the LULUCF land use categories to identify land uses following deforestation. The resulting polygons were then intersected with an IFS map using ARCGIS to derive a land use change and soil type matrix for the periods 1990 to 1995.

3) Modification to deforestation records from 2006-2021 using the NFI

The NFI 2021 and previous NFIs are used to derive deforestation data for the period 2006 to 2021. A unit of land is defined as deforested land if there is a clear indication of land use change, either from limited felling licences or aerial photography and a permanent sample point, which was recorded as unplanted previously clear-felled land in the previous inventory, is still unplanted at the time of the subsequent inventory. The NFI programme will also continue to monitor whether clear felled forest land is replanted.

6.3.2.5 Activity Data for Afforestation Areas

Afforestation areas were derived from IFORIS data (Figure 6.4). Activity data of land afforested since 2006 is derived from the NFI.

Activity Data for Afforestation Areas after 2021

Activity data of land afforested since 2021, after the completion of the third NFI, was derived by GIS analysis of the updated Premium Layer (Figure 6.4), a digitised map of indicative forest soils (IFS) and intersection with NFI grid co-ordinates (Figure 6.9). The resulting species/soil matrix was used to derive species productivity classes for the CBM-CFS3 model.

The soils and land cover datasets were derived from a number of map sources, remotely sensed and ground-truthed data. A land cover map with a minimum resolution of 1 ha was derived using aerial photography and satellite imagery (Fealy et al., 2006). The land cover mapping exercise used the known occurrence of grassland types in Ireland and their relation to soils. Thematic classes include grassland, bog and heath, rocky complexes, bare rock, forest (unenclosed) and scrub, urban land, coastal complexes, and water bodies. The land cover dataset was derived primarily from remotely sensed data, including 1995 Landsat TM satellite imagery, 1995 black and white stereo aerial photography and 2001 ETM satellite imagery.

A digital soil mapping project delivered soil and subsoil/parent material maps by extending information obtained from various surveys using a soil cover model (Fealy et al., 2006). Over 40 per cent of the dataset is a direct derivative of the National Soil Survey (Gardiner and Radford 1980) and has a minimum mapping unit of 1 ha. Subsequently, the FIPS-IFS project produced a firstapproximation soil classification for those areas not previously surveyed by the National Soil Survey (NSS), using a methodology based on remote sensing and GIS. A modelling approach was then adopted to produce a projected map for Ireland using a modular system based on different soil/peat forming factors, such as sub-soils, parent material, vegetation and topography (Fealy et al., 2006 and Loftus et al., 2002). These maps were then combined to create a predictive model of soil/peat occurrence, which is represented in GIS map form.

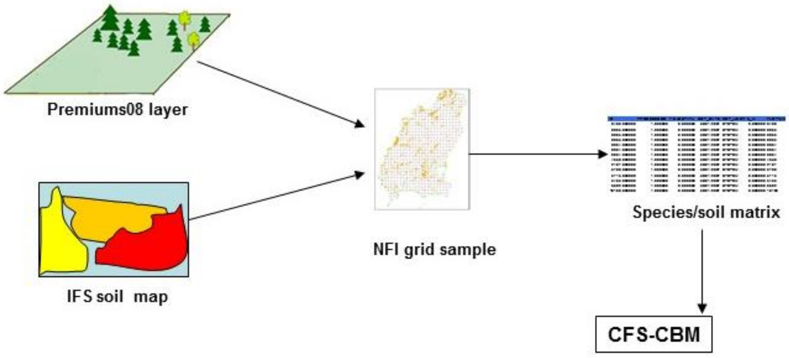


Figure 6.9 Procedure to derive activity data for Afforestation areas after 2020

Previous land use 1990-2000

Initially, the lands converted to forestry were of relatively poor quality, with marginal potential for economic returns under agricultural practices. In more recent years, and especially with the increase in private afforestation, land of higher quality has been converted to forestry, reflecting improved grant-aid under the afforestation programme, the decline in economic returns from conventional farming practices and a preference for less labour-intensive land usage. For deriving the previous land use prior to afforestation between 1990 and 2000 the CORINE 1990-2000 Land Cover Map of Ireland (level 6) was overlaid on NFI sample plots. This overlay combination delineated the individual areas and underlying soil type of afforested lands. It also revealed the plantation date and gave an indication of the previous land use. The previous land use given by CORINE was used as a general guidance.

Based on this analysis of *4.A.2. Land Converted to Forest Land* a constant proportion for land use transitions were applied, where *4.A.2.3 Wetlands Converted to Forest Land* account for 54 per cent of the total area; *4.A.2.2 Grassland Converted to Forest Land* account for 46 per cent of the total area converted to forest in any given year between 1990 and 2000. Additional disaggregation into soil types under each land use transition is also applied to enable the calculation of emissions from organic soils.

Previous land use 2006-2020

The land use prior to afforestation for 2006-2020 was derived using the 2006 and 2021 NFI data (see section 6.3.2.3 and Figure 6.5). Based on this analysis *4.A.2.3 Wetlands Converted to Forest Land* account for 13 per cent of the total area; *4.A.2.2 Grassland Converted to Forest Land* account for 87 per cent of the total area converted to forest. Additional disaggregation into soil types based on NFI data under each land use transition is also applied to enable the calculation of emissions from organic soils.

Previous land use 2000-2006

The percentage of previous land use between 2000 and 2006 were derived from interpolation of the 1990-2000 and 2006-2021 time series. Based on this analysis of *4.A.2. Land Converted to Forest Land* a constant proportion for land use transitions were applied, where *4.A.2.3 Wetlands Converted to Forest Land* account for 54 per cent of the total area; *4.A.2.2 Grassland Converted to Forest Land* account for 46 per cent of the total area converted to forest in any given year between 1990 and 2000. total area converted to forest in any year between 2000 and 2006.

6.3.2.6 Definition of forest areas and carbon pools

The definition of forest lands is areas with a minimum size of 0.1 hectare, a minimum width of 20 m, trees higher than 5 m and a canopy cover of more than 20 per cent within the forest boundary, or trees able to reach these thresholds *in situ*. This is consistent with the forest definition contained in Decision 16/CMP.1 (FCCC/KP/CMP/2005/8/Add.3). The following attributes are also relevant to the definition:

- A tree is a woody perennial of a species forming a single main stem or several stems, and having a definitive crown;
- A forest includes windbreaks, shelterbelts and corridors of trees with an area of more than 0.1 ha and minimum width of 20 m;
- Forest is determined both by the presence of trees/stumps and the absence of other predominant land-uses. Areas under re-establishment (following clearfell) that have not yet reached but are expected to reach a canopy cover of 20 per cent and a minimum tree height of 5 m are included, as are temporarily un-stocked areas, resulting from human intervention, which are expected to be restocked;
- The forest area is determined by the forest boundary. The term forest boundary is defined by any man-made boundary enclosing the forest area or, in the absence of such boundary feature, the boundary of the forest is determined by extending out 1 m from the position of the pith-line of the outermost trees (NFI, 2007a);
- The forest area includes forest roads and other open areas on forest land; forest in national parks, nature reserves and other protected areas such as those of specific scientific, historical, cultural or spiritual interest;
- The forest area excludes tree stands in agricultural production systems, for example in fruit plantations and Christmas tree plantations since these generally do not reach 5m in height;
- The term forest also includes trees in urban parks and gardens, provided these areas satisfy the forest definition.
- Semi-natural forests. There are no unmanaged, natural forests in Ireland. The NFI defines semi-natural forest as native woodlands generally established by natural regeneration, i.e. greater than 80% of the tree species regenerated naturally. Native and non-native tree species are included. This forest land may not be managed in accordance with a formal or an informal plan applied regularly over a sufficiently long period (5 years or more). However, all semi-natural forests are managed for biodiversity, public amenity and pest or disease control. Semi-natural forests are classified as special areas of conservation (SAC) under the National Parks and Wildlife Service (NPWS), and these areas cannot be converted for plantations forests. However, plantation forests can be converted to semi natural forests under the native woodland scheme (NWS) but either managing the forest to enable regeneration of native woodland species or by planting native trees to regenerate to a native woodland. These changes are tracked by the NFI.

Table 6.4 Definition of carbon pools used in LULUCF reporting

LULUCF	Definition
Aboveground biomass	All biomass above stump height (1 % of tree height)
Belowground biomass	Biomass below stump height including roots up to a diameter of 2mm
Deadwood	Standing deadwood, dead stumps, roots (min 2 mm) and logs (min 7cm diameter)
Litter[a]	Needles, leaves and branches up to a diameter of 7cm
Mineral soil	SOC of less than 20% (reported to max depth of 30cm)
Organic soil	SOC of > 20% and depth > 30cm
Organo-mineral soil	Mineral soil with a top organic soil of depth < 30cm

[a]Note: For LULUCF reporting in the CRF table 4A1 and 4A2, litter pools are reported as IE under deadwood. This is because the FORECARB model used to estimate CSC for the historical time series does not differentiate between litter and deadwood pools.

6.3.3 Description of carbon models used

6.3.3.1 CBM-CFS3

Estimation of carbon stock changes by all forests are estimated using a tier 3 model, CBM-CFS3. A detailed description of CBM-CFS3 is outlined by Kurz, et al., (2009). This framework has been selected due to its widespread use in Canada and other EU member states (Grassi et al., 2018, Pilli et al., 2013; 2016). The model replaces the previously developed CARBWARE model (Black, 2016; NIR, 2017) because of a more complete treatment of dead organic matter pools (see QA/QC section). The model integrates NFI data (stands age, area, species, productivity classes and soil types), merchantable volume increment curves, equations to convert volume to biomass components, data on disturbances (see section 6.3.2) and simulates transfers of C between pools and the atmosphere (Figure 6.10). The equations and parameter values for growth, biomass to volume conversions, biomass components, turnover and C transfers for each species, management and disturbance type is defined in an Archive Index Database (AIDB, Kull et al., 2016)

There are 21 C pools in CBM-CFS3, but these match the 5 basic IPCC forest C pools (Table 6.5). The ecosystem process events are simulated as C transfers between C pools on an annual time step (Figure 6.10). Carbon taken up by biomass (net growth) is determined by the volume increment curves (Annex 3.4.B.5) and biomass conversion equations for each species cohort in CBM-CFS3(see Annex 3.4.B.4). Some of the biomass C is transferred to the DOM pool due to mortality and turn over (Figure 6.10).

CBM-CFS3 simulates mortality and litter fall to represent transfers of C from biomass to other DOM pools resulting from tree, foliage, branch, and root mortality (Kurtz et al., 2009). Country specific turnover rates and transfer rates between DOM pools are specified in the AIDB (Microsoft Access database behind CBM-CFS3) (Kull et al., 2016 and Annex 3.4.B.6). Inputs into and emissions from the DOM pool generally increases as mortality or harvests increases. Decomposition of DOM pools are modelled using a temperature-dependent decay rate function (Kurz er al., 2009). This is the only climate depended relationship used in CBM-CFS3. The annual mean temperature for all regions in Ireland is set to 9.5 deg C in the AIDB database of the CBM-CFS3.

Table 6.5 IPCC and CBM-CFS3 carbon pools

IPCC Carbon Pools	**Pool Names in CBM-CFS3**
Living Biomass	
Above-ground biomass	Merchantable stemwood
	Other (sub-merchantable stemwood, tops, branches, stumps, non-merchantable trees)
	Foliage
Below-ground biomass	Coarse roots
	Fine roots
Dead Organic matter (DOM)	
Deadwood	Below-ground fast
	Medium
	Softwood stem snag
	Softwood branch snag
	Hardwood stem snag
	Hardwood branch snag
Litter	Above-ground very fast
	Above-ground fast
	Above-ground slow
Soils	
Soil organic matter	Below-ground very fast
	Below-ground slow
	Black carbon[1]
	Peat[1]

[1] Black carbon and peat are currently not estimated in CBM-CFS3

Disturbance (harvest, afforestation, etc.) impacts are defined using a matrix that describes the proportion of C transferred between pools, as fluxes to the atmosphere, and as transfers to the DOM pools or the timber sector (see Figure 6.10). These are specific transfers between C pools for each disturbance type as defined in the AIDB (Annex 3.4B.7). Harvested timber (products), less harvest residue is then allocated to a separate HWP model (Figure 6.10).

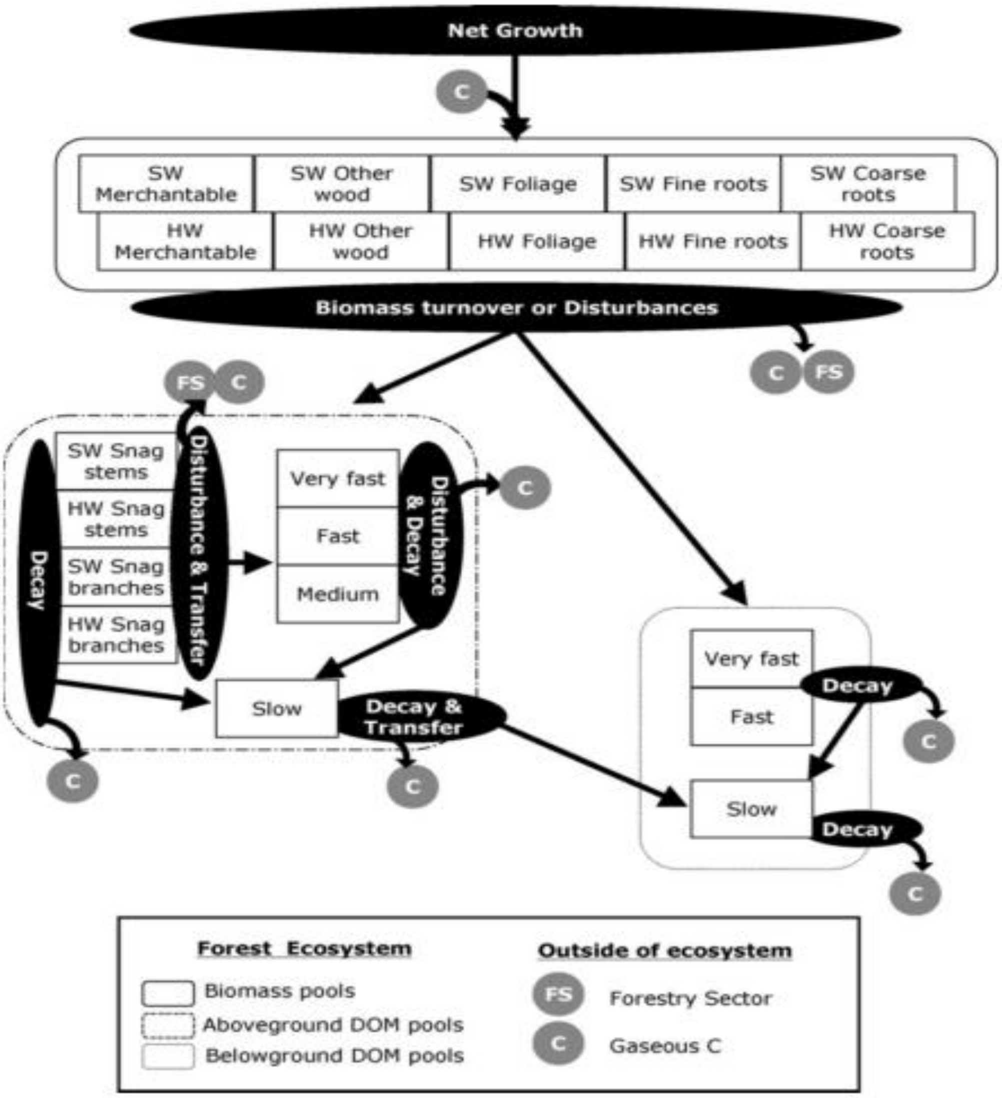


Figure 6.10 A schematic summary of how annual processes and carbon transfer between pools are simulated in the CBM-CFS3 model* (taken directly from Kurz et al., 2009).

*Note that forestry sector (FS) products (i.e. Harvests) are allocated to the HWP model (see section 6.3.7)

Model inputs and controls (simulation databases)

The spatial framework applied by the CBM-CFS3 conceptually follows IPCC reporting method 1 (IPCC GPG, 2006). It uses spatial units defined by their geographic boundaries and all forest stands are geographically referenced to a given spatial unit (SPU). In Ireland, only 1 administrative unit and 1 climatic unit is used (i.e. 1 SPU). This is because of the homogeneous nature of forests and climatic zone within the country. Forest stands are categorised by species cohorts and productivity strata (see Annex 3.4.B.1). These strata have defined yield curves and silvicultural systems (Annex 3.4.B.2). The state of the forest (i.e. the age class structure and area breakdown of species cohorts) with defined management types and soil types is defined using NFI data (Figure 6.3, Annex 3.4.B.1). These age class distributions are redefined after the completion of each NFI cycle. For afforestation scenarios a non-forest area matrix is defined, which specifies the areas available for afforestation since 1990 based on species and soil type (Annex 3.4.B.1). The age class for defined species and management types are specified in an inventory table in the Simulation database.

Scheduling the timing of timber harvests for each species and management type is controlled by a disturbance event table (in the Simulation database), which defines the minimum forest age and biomass available for clear fell, the minimum and maximum forest age for thinning, and the thinning interval. The amount of timber to be harvested (target harvest) for each management scenario and species is specified for each time step. All clear-felled forests are assumed to be replanted after 2 years unless a deforestation disturbance is specified. The total annual target harvest is derived from EUROSTAT data and disaggregated between species and management types based on NFI harvest information. A QA/QC script is run after each simulation to check if the target and obtained harvest is the same. Deforestation areas biomass for each time step is derived using NFI or felling licence information (section 6.2.3.4).

The CBM-CFS3 model runs include sperate simulations for land converted to forest land and for forest land remaining forest land. The program automatically transfers C stock and C stock from the land converted to forest land category to the forest land remaining forest land category after a transition period of 30 years. In order to develop a time series form 1990 onward for the land converted to forest land category the CBM model includes all afforestation land since 1960.

Rationale and assumptions used for DOM simulations

The separate CBM-CFS3 model runs are also implemented to ensure that litter, deadwood and mineral soil pool stock changes from afforestation prior to 1990 (i.e 1960-1990) over the 30-year transition period for land converted to forest land simulation, C stocks for all DOM pools (see Table 6.5), with the exception of the very slow belowground pool (i.e. SOC stocks of the previous land use see Annex 3.4.B.1.), are set to zero (Kurz et al., 2009). After the implementation of the first afforestation event in 1960, DOM CSC changes are simulated based on disturbances, turnover and inputs from growing forest biomass, decomposition from DOM pools and transfer rates between DOM pools (see Kurz et al., 2009, Annex 3.4B.6 and 3.4.B.7). The program then automatically transfers the DOM stocks from the land converted to forest land category to the forest land remaining forest land category after the 30-year transition period.

For the land remaining forest land simulation, a model spin-up is required to ensure that DOM pools are equilibrated before initiation of the simulation (see Kurz et al., 2009). This is done using a stand initialisation function where the forest land remaining forest land area at the year of initiation is subject to a fire disturbance followed by regrowth until the biomass stocks are obtained. The model starts the initialisation will all DOM pools containing zero stocks and simulates each stand through repeated iterations of growth and fire disturbances until the sum of the slow above and belowground slow DOM C pools at the end of two successive iterations meets a difference tolerance of <1% (i.e. equilibrium). This is done to minimise model artefacts appearing as changes in DOM pools at the beginning of the model run and to ensure that DOM pools reflect changes in the disturbances (including afforestation), management or species at the start of the simulation, relative to historical conditions (Kurz et al., 2009). The underlying assumption is DOM stocks are at equilibrium and reflect historical impacts on DOM pools at the start of the simulation.

6.3.3.2 FORCARB

The FORCARB model (described in Annex 3.4.C) was used to calculate carbon stock changes in biomass and DOM pools in forest land remaining forest land for 1990 to 2005. For the time series adjustment of derived C pools, the FORCARB model was run until 2012 and the 1990 to 2006 time series data was re-scaled using the CBM-CFS3 2006 to 2012 data (see section Annex 3.4 C-1) based on the tier 1 2006 IPCC guidelines time series overlap approaches (Volume 1, Chapter 5).

6.3.4 Forest land remaining forest land (CRF 4.A.1)

All forest lands in Ireland are managed. The area of forest land remaining forest land has increased from 226.3 kHa in 1990 to 495.5 kHa in 2022 due to afforestation over the periods 1960 to 1993 (Table 6.6 and CRF 4A.1). However, 21.5 Kha of forest land remaining forest land has been deforested since 1990. The forest land remaining forest land areas are dominated by plantation forestry, predominantly conifer species such as Sitka spruce and lodgepole pine, which make up 58.7 per cent of the total forest area (NFI, 2017). Ireland has a unique forest age class structure due to large legacy afforestation events in the 1950s and again since the late 1980s due to the introduction of an afforestation grant and premium scheme (Black et al., 2012). The area of forest planted on organic soil increased from 90 kHa in 1990 to 324 Kha by 2022 because a large proportion of afforested land transitioning to forest land remaining forest land are located on drained organic soils. Emissions from drained organic soils have a large impact on the GHG profile of the forest land remaining forest land area. By 2022, over 65 per cent of the area is forests planted on organic soils (Table 6.6), which are a net removal for the 1st rotation. However, these forests transition to net emission after 1 to 3 rotations depending on productivity (see Hargreaves et al., 2003; Black et al., 2023). Most of the forest land is managed as plantation forestry with silvicultural management system which have largely remained unchanged since the 1970s. Therefore, observed trends in CSCs in category 4.A.1 and related HWP are driven largely by an increase in the area and associated emissions from drained of organic soils (Table 6.6), increased harvest rates (Figure 6.11), and a shift in age-class structure (Annex 3.4, Figure 3.4.C-1).

The increase in timber harvest from 0.8 Mm^3 in 1990 to over 3.5 Mm^3 by 2022 and increase emissions for organic soils resulted in a transition from a net removal of 2,449 kt CO_2 per year in 1990 to a net emission of 1,243 kt CO_2 per year in 2022 (excl. HWP, Figure 6.11 and Table 6.6). Fluctuations in the level of harvest is consistent with the observed fluctuations in CO_2 removals and emissions. It is also evident that a decline in biomass gains, and corresponding decline in removals, since 1990 is due to a shift to the right in the age-class distribution from 1990 to 1998, which suggest a transition from a younger to an older-aged forest estate (Figure 3.4.C-1, Annex 3.4.C). From 1998 to 2006, this trend is reversed because of a larger occurrence of clearfelling and restocking of sites. The age class shift is exacerbated in afforest lands transitioning to forest land remaining forest land because many of these forests are clearfelled at an age of 30-40 years old. This is particularly evident in 2020 and 2021, where biomass gains declined, when compared to previous years, due to an increase in clearfell harvest (Table 6.6) of previously afforested land.

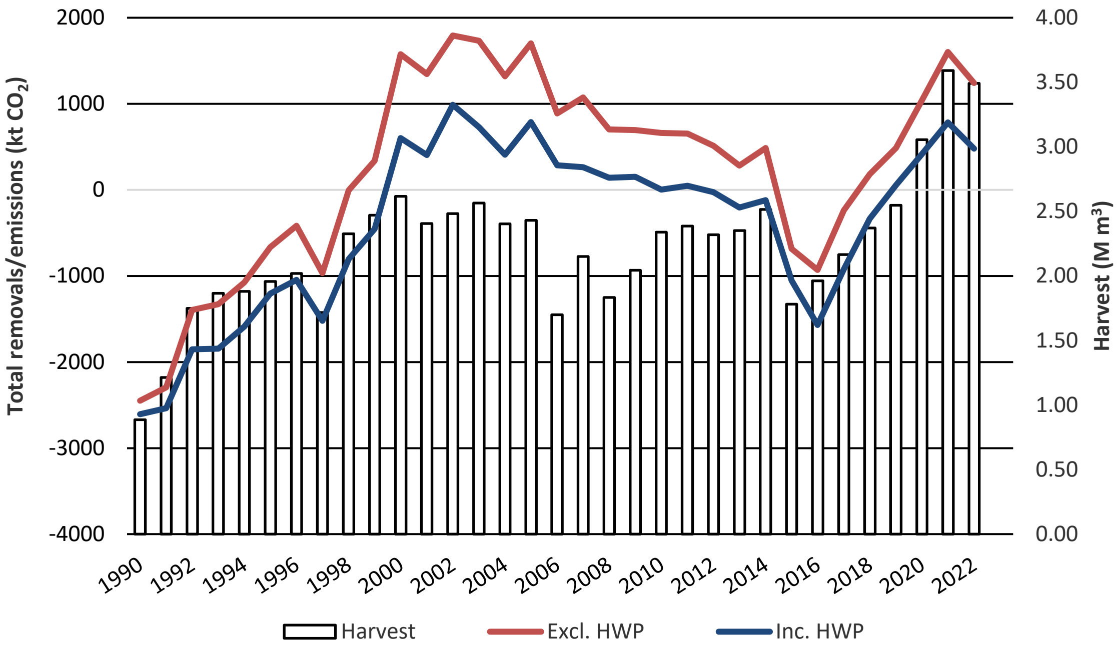


Figure 6.11 Time series of carbon stock changes (including and excluding Harvested Wood Products) and annual harvest rates for FL-FL, category 4.A.1.

6.3.4.1 Forest remaining forest land carbon stock changes

Net biomass, dead organic matter, soil C and CO_2 emissions/removals for the time series 1990-2022 for forest land remaining forest land (i.e. reported in 4.A.1) are presented in Table 6.6. For the historical time series 1990 to 2005, the adjusted FORCARB estimates are reported (see Annex 3.4.C.1). For the 2006 to 2022 time series, the CBM-CFS3 model estimates are reported.

Table 6.6 Time series data for category 4.A.1

Year	Area (kHa)		CSC (Gg C)						Net CO_2 Gg	Harvests[1] (M m³)
			Living biomass			DOM	Mineral Soils	Organic soils	CO_2	
	Total	Organic	Gain	Loss	Net	Net	Net	Net	Total	EUROSTAT
1990	226.33	90.00	2047.28	-1189.39	857.90	-58.13	-5.31	-126.31	-2449.90	0.89
1995	282.01	134.82	2274.07	-1869.13	404.95	-25.64	-6.97	-191.06	-664.67	1.96
2000	312.57	164.26	2432.33	-2451.29	-18.95	-158.11	-8.53	-243.82	1574.53	2.62
2005	347.57	195.34	2625.23	-2569.38	55.85	-206.80	-9.27	-303.90	1701.80	2.43
2010	378.51	225.28	2875.63	-2687.29	188.33	-1.02	-7.25	-360.00	659.78	2.34
2013	394.22	243.60	3021.17	-2674.84	346.33	-27.06	-8.12	-387.68	280.62	2.35
2014	399.89	249.12	3079.03	-2855.53	223.50	44.51	-4.96	-395.81	486.78	2.51
2015	404.88	253.89	3142.15	-2526.92	615.23	-13.96	-7.78	-406.61	-685.21	1.78
2016	411.32	260.15	3338.35	-2608.61	729.74	-47.79	-11.44	-416.50	-931.38	1.96
2017	419.53	269.95	3396.18	-3030.31	365.88	141.67	-8.13	-434.19	-239.20	2.16
2018	430.04	279.08	3457.94	-3147.45	310.49	99.52	-7.90	-451.25	180.14	2.37
2019	444.77	288.78	3518.47	-3312.17	206.30	138.77	-9.45	-468.45	487.03	2.55
2020	459.78	301.35	3665.21	-3557.00	108.21	90.89	-8.16	-474.37	1039.23	3.05
2021	478.93	313.77	3752.38	-3857.90	-105.52	159.59	-8.43	-482.61	1602.18	3.59
2022	495.47	323.98	3857.1	-3816.51	40.60	118.24	-9.15	-488.62	1242.77	3.49

[1] Note: the harvest volumes are calculated as total harvest (FAO/EUROSTAT) minus post-1990 forest harvests minus the deforestation harvest.
[2]Litter and deadwood pools are reported as DOM in CRF 4A.1 because there are no separate estimated for these pools where the FORECARB model was used (1990-2007)

6.3.4.2 Mineral Soils

Mineral soils CSC in category 4A.1 were estimated for the first time in the 2019 submission (Table 6.6 and CRF4A.1) using the CBM-CFS3 modelling framework (Section 6.3.3.1 and Annex 3.4.B).

6.3.4.3 Drainage of organic soils

A large proportion of forest land remaining land occurs on organic soils (Table 6.6 and 6.7), but it is important to note that some of these organic soils were degraded peatlands (upland sheep grazing areas) or rough grazing areas before initial afforestation, particularly since the 1950s. Forest soils are classified as organic soils or (peats) if the peat depth is greater than 30 cm and the organic content is greater than 20 per cent. If the organic or peat layer is less than 30cm then the soils is classified as organo-mineral (or peaty-mineral) soils. The allocation to mineral, organo-mineral and organic soils is determined separately for each year using PSP data from the 2006 and 2021 NFI, based on soil type and forest age attributes. The area of forest soils subjected to emissions/removals is obtained from a matrix of the three general soils types and the forest areas according to FIPS 07 and NFI information. The sample provides a breakdown in percentage of soil types in the forest land remaining forest land and land converted to forest land areas. The total area is scaled up using the annual area in each category. The scaled-up area is adjusted (i.e. reduced) to account for open areas in forest areas (ca. 10 per cent of the total area, NFI, 2006-2021), since these are not planted or drained and emissions are assumed to be zero.

On site emissions from peat soils due to drainage given by equation 6.3.2 is based on new published data (Jovani Sancho et al., 2021), but information on soil classification and peat depth available from the NFI is also taken into account.

$$\Delta C_{So} = \sum_i (A_i \times EF_{soil}) \quad \text{(eq 6.3.2)}$$

The area (Ai) of the 0.05 ha plots with peat soils is multiplied by 20 to scale the measurement up to 1 ha. The on-site EF_{soil} is the mean value of 1.68 t C $ha^{-1}yr^{-1}$ for all forest age classes. Emissions from peaty/mineral soils are calculated in the same way (equation 6.3.3), but a soil depth function (SD) is applied to the emission factor to account for the smaller organic carbon pool available. If soil depth is less than 30 cm then,

$$\Delta C_{So} = \sum_j (A_j \times EF_{soil} \times SD) \quad \text{(eq 6.3.3)}$$

and

$$SD = \frac{depth(cm)}{30cm} \quad \text{(eq 6.3.4)}$$

Ireland uses a country specific emission factor for organic forest soils (Jovani Sancho et al., 2021). This is calculated as the mean on site organic soil EF of 1.68 t C $ha^{-1}yr^{-1}$ over the first rotation. This Tier 2 EF is within the 95 per cent confidence interval of the Tier 1 EF for organic soils in cold wet temperate conditions and the region (2013 Wetlands Supplement to the 2006 IPCC guidelines (Table 2.1, Ch2) and published EFs for organic soils is the UK (Evans et al. (2017).

An additional off-site emission factor of 0.31 t C ha^{-1} $year^{-1}$ for dissolved organic carbon (DOC) runoff from drained organic and organo-mineral soils is applied based on guidance in the 2013 Wetlands Supplement to the 2006 IPCC guidelines (Eq 2.4 and Table 2.2, Ch2). This EF is multiplied by the area of drained organic and mineral forest soils. These emission factors have been applied to all forest over the entire time series regardless of forest age.

Table 6.7 Area (in kha) and emissions from organic soils over the time series for forest land remaining forests (CRF 4.A.1)

					Drained productive area		On-site emissions		Off-site DOC emissions		Total
Year	**Total Area[1]**	**Mineral**	**Organic**	**Open area [2]**	**Organic [3]**	**Organo-mineral[3]**	**Organic**	**Organo-mineral**	**Organic**	**Organo-mineral**	
	(kHa)						kt C				kt CO_2
1990	226.3	136.3	90.0	19.3	35.5	44.8	-59.7	-41.7	-11.0	-13.9	463.1
1995	282.0	147.2	134.8	36.8	62.2	54.2	-104.5	-50.5	-19.3	-16.8	700.6
2000	312.6	148.3	164.3	37.7	84.6	60.9	-142.0	-56.7	-26.2	-18.9	894.0
2005	347.6	152.2	195.3	34.3	110.5	67.7	-185.6	-63.1	-34.2	-21.0	1114.3
2006	352.7	153.4	199.3	29.3	114.4	70.2	-192.2	-65.5	-35.5	-21.8	1154.6
2007	358.8	154.3	204.5	28.4	118.1	72.2	-198.4	-67.4	-36.6	-22.4	1191.1
2008	364.2	154.2	209.9	27.8	121.1	75.0	-203.4	-70.2	-37.5	-23.2	1225.8
2009	372.0	154.1	217.9	29.4	126.2	77.0	-212.1	-72.4	-39.1	-23.9	1274.0
2010	378.5	153.2	225.3	30.5	131.1	78.9	-220.2	-74.7	-40.6	-24.5	1320.0
2011	383.3	151.5	231.8	31.2	135.3	80.9	-227.4	-76.4	-42.0	-25.1	1359.4
2012	389.8	151.5	238.3	31.3	140.2	82.5	-235.5	-78.3	-43.4	-25.6	1403.7
2013	394.2	150.6	243.6	36.3	142.0	83.5	-238.5	-79.3	-44.0	-25.9	1421.5
2014	399.9	150.8	249.1	37.8	146.3	83.9	-245.8	-78.6	-45.4	-26.0	1451.3
2015	404.9	151.0	253.9	37.1	149.1	86.2	-250.5	-83.1	-46.2	-26.7	1490.9
2016	411.3	151.2	260.2	38.8	152.6	88.2	-256.3	-85.5	-47.3	-27.3	1527.1
2017	419.5	149.6	270.0	38.4	159.5	91.2	-268.0	-88.5	-49.5	-28.3	1592.0
2018	430.0	151.0	279.1	38.1	166.8	93.3	-280.2	-90.4	-51.7	-28.9	1654.6
2019	444.8	156.0	288.8	38.4	173.8	95.7	-292.0	-92.8	-53.9	-29.7	1717.6
2020	459.8	158.4	301.3	47.8	175.6	97.6	-295.1	-94.6	-54.5	-30.2	1739.4
2021	478.9	165.2	313.8	56.1	178.2	100.1	-299.3	-97.0	-55.2	-31.0	1769.6
2022	495.5	171.5	324.0	62.3	180.0	101.9	-302.4	-98.8	-55.8	-31.6	1791.6

[1] Total area includes open areas

[2] Open area within forest areas (roads, extraction routes, biodiversity etc).

[3] Area of drained organic (org.) and organo-mineral soils based in NFI 2006 to 2021 (excluding open areas). Organic soils include all soils with a > 20% C and an organic layer greater than 30 cm (e.g. Blanket peats, fens, cutaway peats. Organo-mineral soils are mineral soils with an organic overlay of < 30cm. These include peaty podzols and peaty gleys (Source NFI).

6.3.4.4 Emissions from Biomass Burning

Estimates of emissions from forest biomass burning in Ireland relate to forest wildfires. The target biomass subject for fires is set as a disturbance in the CBM-CFS3 model. This allows the simulation of the loss in biomass and DOM C stock and regrowth due to fire. The disturbance matrix for fires in the CBM-CFS3 model assumes all biomass and DOM is burned. Emissions from fires are based on the following methods and assumptions:

1) All fires are assumed to occur in all forest land classes under *4.A.1 Forest Land Remaining Forest Land* and *4.A.2 Land Converted to Forest Land*. However, because no geographically explicit data on fires are available to distinguish between fires occurring in these categories, these are equally distributed between the two categories based on the proportional area of these categories from 2007 onwards (Table 6.8). This assumption is made because there is evidence that fires generally only occur in forest at the pre-thicket stage of growth when there is enough woody biomass to act as a source for combustion by wildfires;
2) Emissions from the burning of forest biomass and DOM pools are calculated using tier 2 approaches. A carbon release factor of 0.4 is used for wildfires, with emission ratios for methane and nitrous oxide of 0.012 and 0.007, respectively (2006 IPCC Guidelines Table 3 A 1.15). For nitrous oxide a C:N ratio of 0.01 is assumed. The overall implied emission factor for all GHGs as reported in CRF 4(V) is 290 t CO_2 eq ha^{-1} compared to an IEF of 39 t CO_2 eq ha^{-1} when the default values applied as specified in Eq 2.27, Table 2.4, 2.5 and 2.6 in Ch 2 (vol 4) of the 2006 IPCC Guidelines;
3) Emissions directly resulting from fire (i.e. combustion) are included for all years from 1990 (Table 6.9). Data on forest areas were obtained from the Forest assessment reports, reconstitution grant data for grant aided forests and the state-owned forest company (Coillte);
4) Biomass burned per hectare includes all aboveground biomass, litter and deadwood. However, no activity data exists documenting the amount of timber or biomass burned. Therefore, for the forest land remaining forest land category, the average biomass input for combustion is based on an average aboveground biomass C stock for a yield class (YC) 16 crop over a standard rotation- 74.2 t C ha^{-1}, equivalent to 149,450 kg biomass d.wt ha^{-1}. The average C stock for litter and deadwood is estimated to be 14.1 t C ha^{-1}, equivalent to 28,263 kg biomass d.wt ha^{-1}. For the land converted to forest land category, the average aboveground biomass C stock of a 18 year old YC 16 crop is 45.3 t C ha^{-1}, equivalent to 90,526 kg biomass d.wt ha^{-1}. The average C stock for litter and deadwood is estimated to be 6.5 t C ha^{-1}, equivalent to 12,959 kg biomass d.wt ha^{-1};
5) The indirect effect of fires on carbon stock changes include those associated with loss of productivity of the area after fire and re-growth following re-planting, which is assumed to occur in the following year. It is assumed that changes in the area of forest remaining forest due to fire before 1995 were already captured by the FIPS 1995 data underlying the FORCARB model. Therefore, the indirect effects of fires and replanting on carbon stock changes, excluding the direct emission due to combustion, were only applied for the years from 1995 onwards. These are included in CRF Table 4.A.1 since they represent areas replanted.

Table 6.8 Area statistics and emission profiles over the time series 1990 to 2022 for wildfires in categories 4.A.1 and 4.A.2 and reported in CRF Table 4(V)

	Forest land remaining forest land (4A1)							Land converted to forest land (4A2)						Total CRF4V
	Fire area	**Prop area burned**	**Biom&DOM**	**CO_2**	**CH_4**	**N_2O**	**kt CO_2 eq**	**Prop area burned**	**Biom&DOM**	**CO_2**	**CH_4**	**N_2O**	**kt CO_2 eq**	**kt CO_2 eq**
	Ha		**Mg**	**Gg**					**Mg**	**Gg**				
1990	386.25	0.47	32294230.13	47.36	0.21	0.0012	53.47	0.53	21166036.79	31.04	0.14	0.0008	35.05	88.52
1995	595.44	0.49	51837369.52	76.03	0.33	0.0019	85.83	0.51	31433115.60	46.10	0.20	0.0012	52.05	137.88
2000	316.22	0.48	27141486.30	39.81	0.17	0.0010	44.94	0.52	16919177.68	24.81	0.11	0.0006	28.01	72.95
2005	115.00	0.49	10113554.43	14.83	0.06	0.0004	16.75	0.51	6011538.43	8.82	0.04	0.0002	9.95	26.70
2010	1475.62	0.52	135678809.79	199.00	0.87	0.0051	224.65	0.48	73697273.66	108.09	0.47	0.0028	122.02	346.68
2011	1529.32	0.52	141412887.65	207.41	0.91	0.0053	234.15	0.48	75915083.86	111.34	0.49	0.0028	125.70	359.84
2012	44.91	0.52	4189957.78	6.15	0.03	0.0002	6.94	0.48	2207574.44	3.24	0.01	0.0001	3.66	10.59
2013	394.10	0.53	36954879.50	54.20	0.24	0.0014	61.19	0.47	19264362.09	28.25	0.12	0.0007	31.90	93.09
2014	328.47	0.53	31004745.31	45.47	0.20	0.0012	51.34	0.47	15937751.06	23.38	0.10	0.0006	26.39	77.73
2015	184.17	0.53	17472961.29	25.63	0.11	0.0007	28.93	0.47	8883825.32	13.03	0.06	0.0003	14.71	43.64
2016	37.41	0.54	3581970.90	5.25	0.02	0.0001	5.93	0.46	1785083.29	2.62	0.01	0.0001	2.96	8.89
2017	1960.00	0.55	190191642.14	278.95	1.22	0.0071	314.91	0.45	92079841.36	135.05	0.59	0.0034	152.46	467.37
2018	500.00	0.56	49601059.60	72.75	0.32	0.0019	82.13	0.44	22859236.90	33.53	0.15	0.0009	37.85	119.98
2019	57.33	0.58	5858944.58	8.59	0.04	0.0002	9.70	0.42	2521064.54	3.70	0.02	0.0001	4.17	13.88
2020	300.00	0.59	31642961.54	46.41	0.20	0.0012	52.39	0.41	12619440.03	18.51	0.08	0.0005	20.89	73.29
2021	100.00	0.62	10956102.05	16.07	0.07	0.0004	18.14	0.38	3968635.46	5.82	0.03	0.0001	6.57	24.71
2022	100.00	0.63	11280940.95	16.55	0.07	0.0004	18.68	0.37	3779477.66	5.54	0.02	0.0001	6.26	24.94

6.3.4.5 Direct and indirect emissions of N_2O from organic and inorganic fertilisers

Ireland does not report separately the emissions of N_2O due to nitrogen fertiliser use for *4.A Forest Land*. The amount of synthetic fertiliser used in forests is negligible compared to that used in Agriculture. Nitrous oxide emissions from fertiliser applications are based on national fertiliser sales data reported under Agriculture. The notation key IE is therefore used in CRF Table 4(I).

6.3.4.6 Emissions of N_2O and CH_4 from drainage and rewetted organic soils

a) N_2O from drained organic soils

Tier 1 estimates of N_2O emissions due to the drainage of organic soils in forest lands were first reported in the 2009 submission (for the 1990-2007 timeseries). Nitrous oxide emission estimates for drained forest soils are now based on guidance contained in the IPCC 2006 guidelines and the 2013 wetland supplement. The NFI data was used to derive a breakdown of areas for drained nutrient rich and nutrient poor organic soils over the time-series, based on planting year and soil type. Soils were categorised into mineral (soils with no organic layer), nutrient-rich organic (peaty-gleys or organo-mineral soils) and nutrient-poor organic (blanket peats and fen peats). All organic soils areas are assumed to be drained. The total area subjected to drainage excludes open areas within forest areas, where no drainage occurs. The proportion of the three tier 1 soil types subjected to drainage for the time-series are determined from this soil/drainage matrix (Table 6.9). The productive drained areas of the 2 organic soil categories was used to estimate N_2O emissions using equation 11.1 in the 2006 IPCC Guidelines.

The 2013 IPCC Wetland supplement recommends only one emission factor for drained temperate forest (2.8 kg N_2O-N ha^{-1} yr^{-1}) for both nutrient rich and nutrient poor organic soils (Wetland supplement Table 2.5). However, in the quoted literature used to derive these emission factors (Yamulki et al., 2013), these authors suggest the EF for nutritionally poor organic forest soils in Scotland is 0.7 kg N_2O ha^{-1} yr^{-1}. Therefore, we have adopted to use the default EF for nutrient rich organic soils (2.8 N_2O-N ha^{-1} yr^{-1}) and a country specific EF of 0.7 kg N_2O ha^{-1} yr^{-1} for nutrient poor organic soils, since this is more reflective of national circumstances (Table 6.9). The decline in N_2O emissions from organic soils in the forest land remaining forest land category since 1990 is due to a reduction in drained areas due to deforestation activities (Table 6.9).

b) CH_4 from drained land and ditches

Estimation of CH_4 emissions from drained organic soils and forest drain ditches are based on the same activity data used for the determination of N_2O emissions with additional information on the fraction of land covered by drain ditches using Eq. 2.6 of Ch 2 of the IPCC Wetland Supplement 2013.

The default emission factors for $EF_{CH4land}$ (2.5 kg CH_4 ha^{-1} yr^{-1}, Table 2.3 of the Wetland supplement 2013) and $EF_{CH4ditch}$ (217 kg CH_4 ha^{-1} yr^{-1}, Table 2.4 of the Wetland supplement 2013) are used. The fraction of the total areas which is occupied by ditches ($Frac_{Ditch}$) was derived using country specific information (Forestry Scheme manual, 2003; Mulqueen et al., 1999) which specifies drain spacing's. For poor organic soils, such as blanket peats, these typically have 0.3 m drains every 12 m, which equates to a $Frac_{Ditch}$ of 0.0249. This derived country specific $Frac_{Ditch}$ for forest bogs are within the ranges reported for forest bogs and peats reported in Table 2A.1 in Annex 2A.2 of the IPCC Wetland supplement 2013. Richer organo-mineral soils, such as peaty gleys or peaty-podzols require drains every 80 m, which is equivalent to a $Frac_{Ditch}$ of 0.00375.

The decline in CH_4 emissions from organic soils in the forest land remaining forest land category since 1990 is due to a reduction in drained areas due to deforestation activities (Table 6.9).

c) Rewetting of organic soils

Forest soils are managed to maintain drains so that nutrient uptake and crop productivity is maintained. Therefore, forest soils are not rewetted.

Table 6.9 The activity data and N_2O and CH_4 emissions from drainage of forest land remaining forest land

	Area (kHa)				kt N_2O			kt CH_4		
Year	Total Area	Open area	Organic N-poor[1]	Organic N-rich[1]	Organic N-poor	Organic N-rich	Total N_2O	Drained lands	Ditches	Total CH_4
1990	90.0	9.7	35.5	44.8	0.04	0.20	0.24	0.20	0.23	0.43
1995	134.8	18.4	62.2	54.2	0.07	0.24	0.31	0.29	0.38	0.67
2000	164.3	18.8	84.6	60.9	0.1	0.3	0.4	0.4	0.5	0.9
2005	195.3	17.1	110.5	67.7	0.12	0.30	0.42	0.44	0.65	1.09
2006	199.3	14.7	114.4	70.2	0.13	0.31	0.43	0.45	0.68	1.13
2007	204.5	14.2	118.1	72.2	0.13	0.32	0.45	0.47	0.70	1.16
2008	209.9	13.9	121.1	75.0	0.13	0.33	0.46	0.48	0.72	1.20
2009	217.9	14.7	126.2	77.0	0.14	0.34	0.48	0.50	0.74	1.24
2010	225.3	15.3	131.1	78.9	0.14	0.35	0.49	0.52	0.77	1.29
2012	238.3	15.7	140.2	82.5	0.15	0.36	0.52	0.55	0.82	1.37
2013	243.6	18.2	142.0	83.5	0.16	0.37	0.52	0.55	0.83	1.39
2014	249.1	18.9	146.3	83.9	0.16	0.37	0.53	0.57	0.86	1.42
2015	253.9	18.5	149.1	86.2	0.16	0.38	0.54	0.58	0.88	1.45
2016	260.2	19.4	152.6	88.2	0.17	0.39	0.56	0.59	0.90	1.49
2017	270.0	19.2	159.5	91.2	0.18	0.40	0.58	0.62	0.94	1.55
2018	279.1	19.0	166.8	93.3	0.18	0.41	0.59	0.64	0.98	1.62
2019	288.8	19.2	173.8	95.7	0.19	0.42	0.61	0.66	1.02	1.68
2020	301.3	28.1	175.6	97.6	0.19	0.43	0.62	0.67	1.03	1.70
2021	313.8	35.5	178.2	100.1	0.20	0.44	0.64	0.68	1.04	1.73
2022	324.0	42.1	180.0	101.9	0.20	0.45	0.65	0.69	1.06	1.75

[1] Represents drained area of organic and organo mineral soils as reported in Table 4(II)

6.3.4.7 Uncertainty Analysis for Category 4.A.1

Characterisation of uncertainties associated with individual activity and area information was obtained directly or derived from already published studies or by cross comparisons of models with NFI data. If no estimates were available expert judgement was applied (Table 6.10).

The IPCC Tier 1 approach is applied to estimate uncertainties using approach 1 for combining uncertainties given in section 3.2.3.1 of Ch3 Vol 1 of the 2006 IPCC guidelines. However, many of the input variables are auto correlated with each other, and therefore violate the basic assumption in this approach that inputs are statistically independent. For example, biomass pools uncertainty is derived from biomass uncertainty and the forest area uncertainty (Table 6.11). The simple Tier 1 method is adopted until the capacity to develop Monte Carlo approaches is developed and reported in future submissions.

The percentage input uncertainties in the various methodological parameters used for the analysis of carbon stock change in the relevant carbon pools and for the emissions of non-CO_2 gases are listed in Table 6.11. The combined uncertainties of the products of the respective parameters associated with each component pool are calculated using equation 6.3.34 (equation 3.1, Chapter 3, Vol 1, 2006 IPCC guidelines).

$$U_{total} = \sqrt{U_1^2 + U_2^2 + U_3^2 + U_n^2} \qquad \text{(eq 6.3.5)}$$

Where:

U_{total} is the combined uncertainty of the product of the input values U_1, U_2, U_3 and U_n given in Table 6.11, which also indicates the associated input parameters whose uncertainties have been combined. The uncertainties in the reported carbon stock changes reported in the CRF tables are calculated in Table 6.11 as the sum of the uncertainties for carbon pools using equation 6.3.6 (equation 3.2 Chapter 3, Vol 1, 2006 IPCC guidelines):

$$U_{total} = \frac{\sqrt{(U_1 \times x_1)^2 + (U_2 \times x_2)^2 + (U_n \times x_n)^2}}{|x_1 + x_2 + x_n|} \qquad \text{(eq 6.3.6)}$$

Where:

U_{total} is the combined uncertainty, U_1, U_2 and U_n are the uncertainties of pool estimates (Table 6.12) and x_1, x_2 and x_n are the mean values for the respective pools reported in the CRF tables.

Table 6.12 shows that the combined level uncertainty for forest land remaining forest land was 41 per cent in 2022.

Table 6.10 Uncertainty estimates for individual activity and area data sets for forest land remaining forest land

Code	Component	Sub-category	% Uncertainty	Source
A	Biomass stock change	AB and BB	15.8	Validation with of CBM-CFS3 NFI 2006-2012 (accuracy %)
B	Area data	GPAS data	0.6	Derived from Black et al 2009a and comparison of NFI and GPAS data
C	Litter	Li	3.1	Tobin et al, 2006
D	Deadwood	DW	22	Tobin et al, 2007
E	Peat soils	So	38	Jovani Sancho et al., 2021
F	Fire C stocks	fire	15	95 % confidence interval for biomass stocks (NFI)
G	Areas burned	fire area	50	Expert Judgement, guess
H	N_20	N_20 and CH_4, area	12.3	Conf. interval of NFI analysis
I	N_20 EF	N_20 emissions drained	119	Wetland supplement Table 2.5 and Yamulki et al., 2013
J	CH_4 LAND EF	CH_4 emissions drainage	87.2	Wetland supplement Table 2.4
K	CH_4 DITCH EF	CH_4 emissions drainage	126	Wetland supplement Table 2.3
L	Soils DOC	So	43.5	Wetland supplement Table 2.1

Table 6.11 Combined uncertainty estimates for forest land remaining forest land pools

	Component	Equation in NIR	% uncertainty	Uncertainty of combined products (code)
LB net	Biomass	CBM-CFS3	15.8	A+B
DOM	DOM	CBM-CFS3	22.2	B+C+D
SO	Soils	Section 6.3.4.3	57.8	B+E+L
Fires	Fire	Section 6.3.4.4	52.2	F+G
N_20	Drainage of soils	2006 IPCC Guidelines	119.6	H+I
CH_4	Drainage of soils	2006 IPCC Guidelines	153.7	H+J+K

Table 6.12 Uncertainty analysis for forest land remaining forest land since 1990[5]

Year	Category	Year emission/reductions (kt CO_2 eq)	Base year emission/reductions (kt CO_2eq)	Combined uncertainty in year (±%)	Contribution to total variance in year (fraction)	Mean trend in year in relation to base-year (% mean trend)
1990	CRF 4A.1	-2449.9	-2449.9	20.1	0.8	na
	CRF 4 (II)	74.5	74.5	100.5	0.1	na
	CRF4(V)	53.5	53.5	52.2	0.0	na
	Total	-2321.9	-2321.9	19.3	1.0	na
2000	CRF 4A.1	1574.5	-2449.9	48.5	0.8	-164.3
	CRF 4 (II)	119.8	74.5	95.5	0.1	60.7
	CRF4(V)	44.9	53.5	52.2	0.0	-16.0
	Total	1739.3	-2321.9	44.5	1.0	-174.9
2005	CRF 4A.1	1701.8	-2449.9	41.7	0.8	-169.5
	CRF 4 (II)	141.7	141.7	93.9	0.2	0.0
	CRF4(V)	16.7	53.5	52.2	0.0	-68.7
	Total	1860.2	-2254.7	38.9	1.0	-182.5
2010	CRF 4A.1	659.8	-2449.9	36.5	0.5	-126.9
	CRF 4 (II)	166.3	74.5	93.7	0.3	123.2
	CRF4(V)	224.7	53.5	52.2	0.2	320.1
	Total	1050.8	-2321.9	30.1	1.0	-145.3
2015	CRF 4A.1	-685.2	-2449.9	22.7	0.5	-72.0
	CRF 4 (II)	184.7	74.5	93.3	0.5	147.8
	CRF4(V)	28.9	53.5	52.2	0.0	-45.9
	Total	-471.6	-2321.9	27.0	1.0	-79.7
2020	CRF 4A.1	1039.2	-2449.9	40.2	0.7	-142.4
	CRF 4 (II)	212.5	74.5	92.8	0.3	185.1
	CRF4(V)	52.4	53.5	52.2	0.0	-2.0
	Total	1304.2	-2321.9	36.0	1.0	-156.2
2021	CRF 4A.1	1602.2	-2449.9	41.8	0.8	-165.4
	CRF 4 (II)	217.0	74.5	93.0	0.2	191.1
	CRF4(V)	18.1	53.5	52.2	0.0	-66.1
	Total	1837.3	-2321.9	38.3	1.0	-179.1
2022	CRF 4A.1	1242.8	-2449.9	45.6	0.7	-150.7
	CRF 4 (II)	220.2	74.5	93.0	0.3	195.5
	CRF4(V)	18.7	53.5	52.2	0.0	-65.1
	Total	1481.7	-2321.9	41.1	1.0	-163.8

[5] Note that uncertainties for category 4A(II) and 4A(V) include land in the forest remaining forest land category

6.3.4.8 Recalculations for forest land remaining forest land (CRF 4.A.1)

There were significant recalculations to the forest land remaining forestry land category due to an error in calculating the new 30-year transition to forest land remaining forest land in the previous submission. This error has now been corrected. There was also a recalculation of forest land remaining forest land emissions and removals due to new deforestation areas for 2016-2021 based on the 2021 NFI. The change in deforestation areas, based on the 2021 NFI was not reflected in the 2023 submission. This recalculation affects the productive forest areas and areas of drained organic soils for both forest land remaining forest land and land converted to for forest land for the years 2016-2021.

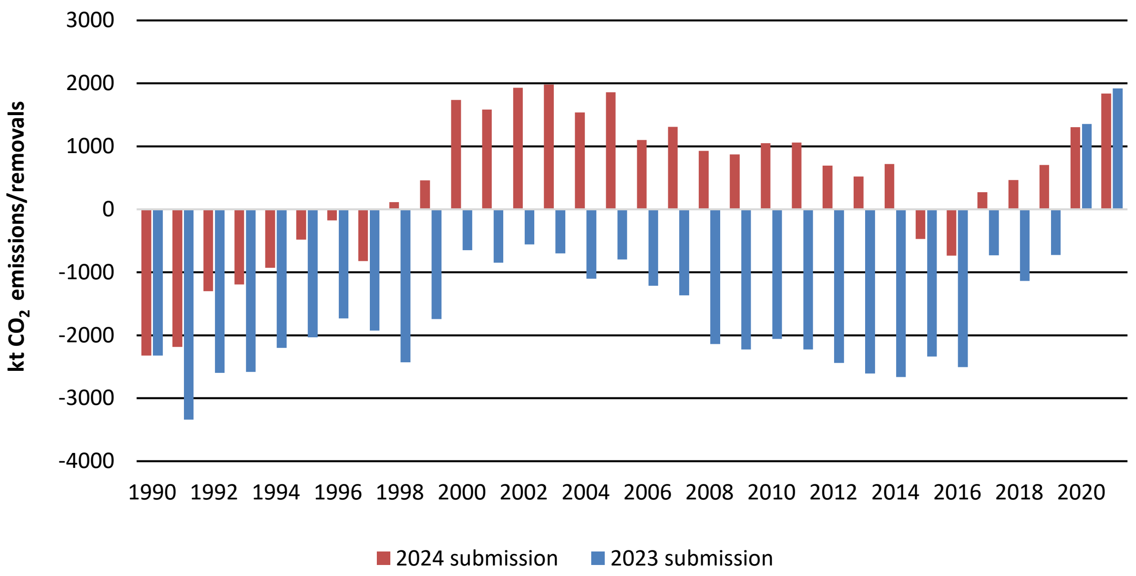


Figure 6.12 Comparison of category 4.A.1 emissions/removals for 2023 and 2024 submissions

6.3.5 Land converted to forest land (CRF 4.A.2)

Forest cover has increased from less than 1 per cent in 1900 to over 11 per cent by 2022. Over 591 kha has been afforested in Ireland since 1970. A total of 301 kha has been afforested between 1992-2021, but 2 kha of the land converted to forest land area was deforested over the same period. The land converted to forest land area (i.e. afforested areas less than 30 years old) has increased from 254.7 kha in 1990 to a peak of ca.355 kha by the mid-2000s and a subsequent decline to 285 kha by 2022 (Table 6.12). These changes in the land converted to forest land areas are due to fluctuations in afforestation rates over the period 1960 to 2022. Afforestation rates peaked at 23 kha per year in 1996 followed by a steady decline to just over 2 kha by 2022. The majority of the land afforested in recent years (since 1995) has been privately-owned agricultural land. Afforestation continues to be incentivised by the State through establishment grants and annual premiums (for maintenance purposes and to reflect income foregone by landowners during the early growing years of the new forest). Most afforestation area in the 1990s (ca. 59 per cent) occurred on wetlands (drained organic soils), but current annual afforestation rates of wetlands have declined by 96 per cent since the peak in 2001 due to regulations introduced to limit planting of unenclosed land (peatlands). Grasslands are now the dominant land use transition to forestry, representing 56.2 per cent of afforested land since

1990. In 2022 nearly all land converted to forest land was grassland (92%), although some of these grasslands were previously drained organic soils.

There is a significant decline in the area of organic soils in the land converted to forest land category since 2005 due to a) a decline in the area of organic soils planted since 2000s and b) the transition of organic soil forest areas from the land converted to forest land category to the forest land remaining forest land after 30 years (Table 6.6 and 6.13).

The emission/removal profile of the land converted to forest land area (category 4.A.2) shows a steady increase in removals. (particularly in biomass pools) from 1990 to a peak of 4,424 kt CO_2eq. by 2014 followed by a decline in removals as afforestation rates declined and the level of harvest (primarily thinning) increased (Figure 6.13).

Harvest rates have generally increased over time as the age profile[2] of the land converted to forest land area increased (Figure 6.13). For 2020 to 2022, the amount of timber available for harvest reduced due to transition of forest areas from the land converted to forest land to the forest land remaining forest land category. In 2022, timber harvests from the land converted to forest land only represents ca 15 percent of the total annual harvest. The lower harvest in 2020 to 2022 resulted in higher net removals, compared to previous years (2015-2019) where harvest rates were higher.

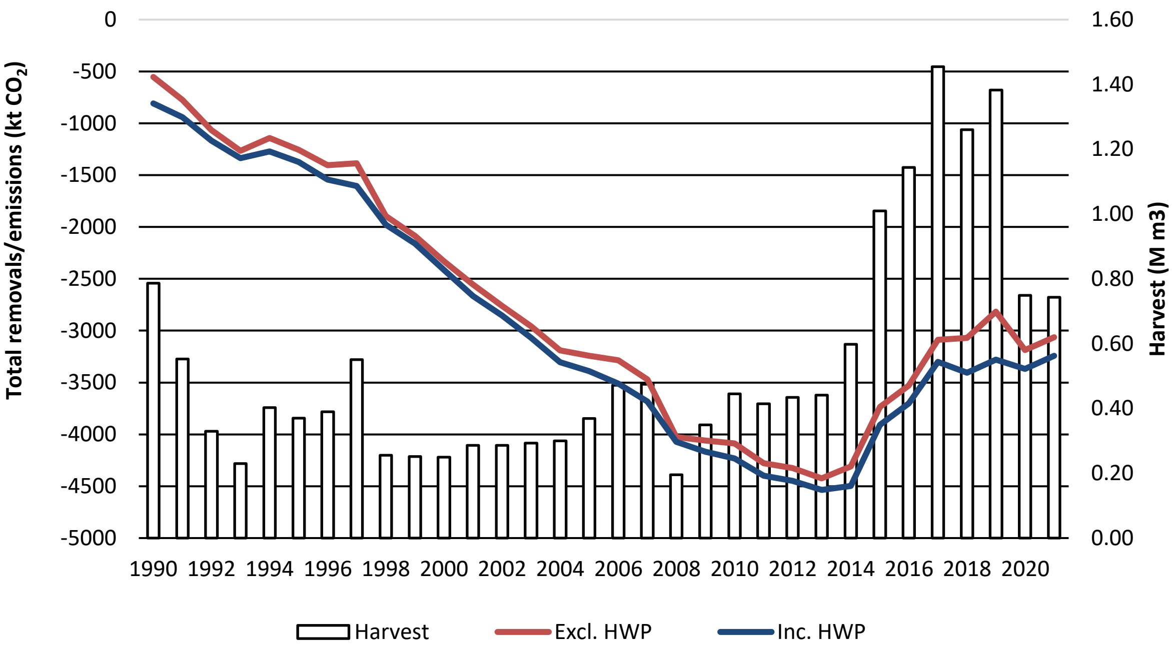


Figure 6.13 Timeseries of carbon stock changes (including and excluding Harvested Wood Products) and annual harvest rate for category 4.A.2.

Table 6.13 shows the net biomass, dead organic matter, soil C and net CO_2 emissions/removals for the time series 1990-2022 for lands converted to forest land (i.e. reported in category 4.A.2). The CBM-CFS3 model is used to estimate CSCs for the data time series.

Table 6.13 Time series for forest category 4.A.2

	Area (kha)				CSC (kt C)				Net CO_2 kt	Harvests[1] (M m³)
			Living biomass			DOM	Mineral Soils	Organic soils	Total	
Year	**Total**	**Organic**	**Gain**	**Loss**	**Net**	**Net**	**Net**	**Net**		**Eurostat**
1990	254.74	197.79	1119.54	-772.74	346.80	143.96	-4.35	-335.48	-553.38	0.79
1995	293.66	208.54	1186.32	-590.60	595.72	113.00	-6.32	-360.14	-1254.96	0.37
2000	334.61	220.24	1485.79	-627.80	857.99	146.99	-3.02	-367.04	-2328.02	0.25
2005	354.79	222.34	1877.26	-836.21	1041.05	198.67	3.66	-359.40	-3241.25	0.37
2006	355.70	218.83	1943.99	-918.06	1025.93	215.10	4.31	-349.62	-3284.31	0.47
2007	355.18	215.55	2021.84	-952.83	1069.01	216.09	3.98	-342.81	-3469.65	0.47
2008	354.02	212.15	2093.43	-847.21	1246.22	184.06	3.90	-336.18	-4026.01	0.19
2009	352.02	206.82	2166.07	-958.39	1207.67	222.55	4.42	-327.59	-4059.21	0.35
2010	353.07	203.23	2235.13	-1049.38	1185.75	246.70	5.24	-323.37	-4085.84	0.45
2011	353.35	199.32	2297.15	-1066.16	1230.99	248.07	5.34	-317.58	-4278.32	0.41
2012	352.68	195.51	2345.97	-1120.98	1225.00	260.37	5.72	-311.19	-4326.26	0.43
2013	352.91	192.58	2400.75	-1160.91	1239.84	267.29	5.82	-306.29	-4424.43	0.44
2014	353.00	190.24	2453.38	-1268.17	1185.21	286.34	6.22	-302.52	-4309.25	0.60
2015	353.51	188.28	2476.23	-1496.74	979.49	332.06	6.96	-299.29	-3737.15	1.01
2016	352.36	185.36	2472.85	-1564.27	908.57	343.56	6.45	-296.28	-3528.46	1.14
2017	349.28	178.68	2446.05	-1720.61	725.44	396.24	6.16	-285.75	-3087.63	1.46
2018	341.60	171.86	2425.72	-1638.41	787.31	319.48	4.76	-274.71	-3068.42	1.26
2019	330.03	164.38	2384.68	-1672.97	711.70	313.80	5.74	-262.75	-2817.79	1.38
2020	316.64	153.45	2233.02	-1291.36	941.66	169.96	2.58	-245.18	-3186.42	0.75
2021	299.51	143.05	2158.40	-1275.04	883.35	177.42	3.92	-228.94	-3064.41	0.74
2022	285.07	134.92	2056.08	-1171.01	885.07	182.48	3.85	-214.11	-3143.40	0.64

[1] The harvest volumes show a comparison of the EUROSTAT and modelled harvest using FORCARB and the CBM-CFS3 model

6.3.5.1 Initial biomass losses from grassland converted to forest

The tier 1 default approach is used to calculate grassland biomass losses in the year areas are afforested. The carbon loss is quantified as the net of carbon lost on conversion to forest assuming instantaneous oxidation of all grassland biomass (i.e. C_{before} see eq 6.3.7). The dry matter content of grassland is taken as 13.6 tonnes ha^{-1} and the carbon content of dry matter is 0.5 per cent (Table 6.1 Chapter 6 Vol 4 2006 IPCC Guidelines). The root to shoot (R) value of 4 t dry matter of roots to per t of aboveground biomass is used to calculate belowground and aboveground biomass losses (Table 6.1 CH6 Vol 4 2006 IPCC Guidelines). The biomass after planting (C_{after}) is based on an initial seedling stocking rate of 2500 trees per ha using mean seeding biomass estimates for aboveground biomass of 21.3 g/seedling and a belowground biomass of 12.9 g per seedling, derived from Coillte nursery trials. The annual growth (DC_{growth}) is already calculated in CBM-CFS3.

The carbon stock change in biomass on the grassland area (A) converted to forest is then calculated using eq 6.4.1, derived from eq 2.15 from Chapter 2 Vol 4 of the 2006 IPCC guidelines as follows:

$$\Delta C = A * [(C_{after} – C_{before}) + DC_{growth}] \qquad \text{(eq 6.3.7)}$$

Where A is the area of grassland converted to forest to productive forest land (i.e. excluding unplanted areas).

6.3.5.2 Mineral Soils

Grassland converted to forest land on mineral soils are demonstrated to result in an initial emission which reverts to a removal as C transfers from the DOM accumulate (Table 6.13). Mineral soils are aggregated in to 4 World Reference Base soil classes with different initial slow below ground C pool values to initiate the CBM-CFS3 model (see Annex 3.4B and section 6.3.3.1). Initial slow belowground pools for organic soils are set to zero in the model because emissions are based on tier 2 emission factors (see 6.3.5.3 below).

6.3.5.3 Organic Soils

The same approaches as described for forest land remaining forest land were used to estimate emissions from organic soils in lands converted to forest land (section 6.3.4.3). The allocation of emission estimates for the sub-categories *4.A.2.1* to *4.A.2.5* are based on the proportion of lands converted to forests.

Table 6.14 Area (in kha) and emissions from different organic soils types and over the timeseries for land converted to forests (CRF 4.A.2)

					Drained productive area		On-site emissions		Off-site DOC emissions		Total
Year	Total Area[1]	Mineral	Org.	Open area [2]	Org. [3]	Org.-mineral[3]	Org.[4]	Org.-mineral[4]	Org.[6]	Org.-mineral[6]	
	(kha)						kt C				kt CO_2
1990	254.7	57.0	197.8	21.0	149.0	32.5	-250.3	-28.9	-46.2	-10.1	1230.1
1995	293.7	85.1	208.5	18.2	158.7	36.9	-266.6	-32.9	-49.2	-11.4	1320.5
2000	342.2	120.8	221.4	31.8	159.2	41.6	-267.5	-37.1	-49.4	-12.9	1345.0
2005	354.8	132.4	222.3	39.5	154.7	42.9	-260.0	-38.2	-48.0	-13.3	1317.8
2010	353.1	149.8	203.2	43.1	136.5	42.0	-229.3	-38.8	-42.3	-13.0	1185.7
2011	353.3	154.0	199.3	43.3	133.7	41.3	-224.5	-38.8	-41.4	-12.8	1164.5
2012	352.7	157.2	195.5	43.6	130.6	40.8	-219.4	-38.7	-40.5	-12.6	1141.0
2013	352.9	160.3	192.6	44.0	128.7	39.9	-216.2	-37.9	-39.9	-12.4	1123.0
2014	353.0	162.8	190.2	44.1	127.0	39.5	-213.4	-37.5	-39.4	-12.2	1109.2
2015	353.5	165.2	188.3	44.4	125.8	38.8	-211.4	-36.9	-39.0	-12.0	1097.4
2016	352.4	167.0	185.4	44.4	124.3	37.7	-208.8	-37.2	-38.5	-11.7	1086.4
2017	349.3	170.6	178.7	44.0	120.1	36.1	-201.7	-35.6	-37.2	-11.2	1047.8
2018	341.6	169.7	171.9	42.9	115.1	35.2	-193.4	-34.7	-35.7	-10.9	1007.3
2019	330.0	165.6	164.4	41.4	110.1	33.7	-184.9	-33.3	-34.1	-10.5	963.4
2020	316.6	163.2	153.4	39.5	102.4	31.9	-172.0	-31.5	-31.7	-9.9	899.0
2021	299.5	156.5	143.0	37.2	95.9	29.4	-161.1	-29.0	-29.7	-9.1	839.4
2022	285.1	150.1	134.9	37.5	89.6	27.6	-150.6	-27.2	-27.8	-8.5	785.1

[1] Total area includes open areas

[2]Open area within forest areas (roads, extraction routes, biodiversity etc).

[3] Productive area of drained organic (org.) and organo-mineral soils based in NFI 2006 and 2017 (excluding open areas). Organic soils include all soils with a > 20% C and an organic layer greater than 30 cm (e.g. Blanket peats, fens, cutaway peats. Organo-mineral soils are mineral soils with an organic overlay of < 30cm. These include peaty podsols and peaty gleys (Source NFI).

[4]On-site emissions are calculated using Eq 6.3.23 and 6.2.24 and areas of productive and rained organic and organo-mineral soils.

[5]Off-site emissions are calculated using and EF of -0.31 tC /ha and the area of drained productive organic and organo-mineral soils using Eq 2.4 and Table 2.2, Ch2 of the 2013 IPCC Wetlands supplement.

6.3.5.4 Emissions from Biomass Burning

The methodology for estimating emissions from biomass burning is discussed in category *4.A.1* (see section 6.3.4.4).

6.3.5.5 Emissions of N_2O from nitrogen fertiliser application

Ireland does not report separately the emissions of N_2O due to nitrogen fertiliser use for *4.A Forest Land*. The amount of synthetic fertiliser used in forests is negligible compared to that used in agriculture and therefore all N_2O emissions from nitrogen fertiliser application are reported under agriculture. The notation key IE is therefore used in CRF Table 4(I).

6.3.5.6 Emissions of N_2O and CH_4 from drainage and rewetted organic soils

The methodology for estimating N_2O and CH_4 emissions from drainage of organic soils is discussed section 6.3.4.6.

a) N_2O from drained organic soils

The increase in N_2O emissions from organic soils in the land converted to forest land category since 1990 is due to an increase in afforestation of organic soils under the grants and premiums scheme (Table 6.15).

b) CH_4 from drained lands and ditches

The increase in CH_4 emissions from organic soils in land converted to forest land category since 1990 is due to an increase in afforestation of organic soils under the grants and premiums scheme (Table 6.16).

c) Rewetting of organic soils

Forest soils are managed to maintain drains so that nutrient uptake and crop productivity is maintained. Therefore, forest soils are not rewetted.

Table 6.15 The area, activity data and N_2O and CH_4 emissions from the drainage of land converted to forest land

	Area (kHa)				kt N_2O			kt CH_4		
Year	**Total Area**	**Open area**	**Organic N-poor**	**Organic N-rich**	**Organic N-poor**	**Organic N-rich**	**Total N_2O**	**Drained lands**	**Ditches**	**Total CH_4**
1990	15.8	1.9	6.6	2.1	0.00	0.01	0.01	0.02	0.04	0.06
1995	110.8	13.2	43.0	16.0	0.03	0.07	0.10	0.14	0.25	0.39
2000	184.5	22.0	67.2	25.7	0.05	0.11	0.16	0.23	0.38	0.61
2005	244.0	29.0	88.6	36.0	0.06	0.16	0.22	0.31	0.51	0.81
2010	280.4	35.6	94.3	47.7	0.07	0.21	**0.28**	0.35	0.55	**0.90**
2012	287.1	36.6	96.1	49.1	0.07	0.22	**0.28**	0.36	0.56	**0.92**
2013	292.9	37.6	97.8	50.2	0.07	0.22	**0.29**	0.36	0.57	**0.93**
2014	299.1	38.6	98.3	50.5	0.07	0.22	**0.29**	0.37	0.57	**0.94**
2015	305.2	39.5	101.0	50.5	0.07	0.22	**0.29**	0.37	0.59	**0.96**
2016	311.1	40.4	103.1	52.4	0.07	0.23	**0.30**	0.38	0.60	**0.98**
2017	352.4	44.4	124.3	37.7	0.14	0.17	**0.30**	0.40	0.70	**1.10**
2018	349.3	44.0	120.1	36.1	0.13	0.16	**0.29**	0.38	0.68	**1.06**
2019	341.6	42.9	115.1	35.2	0.13	0.15	**0.28**	0.37	0.65	**1.02**
2020	330.0	41.4	110.1	33.7	0.12	0.15	**0.27**	0.35	0.62	**0.97**
2021	316.6	39.5	102.4	31.9	0.11	0.14	**0.25**	0.33	0.58	**0.91**
2022	299.5	37.2	95.9	29.4	0.11	0.13	**0.23**	0.31	0.54	**0.85**

6.3.5.7 N_2O emissions from mineral soils as a result of change of management (F_{SOM})

Emissions of N_2O from mineral soils based on mineralisation rates due to loss of organic C from mineral soils cannot be estimated using the IPCC approaches because the CBM-CFS3 model does not model SOC. The CBM-CFS3 model soil pool includes very fast below ground C (Table 6.5), which represent labile C from root turnover. Losses from the slow and very fast belowground pool to the atmosphere are reported (stored) separately. Therefore, N_2O emissions due to mineralisation of SOC due to land use change are not significant and are reported using the notation key “NE”.

Justification for not reporting F_{SOM}

Benanti et al., (2014) show that total N_2O emissions from afforested Irish coniferous stands vary from 0-10 kg N_2O ha^{-1} yr^{-1}, but it was not clear how much of this emission is due to mineralisation of SOC. Broadleaf emissions are suggested to be less than 1 kg N_2O ha^{-1} yr^{-1} (Benanti et al., 2014). Based on this information and the following assumptions it is evident that N_2O emissions from mineralisation of SOC following afforestation is insignificant (see paragraph 37 of 24/CMP19):

- Assuming the abovementioned maximum reported N_2O emission value of 10 kg N_2O ha^{-1} yr^{-1} for conifers (70 per cent of forest area) and 1 kg N_2O ha^{-1} $yr^{-1}$for broadleaves (30 per cent of forest area).
- Less than 1 per cent of all N mineralisation in forest soils comes from SOC turnover (Strange et al., 2000), so it can be assumed that 1 per cent of total N_2O emissions relate to F_{SOM} emissions.
- The area of afforested mineral soils was 150.15 kha in 2022
- The highest estimated total F_{SOM} N_20 emissions would be:
  ((10*0.7) +(1*0.3)) *0.01*150150*265)/1000000 = 0.83 kt CO_2 eq per year in 2022
- The total national emission for 2022 (incl. LULUCF) is 64,587.58 kt CO_2 eq
- Therefore, we demonstrate that these emissions are less than 500 kt CO_2 and they are less than 0.05 percent of the total national emissions in 2022.

6.3.5.8 CO_2 emissions from urea application to soils

All fertiliser application related emissions, including CO_2 emissions from urea application are reported under *3. Agriculture* because these are based on national sales data (IE).

6.3.5.9 Uncertainty analysis for category 4.A.2

The same uncertainty analysis was carried out for lands converted to forest land as was undertaken for forests remaining forest land (Table 6.16). Table 6.16 shows that the uncertainty of estimates for land converted to forest land was 30.2 per cent in 1990, decreasing to 14 per cent by 2022.

Table 6.16 Uncertainty analysis for lands converted to forest land as reported in category 4.A.2

Year	Category	Year emission/reductions (kt CO_2 eq)	Base year emission/reductions (kt CO_2eq)	Combined uncertainty in year (±%)	Contribution to total variance in year (fraction)	Mean trend in year in relation to base-year (% mean trend)
1990	CRF 4A.2	-322.7	-322.7	18.3	0.3	na
	CRF 4(II)	181.5	181.5	83.1	0.7	na
	CRF4(V)	35.0	35.0	52.2	0.1	na
	Total	-106.2	-106.2	30.2	1.0	na
2000	CRF 4A.2	-2121.5	-322.7	14.9	0.6	557.5
	CRF 4(II)	200.3	181.5	84.4	0.3	10.4
	CRF4(V)	28.0	35.0	52.2	0.0	-20.1
	Total	-1893.2	-106.2	15.2	1.0	1683.4
2010	CRF 4A.2	-2961.1	-322.7	14.2	0.7	817.7
	CRF 4(II)	197.6	181.5	85.5	0.3	8.9
	CRF4(V)	10.0	35.0	52.2	0.0	-71.6
	Total	-2753.5	-106.2	14.3	1.0	2493.7
2015	CRF4A.1	-3686.2	-322.7	13.7	0.7	1042.4
	CRF 4A II	178.4	181.5	86.6	0.2	-1.7
	CRF4(V)	122.0	35.0	52.2	0.1	248.2
	Total	-3385.8	-106.2	13.4	1.0	3089.3
2020	CRF4A.1	-2712.4	-322.7	14.0	0.8	740.6
	CRF 4A II	117.2	181.5	86.6	0.2	-35.4
	CRF4(V)	6.3	35.0	52.2	0.0	-82.1
	Total	-2588.9	-106.2	13.8	1.0	2338.7
2021	CRF4A.1	-2121.5	-322.7	14.9	0.6	557.5
	CRF 4A II	200.3	181.5	84.4	0.3	10.4
	CRF4(V)	28.0	35.0	52.2	0.0	-20.1
	Total	-1893.2	-106.2	15.2	1.0	1683.4
2022	CRF4A.1	-2961.1	-322.7	14.2	0.7	817.7
	CRF 4A II	197.6	181.5	85.5	0.3	8.9
	CRF4(V)	10.0	35.0	52.2	0.0	-71.6
	Total	-2753.5	-106.2	14.3	1.0	2493.7

6.3.5.10 Recalculations for lands converted to forest land (CRF 4.A.2)

There were significant recalculations to the land converted to forestry land category due to an error in calculating the new 30-year transition to forest land remaining forest land in the previous submission. This error has now been corrected. There was also a recalculation of emissions and removals due to new deforestation areas for 2016-2021 based on the 2021 NFI. The change in deforestation areas, based on the 2021 NFI was not reflected in the 2023 submission.

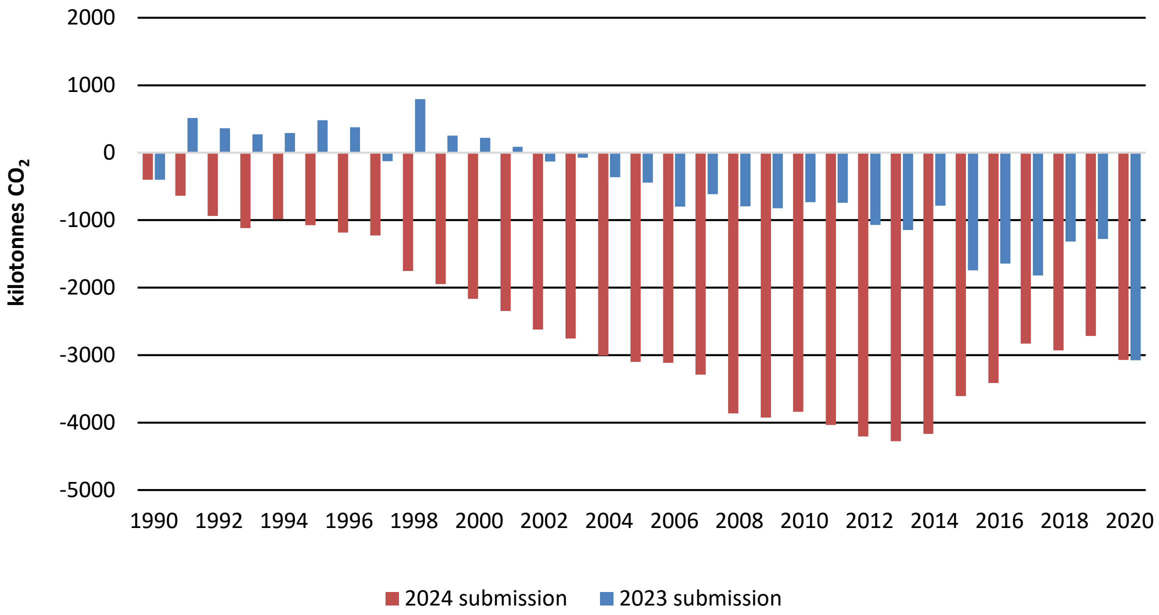


Figure 6.14 Comparison of category 4.A.2 emissions/removals for the 2023 and 2024 submissions

6.3.6 Deforestation Areas (CRF 4.B.2 to 4.F.2)

This section describes deforestation areas reported under forest converted to other lands under sub-categories *4.B.2* to *4.F.2*. This submission reports deforested land using the default 20-year transition period. However, no historical data is available on deforestation prior to 1990. Reported historical deforestation trends (1990-2022) show a marked increase in deforestation from 2000 to 2006 and a shift in the major land use transitions into grassland before 2000 and to settlements, wetlands and other land after 2000 (Table 6.17). These findings are consistent with a) an increase in building and infrastructural developments on forest land due to high economic growth in the late 1990s to mid-2000s; and b) an increase in deforestation of peatland forests following the introduction of EU LIFE peatland restoration scheme in 2004[6] . There was an increase in deforestation to settlements during mid 2000s, but these rates have decreased since 2016. Deforestation to grasslands is now the predominant forest land conversion.

The estimate of final land use after deforestation is based on an analysis of the CORINE land cover change from 1990 to 2000, the NFI and the Forest Inventory and Planning Strategy (FIPS) data up to 2005. Post 2006 analysis is based on detailed information from the 2006 and 2017 and 2021 NFI.

[6] http://life04.raisedbogrestoration.ie/index.html

Table 6.17 Land use change and soil type matrix showing annual deforestation areas (kha/year) associated with different land uses and soils types.

	TOTAL Area		Grassland		Settlement		Wetland		Other	
	Total	Organic	Total	Organic	Total	Organic	Total	Organic	Total	Organic
1990	0.02	0.01	0.01	0.01	0.01	NO	NO	NO	0.00	NO
1995	0.44	0.03	0.31	0.03	0.05	NO	NO	NO	0.08	NO
2000	2.63	0.26	1.77	0.09	0.22	NO	0.17	0.11	0.46	0.06
2005	6.91	1.40	3.78	0.37	1.08	NO	1.02	0.68	1.03	0.34
2010	14.09	5.40	5.37	0.37	3.87	2.00	1.82	1.48	3.03	1.54
2011	15.67	5.79	6.56	0.36	3.86	2.00	2.22	1.88	3.03	1.54
2012	16.45	6.58	6.55	0.36	4.65	2.80	2.22	1.88	3.03	1.54
2013	18.03	6.98	7.74	0.35	4.64	2.80	2.62	2.28	3.02	1.54
2014	18.41	7.37	7.73	0.34	4.63	2.80	3.02	2.68	3.02	1.54
2015	18.88	8.17	7.47	0.34	4.63	2.80	3.82	3.48	2.96	1.54
2016	19.74	8.57	7.60	0.34	5.03	3.20	4.22	3.88	2.89	1.54
2017	19.81	8.57	7.73	0.34	5.03	3.20	4.22	3.88	2.82	1.54
2018	20.68	8.57	7.87	0.34	5.83	3.20	4.22	3.88	2.76	1.54
2019	20.74	8.57	8.00	0.34	5.83	3.20	4.22	3.88	2.69	1.54
2020	20.69	8.34	8.40	0.29	5.66	3.20	4.05	3.77	2.57	1.49
2021	19.83	8.12	8.00	0.23	5.49	3.20	3.88	3.66	2.46	1.43
2022	19.15	7.89	7.62	0.17	5.48	3.21	3.71	3.54	2.34	1.37

* No transitions from forest to cropland were detected

6.3.6.1 Deforestation Losses

Carbon stock changes associated with deforestation reported in all relevant CRF tables include those for the total standing biomass of all trees removed at clear fell (i.e. all biomass carbon is assumed to be immediately oxidised):

$$C_{L(Total)} = C_{L(AB)} + C_{L(BB)} = TOTAL_{(Biomass)}lost \quad \text{(eq 6.3.8)}$$

The target harvest for deforested lands for CBM-CFS3 simulation (Section 6.33 and Annex 3.4B) is based on the carbon stock losses (CL) in the above ground (AB) and below ground (BB) pools were calculated differently depending on the activity data available, but in a hierarchical order as follows:

1) Total biomass and DOM losses were directly determined from the NFI permanent sample plot tree data and allometric equations as described in Annex 3.4.B.

2) Where plots were clearfelled before 2006 from the standing volume (V) of the forest stand, as specified by Coillte plot queries, a basic density (D) in the range 0.35 to 0.55 (depending on tree species), a biomass expansion factor (BEF) of 1.68 to 4 t/t^{-1} (Black et al., 2004) a carbon fraction (CF) of 0.5 and a root to shoot ratio R of 0.2, as described in Eq 6.3.9 and 6.3.10).

$$TOTAL_{(AB)} = (V \times D \times BEF \times CF) \times 1/(1 - R) \quad \text{(eq 6.3.9)}$$

$$TOTAL_{(BB)} = TOTAL_{(AB)} \times R \quad \text{(eq 6.3.10)}$$

The equations are similar to those presented in equation 2.8, Chapter 2, Volume 4 of the 2006 IPCC guidelines. However, the term (1-R) is included for above ground biomass because BEF is defined as the ratio of total biomass (including roots) to timber biomass. Similarly, the term R is included in the below ground biomass calculation.

3) There is no activity data for deforested areas before 2006, therefore the 2006-2013 mean AB (65.9 t C ha^{-1}), BB (17.2 t C ha^{-1}), litter and deadwood (16.4 t C ha^{-1}) C stock was applied as an IEF for these deforested areas. (see section 6.3.3.1.2).

4) Biomass gains for settlements and other lands are reported as NO in accordance with the 2006 IPCC guidelines. Biomass gains in land transitions to rewetted wetland are reported under soils (IE, soil).

It is important to note that many deforested lands are not fully stocked before clearfell and land use change, with the exception of;

- Clearfelled non-regenerated land within a 5-year period (1600 ha since 2006 with a mean biomass stock of 230 t C ha^{-1}),
- EU LIFE bog restoration projects in 2007 (400 ha, biomass stock of 176 t C ha^{-1}),
- Wind farm conversions in 2007 (400 ha, biomass stock of 230 t C ha^{-1}),
- Grassland conversion in 2009. (400 ha, biomass stock of 97 t C ha^{-1})

The accumulated litter and DOM pool are assumed to be immediately oxidised when deforestation occurs. The approach adopted to apply an instantaneous oxidation to litter and DOM (i.e. harvest residue, stumps and roots) in forests land converted to other land is based on the **conservativeness** principal. The rationale for this assumption is explained for the land use transitions for forestry indicated below:

a) *Forest conversion to rewetted wetlands*. Most forest conversion to wetland involves EU wetland conservation measures, where drains are blocked to encourage peat vegetation regeneration. This would create anaerobic condition for remaining harvest residues (stumps, lying deadwood and litter) resulting in very low decay at rates lower than those used in Ch 11 of the 2006 IPCC Guidelines for 1st rotation crops.

    i. Organic soils emissions due to rewetting are estimated using the 2013 IPCC Wetland supplement (see section 6.3.6.1.1). Biomass gains after conversion to rewetted and regenerating wetlands are included in on-site removals (see section 3.2.1 of the 2013 Wetland supplement) and are therefore reported using the notation key “IE”.

    ii. The remaining forest conversions to wetlands occur for peat extraction (i.e. 400 ha in 2007). The tier 1 default of zero emissions/removals for biomass are applied to peat extraction sites (2006 IPCC guidelines and 2013 Wetland supplement). The emissions from organic soils used in peat extraction are outlined in section 6.3.6.1.2).

b) Recent evidence of forests conversion to grassland and settlements suggests that harvest residues are removed after harvest. The current common practice is to chip woody residues for bio-fuel or horticultural purposes (expert opinion, Forest Service DAFM). In this case, we would argue that instantaneous oxidation should be applied since these are in essence harvested wood products and in the case of compost would decay relatively quickly. In some cases, it is possible that forest residues are ploughed, piled up and left on site to decay over time. However, there is no data to support this, so the conservative approach of instantaneous oxidation is applied.

Table 6.18 Forest Land converted to other lands (4B2,4C2, 4D2 and 4E2) carbon stock changes and the harvest time series 1990-2022

Area (kHa)		CSC (Gg C)						Net CO2 Gg	Harvests
		Living biomass			DOM	Mineral Soils	Organic soils	Total	(m³)
Year	Total	Gain	Loss	Net	Net	Net	Net		
1990	0.02	0.06	-1.64	-1.58	-0.35	-0.01	-0.02	7.22	3434
1995	0.44	1.81	-27.71	-25.89	-5.62	-0.16	-0.11	116.54	55560
2000	2.63	2.72	-71.24	-68.52	-14.44	-0.80	-0.51	308.98	142858
2005	6.91	2.72	-71.24	-68.52	-14.44	-2.17	-2.47	321.20	142858
2010	14.09	5.44	-45.69	-40.25	-6.01	-5.64	-10.24	227.87	94537
2011	15.67	8.16	-56.57	-48.41	-28.58	-4.41	-10.41	336.64	97715
2012	16.45	NO	-42.22	-42.22	-12.80	-4.39	-11.98	261.77	86063
2013	18.03	8.16	-123.91	-115.75	-45.76	-3.69	-12.14	650.23	236898
2014	18.41	NO	-0.99	-0.99	0.00	-3.65	-12.31	62.16	2216
2015	18.88	NO	-252.92	-252.92	-44.06	-3.54	-12.69	1148.42	521347
2016	19.74	2.72	-163.70	-160.98	-7.55	-3.65	-12.87	678.53	340817
2017	19.81	2.72	-40.29	-37.57	-12.77	-3.46	-13.13	245.39	78774
2018	20.68	2.72	-100.88	-98.16	-3.36	-3.22	-13.31	432.83	202424
2019	20.74	2.72	-29.41	-26.69	-6.35	-2.98	-13.43	181.29	57501
2020	20.69	5.44	-44.72	-39.28	-5.32	-2.44	-13.06	220.37	87436
2021	19.83	NO	NO	NO	NO	-2.03	-12.67	53.91	NO
2022	19.15	0.13	-5.85	-5.72	-1.93	-1.77	-11.82	77.90	12332.47

6.3.6.2 Mineral Soils

Carbon stock changes in mineral soils converted to grasslands were reported for the first time in 2019 using tier 2 SOC values based on new research information (Table 6.20, 6.21 and 6.22). A soil database for all national research information (Black et al., 2014) and the Irish Soil Information System soil pits (http://gis.teagasc.ie/soils/) was collated and general soils were reclassified into WRB categories (Table 6.19). The mean SOC value for the 4 major World Reference Base soil classes and tier 2 SOC_{ref} values were used as specified in Vol4 Ch2 equation 2.25 of the 2006 IPCC guidelines.

Table 6.19 Relationships between general soil group, WRB soils and IPCC reference soils and tier 2 SOC_{ref} values for major soil types

				SOC_{ref} (T2)	
Generalised soil groups	**WRB ref**	**Soil code**	**IPCC ref**	**Mean**	**Sdev**
Acid Brown Earth, Brown Earth	Cambisol	CA	HAC soil	**94.24**	**36.28**
Gley (undefined), Groundwater gleys, Surface-water gleys, Alluvial soil	Gleysols, Stagnosols, Fluvisols	G	Wet soils	**109.44**	**45.28**
Luvisols, Grey Brown Podzolics, Lithosols, Rendzinas	Luvisols, Leptosols	L	HAC soil	**105.01**	**51.04**
Podzols, Iron-pan Podzols, Brown Podzolics	Podzols	P	Spodic soils	**93.16**	**41.92**

Land use change factors (F_{lu}) were derived for three land use categories (Table 6.19). However, since there is an interaction between F_{lu} and soil type (see Black et al., 2014) and because there was no significant differences for land use classes (based on ANOVA and LSD, see average value in Table 6.20) to each other (see average values for land uses)), F_{lu} factors were derived for the four soil groups. The default transition period of 20 years was applied.

Table 6.20 Tier 2 F_{LU} values for the major soil types (see code in Table 6.19)

	Land use factor (F_{lu})			
Soil Group	**Cropland**	**Forest**	**Improved grassland (pasture)**	**Unimproved grassland (rough grazing)**
CA	0.87abc	1.03b	1.09ab	0.91c
G	0.91ab	1.13a	0.85b	0.89a
L	0.92bc	0.83c	1.37a	0.99ab
P	0.69a	1.04a	1.09a	0.94a
Average	**0.87a**	**1.04a**	**1.05a**	**0.92a**
IPCC tier 1	**0.69***	**1**	**1.14****	**0.98*****

* Mean F_{LU} values with different alphabetical letters are significantly different to each other based on type III ANOVA and Tukets significant difference test. Crop land factors are not significant due to the low number of representative samples in the database.

For deforestation to settlement (*4E*) and other land (*4F*) categories we use a conservative estimate, as used by other countries (e.g. Finland, Sweden), that 20 per cent of SOC is emitted over a 20-year period in these soils. A mean SOC stock of 110 t C ha^{-1} was used based on the highest SOC_{ref} value (see Table 6.19), since there is no national data on SOC values for these land use transitions. It should be noted that this is a conservative approach since:

- All deforested land allocated to the other land use category (Table 3.4.A.3, Annex 3.4.A) are forest lands which have been clearfelled but not replanted within a 5-year period. These lands have not undergone a land use transition but are defined as deforestation to comply with the requirements set out in the annex to decision of 2CMP/8;
- Land converted to settlement contains green areas which will not reduce SOC as a result of deforestation. However, it is assumed that the total deforested area emits CO_2 form mineral soils because there is no activity data to determine the percentage green area in urban areas.

Mineralisation emissions of N_2O due to the loss of SOC (Fsom) due to deforestation to grassland, settlement and other land is estimated using Eq. 11.8 in Ch. 11 of the 2006 IPCC Guidelines, CSC for mineral soils (see above), and the default C:N ratio of 15.

6.3.6.3 Organic soils

Drained organic soils

Grasslands (4C): Emissions of CO_2 from deforested grasslands are assumed to occur because lands are likely to be shallowly drained because they are temperate rich organic soils. The default on-site emission factor of 3.6 t C ha^{-1} (Table 2.1 of the 2013 IPCC Wetland Supplement), and off-site EF_{DOC} of 0.31 t C ha^{-1} are used (Table 2.2 of the 2013 IPCC Wetland Supplement).

The default emission factors and methods for temperate shallow drained nutrient rich organic soils are used for CH_4 emissions from deforested grasslands (Eq. 2.6 of 2013 IPCC Wetland Supplement). For CH_4-land emissions the default $EF_{CH4\text{-}land}$ of 39 kgCH_4 ha^{-1} and $FRAC_{ditch}$ of 0.05 is used for shallow drained grasslands (Tables 2.3 and 2.4 of the 2013 IPCC Wetland Supplement). The emission factor from shallow drains EF_{drain} of 527 kg CH_4 ha^{-1} is used (Table 2.4 of the 2013 IPCC Wetland Supplement).

Default emission factors (1.6 kg N-N_2O ha^{-1}, Table 2.5 of the 2013 IPCC Wetland Supplement) and methods (Eq. 2.7) for temperate shallow drained nutrient rich organic soils are used for N_2O emissions from deforested grasslands.

Settlements (4E) and other lands: The 2013 IPCC Wetland Supplement and 2006 IPCC Guidelines provide no methodology for drained organic soils under settlement. Therefore, emissions from organic soils converted to settlement and other land are assumed to continue using the on-site and DOC EFs and methods outlined in eq. 6.3.23 and 6.3.24 and described in section 6.3.3.1.2 (Soils). Emissions of CH_4 and N_2O for deforestation to settlements and other lands are not reported.

Peat extraction (4D): For the deforestation of land to peat extraction the default emission factors and methods are used (Ch 2 of 2013 IPCC Wetland Supplement). For CO_2 emissions, default on-site $EF_{\text{-}land}$ 2.8 t C ha^{-1} and the $EF_{\_DOC}$ of 0.31 t C ha^{-1} is used (Table 2.1 and 2.2 of the 2013 IPCC Wetland Supplement).

Wetlands (4D): For CH_4, $CH_{4\text{-}land}$ emissions the default $EF_{CH4\text{-}land}$ of 6.1 kg CH_4 ha^{-1} and $FRAC_{ditch}$ of 0.05 is used (Tables 2.3 and 2.4 of the 2013 IPCC Wetland Supplement). The emission factor for drained peat extraction sites of EF_{drain} of 542 kg CH_4 ha^{-1} is used (Table 2.4 of the 2013 IPCC Wetland Supplement). Default emission factors (1.6 kg N-N_2O ha^{-1}, Table 2.5 of the 2013 IPCC Wetland Supplement) and methods (Eq. 2.7) for temperate shallow drained nutrient rich organic soils are used for N_2O emissions from deforested grasslands.

Rewetting of organic soils

Emissions from organic soils following forest conversion back to wetlands (4D i.e. rewetting of organic soils) include on-site emission/removals (i.e. C-composite) and off-site DOC emissions (section 3.2.1 of the 2013 wetland supplement). On site removals, due to non-woody vegetation/organic soils bio-geochemical reactions are assumed to not occur (NO) because peat soils are re-saturated since drainage does not occur on regenerated wetlands (as part of EU LIFE peatland regeneration projects). On-site emissions are estimated based on the area of rewetted soils, the default emission factor EF_{CO_2} of -0.23 (Table 3.1 and Eq 3.4 of the 2013 IPCC Wetland Supplement). Off-site DOC emissions are estimated using Eq. 3.5 and the default $EF_{DOC\text{-}rewetted}$ of -0.24 (Table 3.2 of the 2013 IPCC Wetland Supplement). The EF for CH_4 due to rewetting is 92 kg CH_4 ha^{-1} (Eq 3.8 and table 3.3 of the 2013 IPCC Wetland Supplement).

6.3.6.4 Uncertainties for deforestation estimates

The same uncertainty analysis was carried out for lands converted to forest land as was undertaken for forests remaining forest land (Table 6.23). The only different sources of uncertainty in this analysis (see Table 6.21 and 6.22) are the uncertainty due to the different activity data used for deforestation areas and additional pools, particularly for category *4(III)*.

Table 6.21 Uncertainty estimates for individual activity and area data sets for deforested lands

Code	Component	Sub-category	% Uncertainty	Source
A	Biomass algorithms	AB and BB	12.00	Black et al 2007
B	C fraction	All biomass pools	0.87	Black et al 2007
C	Volume to biomass	Defor losses	38.50	Felling licences and BEF uncertainty, Black 2004
D	Area deforestation	NFI, OSI aerial photos	46.70	Sample strata uncertainly analysis/ new deforestation methods
E	Litter	Li	3.10	Tobin et al, 2006
F	Deadwood	DW	22.00	Tobin et al, 2007
G	Peat soils and DOC	So	90.00	Assume same as Tier 1 (Table 2.3,2.3.1 CH2, 2006 IPCC Guidelines)
I	Drained area	N_20 and CH_4 drained	12.30	Conf. interval of NFI analysis
J	N_20 emission factors drainage	N_20 emissions	119.00	Wetland Supplement Table 2.5 and Yamulki et al., 2013
K	CH_4 EF ditches	CH_4 emissions	87.20	Wetland Supplement Table 2.4
L	CH_4 EF lands	CH_4 emissions	126.00	Wetland Supplement Table 2.3
M	N_20 EF mineralisation	N_20 emissions	66.00	2006 IPCC Guidelines Eq 11.8
N	DOC emissions from drained soils	So	43.50	Wetland Supplement Table 2.1
O	Mineral soil EF to settlement	So	50.00	Review of NIRs from other countries e.g. Finland and Sweden
P	Peat extraction EF CO_2	So	69.81	Wetland Supplement Table 2.1 and 2.2
Q	Rewetting CO_2	So	125.36	Wetland Supplement Table 3.1and 3.2
R	Rewetting CH_4	CH4 emissions	240.00	Wetland Supplement Table 3.3
S	SOC	SOC	61.2	SOLUM project - inprep

It is important to note that the uncertainty estimates and net emissions for deforestation are a sub-total of the total emissions presented in *4(II)* and *4(III)* (i.e. this does not include emissions from other land uses (deforestation transitions)).

Table 6.22 Combined uncertainty estimates for deforested land

	Component	Equation in NIR	% uncertainty	Uncertainty of combined products (code)
LB net	Biomass	Eq 6.3.2 and 6.3.9	61.71	A, B, C, D
DOM	DOM (deadwood and litter)	Eq 6.3.16	64.48	B, C, D, E, F
SO	Soils	Eq 11.23 (So) and Wetland Supplement	197.50	D, G, N, O, P, Q, S
N_2O	N_20 drainage	Wetland Supplement	128.43	D, I J
CH_4	CH_4 drain and rewetting	Wetland Supplement	285.01	I, K, L, R

Table 6.23 Uncertainty estimates for deforested land

Year	Category	Year emission/reductions (kt CO_2 eq)	Base year emission/reductions (kt CO_2eq)	Combined uncertainty in year (±%)	Contribution to total variance in year (fraction)	Mean trend in year in relation to base-year (% mean trend)
1990	CRF 4B-E	7.22	7.22	51.10	0.92	na
	CRF 4 (II)	0.01	0.01	197.87	0.01	na
	CRF4 (III)	0.43	0.43	66.00	0.07	na
	Total	**7.66**	**7.66**	**47.01**	**1.00**	**na**
2000	CRF 4B-E	308.98	7.22	51.47	0.91	4181.04
	CRF 4 (II)	0.63	0.01	223.63	0.01	4562.82
	CRF4 (III)	21.42	0.43	66.00	0.08	4930.65
	Total	**331.03**	**7.66**	**46.65**	**1.00**	**4223.41**
2005	CRF 4B-E	321.20	7.22	50.52	0.77	4350.41
	CRF 4 (II)	3.45	3.45	226.22	0.04	0.00
	CRF4 (III)	60.71	0.43	66.00	0.19	14156.45
	Total	**385.36**	**7.66**	**47.37**	**1.00**	**4932.95**
2010	CRF 4B-E	227.87	7.22	64.70	0.53	3057.28
	CRF 4 (II)	9.51	0.01	151.50	0.05	70126.15
	CRF4 (III)	179.46	0.43	66.00	0.42	42044.26
	Total	**416.84**	**7.66**	**55.91**	**1.00**	**5344.14**
2015	CRF 4B-E	1148.42	7.22	51.67	0.80	15812.03
	CRF 4 II	16.70	0.01	188.21	0.04	123264.42
	CRF4III	174.82	0.43	66.00	0.16	40954.74
	Total	**1339.95**	**7.66**	**44.75**	**1.00**	**17400.35**
2020	CRF 4B-E	223.55	7.48	66.52	0.49	2888.23
	CRF 4 II	18.59	0.01	201.43	0.12	131198.12
	CRF4III	181.29	0.43	66.00	0.39	42473.27
	Total	**423.44**	**7.92**	**62.06**	**1.00**	**5245.63**
2021	CRF 4B-E	57.09	7.48	197.50	0.43	663.14
	CRF 4 II	17.99	0.01	200.30	0.14	126933.24
	CRF4III	169.21	0.43	66.00	0.43	39636.80
	Total	**244.29**	**7.92**	**84.09**	**1.00**	**2984.03**
2022	CRF 4B-E	82.80	7.48	131.64	0.44	1006.82
	CRF 4 II	17.39	0.01	199.01	0.14	122735.99
	CRF4III	161.77	0.43	66.00	0.43	37888.69
	Total	**261.96**	**7.92**	**51.41**	**1.00**	**3207.14**

6.3.6.5 Recalculations for deforestation

There were no recalculations for deforestation (Figure 6.15).

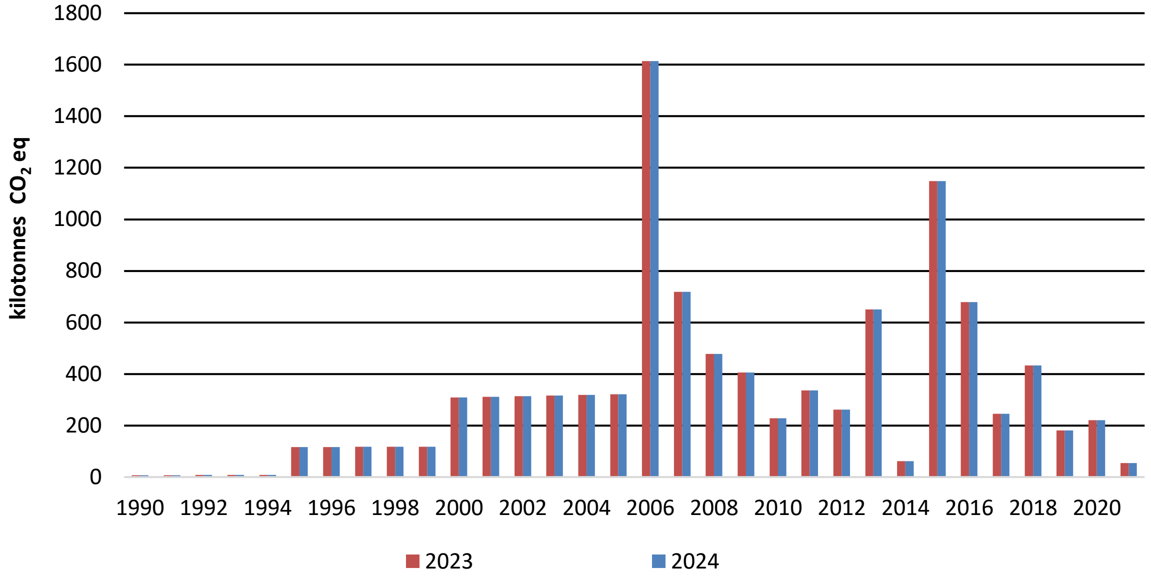


Figure 6.15 Comparison of deforestation emissions for the 2023 and 2024 submissions

6.3.7 Harvested Wood Products (4.G)

6.3.7.1 Harvested wood products methodological approach

Harvested wood products (HWP) are reported based on the domestic production approach outlined in the 2013 Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol.

The primary activity data used for estimating HWP CSC is the EUROSTAT and FAO data from 1961 to 2022. The FAO/EUROSTAT data is used to calibrate the FORCARB and CBM-CFS3 model harvests as described in section 6.3.2.4 and Annex 3.4. The domestic harvest, imported and exported timber flows from 1961 to 2022 are shown in CRF Table 4Gs.2. The methods used to derive HWP for land converted to forest land, land remaining forest land and domestically produced HWP is outlined in the following steps below.

Sawnwood (SW), wood-based panel (WBP), paper and paper board (PPB) HWP feed stock are derived from FAO/EUROSTAT data using Eq 2.8.1 and 2.8.2 of the 2013 IPCC Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol. This uses the data produced in CRF 4.Gs2 and f_{irw} and f_{pulp} ratios to derive the volume of SW, WBP and PPB (see Table 6.25). There is no import and export data for SW and WBP after 2018 due to a change in methodology used by the CSO to collate national statistics data. Therefore, the 2018 f_{IRW} is used for the years 2019-2022 (Table 6.25).

a) Volumes of the SW and WBP HWP from domestic harvest are converted to tC using default conversion factors. The aggregate value of 0.458 and 0.595 Mg m^{-3} is used for SW and WBP, respectively (Table 2.8.1 2013 IPCC supplement). A carbon fraction of 0.5 is used for SW and a C fraction of 0.454 for WBP (Table 2.8.1 of the 2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol). The final inflows of different domestically produced HWP are shown in Table 6.24.

b) Harvest product data was further extrapolated back to 1900 using regression equations using exponential function for each wood product (WP_j):

$$WPj = e^{0.015(year-1961)\times tC1961j} \qquad \text{(eq 6.3.11)}$$

where *year* is the specific year before 1961 and $tC1961_j$ is the t C feedstock for the wood product j in 1961. Historic consumption rates from 1900-1960, using a growth rate of 1.15 per cent yr^{-1}, were used to estimate emissions from products entering the system prior to 1961, as outlined in 2006 IPCC guidelines.

c) The estimation of the annual fraction of harvest originating from the different forest activities (i.e. forest remaining forest (FM), land converted to forest (AR) and deforested (D) harvest) are then derived using Eq. 2.8.3 in Ch 2 of the IPCC supplementary guidance. The input information for the different activities (*j*) are derived from harvest data shown in Table 6.7, Table 6.13 and Table 6.18 in the section above, domestic production fraction and allocations from sawnwood, wood-based panels and paper (Table 6.24).

d) The estimation of the annual amount of HWP being produced from domestic harvest, which is related to the 3 different forest activities is then determined using Eq. 2.8.4 of the 2013 IPPC Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol.

Table 6.24 Annual domestic harvest fraction (F_{IRW}, (eq 2.81 IPCC 2013)), inflows of sawnwood (SW), wood-based panels (WBP), paper and paper board (PPB) from domestic harvest

Year	f_{IRW}	**Sawnwood (SW)**	**Wood based panels (WBP)**	**SW**	**WBP**	f_{pulp}	**Paper and paperboard (PPB)**
		m^3	m^3	tC	tC	Eq 2.8.2	tC
1961	0.944	45317	20487	10378	5511	0.72	3535
1970	0.930	47635	112575	10908	30283	0.07	3591
1980	0.973	125589	62355	28760	16774	0.19	7797
1990	0.981	378570	235380	86693	63317	NO	NO
1995	0.973	659910	327035	151119	87972	NO	NO
2000	0.960	852517	715207	195226	192391	NO	NO
2005	0.908	921476	794376	211018	213687	NO	NO
2010	0.947	731414	758484	167494	204032	NO	NO
2015	0.894	809425	687536	185358	184947	NO	NO
2016	0.911	899608	704883	206010	189614	NO	NO
2017	0.896	948192	749233	217136	201544	NO	NO
2018	0.917	929900	740985	212947	199325	NO	NO
2019	0.917	967009	770555	221445	207279	NO	NO
2020	0.917	943725	752002	216113	202288	NO	NO
2021	0.917	1050928	837426	240662	225267	NO	NO
2022	0.917	1004360	800318	229998	215285	NO	NO

The Tier 2 first order decay model Forestry production and trade data from 1961-2021 from FAO, projected HWP inflows (see above) and historical growth for timber utilisation (see below) were used to estimate harvested wood product (HWP) emissions/removals in Ireland using a model based on the 2006 IPCC Guidelines approach; i.e. the Pingoud and Wagner model:

$$C_{i+1} = e^{-k} \times C_i + \left[\frac{(1-e^{-k})}{k}\right] \times Inflow_i \qquad \text{(eq 6.3.12)}$$

$$\Delta C_i = C_{i+1} - C_i \qquad \text{(eq 6.3.13)}$$

Where:

i = year

C_i = the carbon stock in the particular HWP category from a particular forest activity at the beginning of year i, kt C

k = decay constant of first-order decay for HWP category given in units yr^{-1} (k = ln(2)/HL, where HL is half-life of the HWP pool in years (see below).

$Inflow_i$ = the inflow to the particular HWP category (HWP_j) during year i, kt C yr^{-1}

ΔC_i = carbon stock change of the HWP category during year i, kt C yr^{-1}

Default half-lives of two years for paper, 25 years for wood-based panels, and 35 years for saw[n] wood[7] were used to estimate emissions resulting from products coming out of use.

The final HWP data for forest lands (including deforestation harvest) is shown in Table 6.25. HWP CSC have increased since 1990 due to a decrease in the level of harvest coming from forest categories 4A.1 and 4A.2.

6.3.7.2 HWP uncertainties

Sources of uncertainties related to the FAO were considered to be 15 per cent because national data is based on a systematic survey (Table 6.26). The 2006 IPCC Guidelines provides no HWP (Chapter 12) category specific uncertainties for allocation into HWP categories, C conversion factors or product density conversion factors for biomass, so the same uncertainty was used for all HWP categories (Table 6.26). The combined uncertainty for HWP is 24.2 percent (Table 6.27).

7 Product categories, half-lives and methodologies outlined in para 27, page 31 of FCCC/KP/AWG/2010/CRP.4/Rev.4

Table 6.25 Detailed inflows and CSC for different HWP categories from harvest forest land (including deforestation)

Year	Sawn wood (kt C)			kt CO_2	WBP (kt C)			kt CO_2	Paper (kt C)			kt CO_2	Total
	Gain	Loss	Net	In use	Gain	Loss	Net	In use	Gain	Loss	Net	In use	kt CO_2
1990	86.69	-18.20	68.49	-251.12	63.32	-18.76	44.56	-163.37	0.00	-0.40	-0.40	1.45	-413.04
1995	151.12	-28.53	122.59	-449.49	87.97	-25.12	62.85	-230.47	0.00	-0.07	-0.07	0.26	-679.70
2000	195.23	-40.35	154.88	-567.89	192.39	-40.91	151.48	-555.41	0.00	-0.01	-0.01	0.05	-1123.25
2005	211.02	-55.35	155.67	-570.78	213.69	-61.26	152.43	-558.90	0.00	0.00	0.00	0.01	-1129.67
2010	167.49	-67.83	99.66	-365.43	204.03	-80.40	123.63	-453.30	0.00	0.00	0.00	0.00	-818.73
2011	166.31	-69.77	96.54	-353.96	189.34	-83.58	105.75	-387.76	0.00	0.00	0.00	0.00	-741.72
2012	163.94	-71.64	92.29	-338.41	176.34	-86.30	90.05	-330.18	0.00	0.00	0.00	0.00	-668.59
2013	169.74	-73.51	96.23	-352.85	173.12	-88.71	84.40	-309.48	0.00	0.00	0.00	0.00	-662.33
2014	187.29	-75.57	111.72	-409.64	187.64	-91.22	96.42	-353.53	0.00	0.00	0.00	0.00	-763.17
2015	185.36	-77.74	107.62	-394.59	184.95	-93.82	91.13	-334.13	0.00	0.00	0.00	0.00	-728.72
2016	206.01	-80.06	125.95	-461.83	189.61	-96.38	93.24	-341.87	0.00	0.00	0.00	0.00	-803.70
2017	217.14	-82.63	134.50	-493.17	201.54	-99.09	102.45	-375.66	0.00	0.00	0.00	0.00	-868.83
2018	212.95	-85.23	127.72	-468.29	199.33	-101.86	97.46	-357.36	0.00	0.00	0.00	0.00	-825.66
2019	221.44	-87.82	133.63	-489.96	207.28	-104.64	102.64	-376.36	0.00	0.00	0.00	0.00	-866.32
2020	216.11	-90.39	125.73	-461.00	202.29	-107.37	94.91	-348.02	0.00	0.00	0.00	0.00	-809.01
2021	240.66	-93.09	147.57	-541.08	225.27	-110.29	114.98	-421.60	0.00	0.00	0.00	0.00	-962.69
2022	230.00	-95.88	134.12	-491.76	215.29	-113.29	101.99	-373.97	0.00	0.00	0.00	0.00	-865.73

Table 6.26 Detailed inflows and CSC for different HWP from category 4.A

Code	Component	Sub-category	% Uncertainty	Source
A	HWP categories	SW, WBP, Pulp	15.00	Pg 2.135 Section 2.8.3 Ch IPCC 2013 supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol
B	FAO data	All	15.00	Table 12.6 Ch 12 2006 IPCC Guidelines
C	C conversion factor from dry weight	All	10.00	Table 12.6 Ch 12 2006 IPCC Guidelines
D	Density	All HWP categories	25.00	Table 12.6 Ch 12 2006 IPCC Guidelines
	Combined uncertainty		24.24	

Table 6.27 Uncertainty of HWP estimates for all forest harvests

Year	Year emission/reductions (kt CO_2 eq)	Base year emission/reductions (kt CO_2eq)	Combined uncertainty in year (±%)	Mean trend in year in relation to base-year (% mean trend)
1990	-413.04	-413.04	24.24	na
1995	-679.70	-413.04	24.24	64.56
2000	-1123.25	-413.04	24.24	171.95
2005	-1129.67	-413.04	24.24	173.50
2010	-818.73	-413.04	24.24	98.22
2011	-741.72	-413.04	24.24	79.58
2012	-668.59	-413.04	24.24	61.87
2013	-662.33	-413.04	24.24	60.35
2014	-763.17	-413.04	24.24	84.77
2015	-728.72	-413.04	24.24	76.43
2016	-803.70	-413.04	24.24	94.58
2017	-868.83	-413.04	24.24	110.35
2018	-825.66	-413.04	24.24	99.90
2019	-866.32	-413.04	24.24	109.74
2020	-809.01	-413.04	24.24	95.87
2021	-962.69	-413.04	24.24	133.07
2022	-865.73	-413.04	24.24	109.60

6.3.7.3 Recalculations in HWP

There were no recalculations in HWP in the 2024 submission (Figure 6.16)

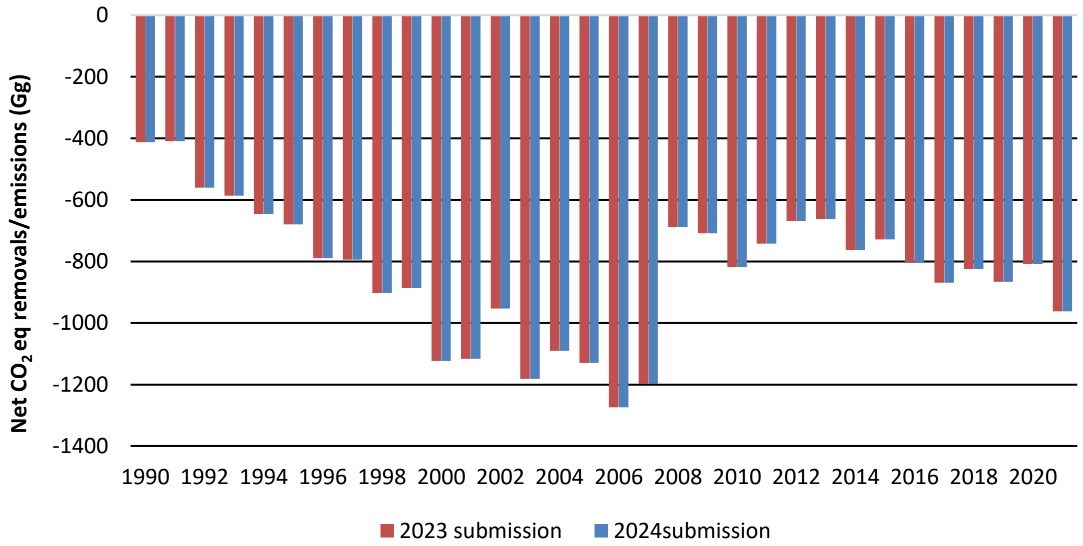


Figure 6.16 Comparison of HWP removals for the 2023 and 2024 submissions

6.3.7.4 Planned improvements for Forest Land (4.A)

Currently there are no planned improvement to the forest land category. However, the CBM-CFS model is being recalibrated using the 2021 NFI, with the following objectives:

- Revision of growth and standing volume curves for different species strata based on additional inventory data (competed in 2023, but not yet implemented);
- Introduction of additional species strata to better characterise growth and standing stock in thinned and un thinned stands (completed in 2023 but not yet implemented);
- Revision of deadwood parameters such as stem mortality and turnover to the medium DOM pools based on NFI data form 2006-2021 (ongoing).
- Calibration of CBM_CFS and validation of biomass, deadwood, litter and soil C stocks using NFI data for 2017-2017 (planned completion for end of 2024.

6.4 Cropland (4.B)

6.4.1 Description

The Definition of Cropland includes “*all annual and perennial crops as well as temporary fallow land”.* This definition includes crops and temporary grassland managed as part of crop rotation systems. The definition also includes hedgerows associated with cropland systems.

Figure 6.17 shows the long-term historic record in areas under crops since 1847. The historic data and more recent data are based on different survey methodologies, but common, under lying, trends are evident. The most notable trend is the long-term reduction in the area under cropland with increased production of crops seen during the first world war (1914-1918) and second world war (1939-1945).

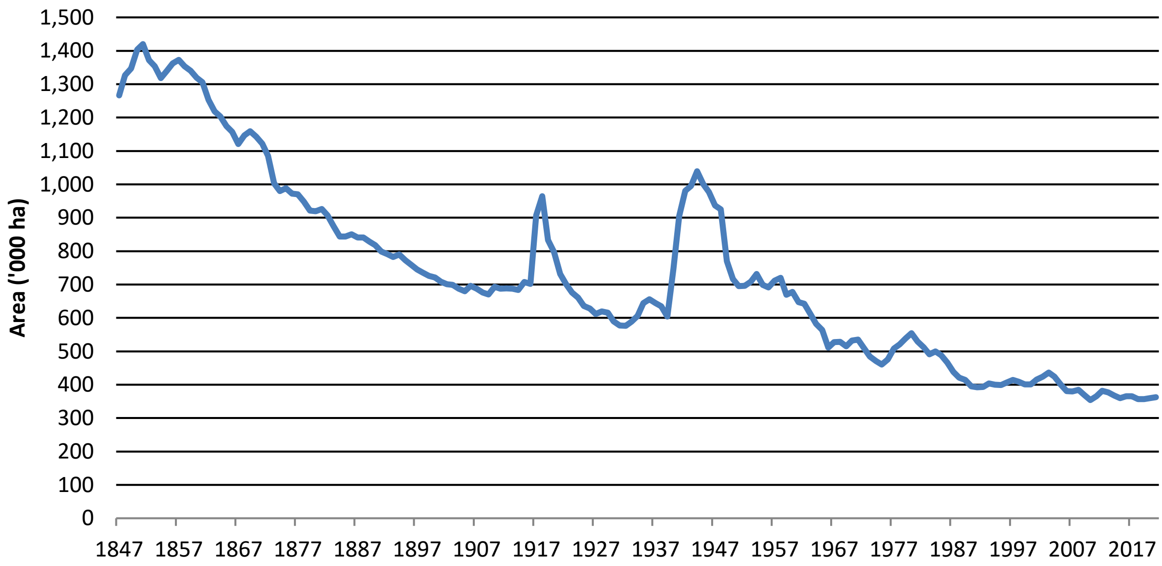


Figure 6.17 Long term time series of areas under crops in Ireland since 1847 to present day

The analysis of cropland area was revised significantly in the 2016 submission. Previously, the area of land associated with cropland was based solely on the annual total utilised agriculture area of crops reported by the CSO. Changes in cropland areas were based on the inter-annual variation in this reported area. The approach led to large inter-annual transitions between Cropland and Grassland land use categories and failed to identify the full extent of land use patterns associated with rotation between cropland and temporary grassland.

The previous approach did not present a complete analysis of the role of temporary grasslands managed as part of a rotational cropland system. This was due to under recording of fallow/setaside areas, and a lack of analysis of the dynamic history of land management at an individual field level. As such the previous assessment of cropland area did not fully represent those lands which would fall under the 2006 IPCC guidelines for the Cropland category: *"Cropland includes all annual and perennial crops as well as temporary fallow land (i.e., land set at rest for one or several years before being cultivated again)"* and *"Arable land which is normally used for cultivation of annual crops but which is temporarily used for forage crops or grazing as part of an annual crop-pasture rotation (mixed system) is included under cropland"*.

The revised approach for the 2016 submission and all subsequent submissions, is based on detailed analysis of the Land Parcel Information System (LPIS) data, collated annually by the Department of Agriculture Food and the Marine (DAFM). The LPIS is a description of all parcels of land covered under various agricultural and rural environmental administrative schemes, in Ireland, since 2000. The system is subject to systematic audit, and provides robust and detail information on croplands. Although the LPIS was not designed to enable tracking of land use over time, careful post-processing and analysis of the data has demonstrated that the tracking of land use, at the resolution of individual parcels is possible with a high degree of consistency (Zimmermann, 2016). Table 6.30 shows several examples of tracking of individual parcels of agricultural land use based on the LPIS dataset.

It is clear that cropland land parcels are managed in a wide variety of ways, ranging from those which are recorded as under crops in all years, indicative of continuous cultivation, to those which have spent only short periods under crops with the remainder in temporary grass.

Based on the analysis of the LPIS, Croplands are identified as those lands which have been cultivated (to grow a crop) in the reporting year, and those lands which are under temporary grassland, but have been recorded as having been also used to grow a crop (cultivated) at some time since 2000. Crops and temporary grasslands combined comprise the area of suitable lands which represent a stable cohort area of Cropland land use. No distinction is currently made between crop types, and the main factor influencing changes in long term carbon profile is the period spent under temporary grass and conventional tillage practices.

The definition excludes permanent grasslands which have been managed exclusively for grazing (pasture) or harvested (silage and hay). However, the temporary grasslands included in Cropland continue to be considered actively managed in the reporting year, often for livestock grazing.

The Central Statistics Office (CSO), provides annual statistics for Utilised Agricultural Area under various land uses, including a detailed breakdown on various crop types and grassland management (pasture, rough grazing, hay and silage). However, the CSO data does not differentiate between permanent and temporary grasslands.

An analysis of historical areas under crops shows a significant decline in crops over a sustained period of decades (Figures 6.17 and 6.18). This is consistent with major changes in the agricultural economy and rural demographic in Ireland over several generations. It is clear that, over time, cropland activities have consolidated into regions with suitable soils and benign climate characteristics.

Figure 6.19 shows a screen capture image of GIS data layers used in the assessment of crop rotation patterns. The image illustrates an example of the attribute data that has been condensed to provide a history of the agricultural use of a parcel since 2000. The rate of switching between cropland and temporary grassland is shown in the legend. The spatial pattern of these rotation patterns provides additional support for the assumption that the cohort of Croplands has been stable since the LPIS was initiated in 2000.

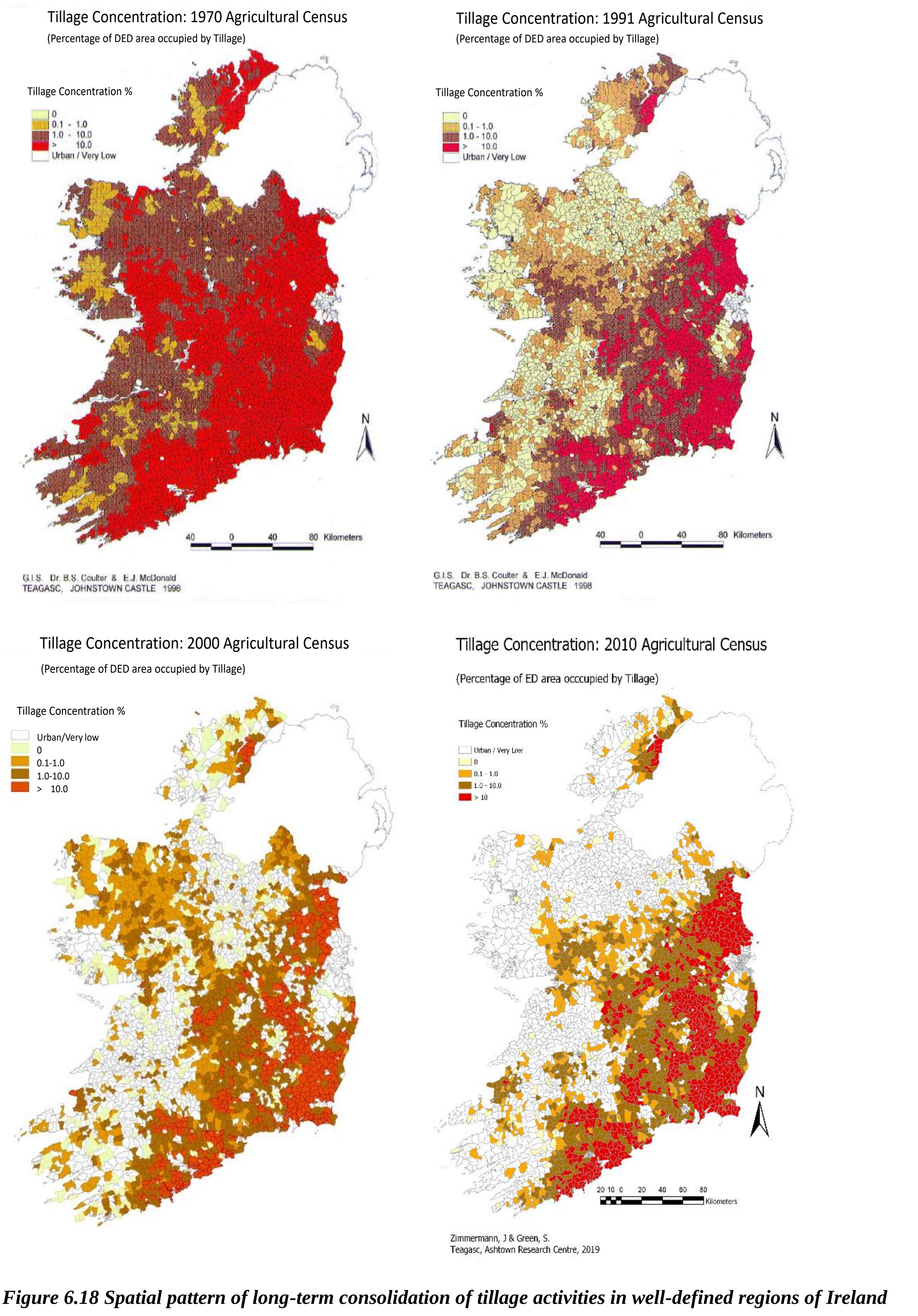


Figure 6.18 Spatial pattern of long-term consolidation of tillage activities in well-defined regions of Ireland

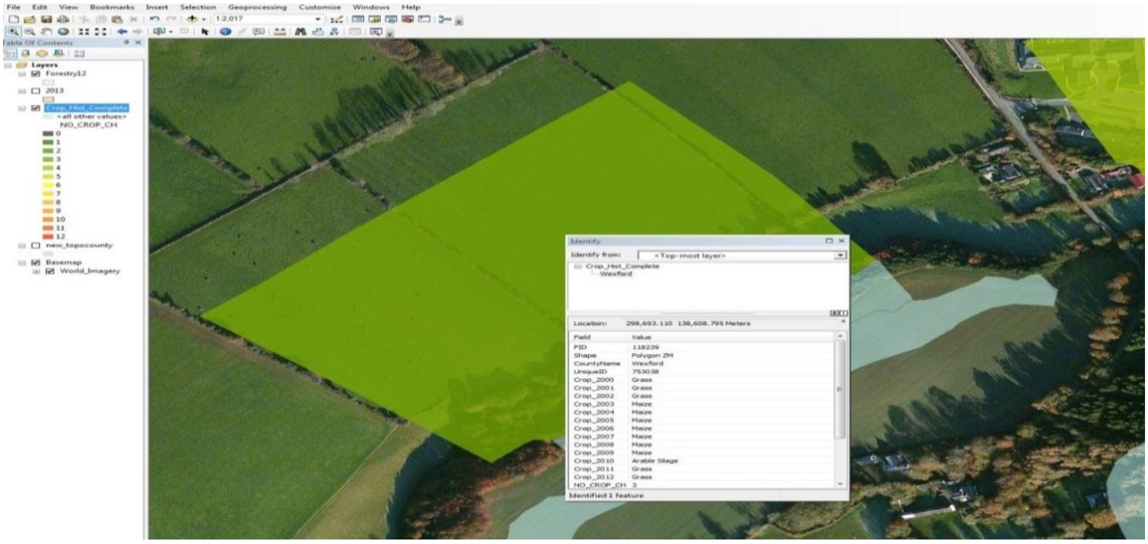


Figure 6.19 GIS layers showing attribute data for an individual land parcel associated with Land Parcel Information System

There is no evidence currently, in the analysis of crop rotation patterns, of any permanent (20 yrs) transition from cropland to grassland. This may reflect two important features of land ownership and land use in Ireland. Firstly, there is a low turnover of land sales in Ireland, with farms remaining in family ownership. Secondly, as a consequence, there is a high level of land rental and leasing on short term agreements. This means it is relatively easy for a tillage farmer to expand production area in response to projected market conditions and sentiment, without the need for major investment in land purchases. It also means that individual parcels on soils suitable for crops may remain under grass for long periods, due to existing leasing arrangements with grassland farms/farmers.

Hedgerows are maintained as an integral system of cropland systems to protect crops against livestock incursion, and to define parcel boundaries. There is anecdotal evidence of hedgerow removal to consolidate adjoining parcels, to facilitate access and traffic of machinery; however, hedgerow surveys across Ireland suggest that removal has not occurred on the same scale as other parts of Europe. Additional work is required to quantify change in hedgerows in Ireland, both in terms of extent and condition, and the inventory agency has funded a number of research initiatives on this topic. At present, a consistent time series of changes in hedgerow extent or condition is not available and methodological issues still exist with respect to their mapping and change over time.

6.4.2 Soil Type and Soil Organic Carbon

For all non-forest land use categories, soil organic carbon (SOC) is the basic parameter in the default IPCC estimation methods for determining carbon stock changes in soils, which is a significant source of carbon emissions in land management and conversion categories in LULUCF. With the exception of forest soils, the organic carbon status of Irish soils is established from the soil type and the default reference soil organic carbon stocks (SOC_{ref}) for cold, temperate moist regions (Tables 2.3, Chapter 5 Volume 4 of the 2006 IPCC guidelines, and the relevant sections of the 2013 Wetlands Supplement). The Indicative Soils Map of Ireland (Fealy and Green, 2009) is the base soil data source used in this analysis for soil type information in Ireland. Mineral soils as identified from the soil map are allocated to the HAC (high activity clay), LAC (low activity clay), sandy and humic soil classes used by the IPCC, while drained peats/organic soils are allocated to the IPCC wetlands class as shown in Table 6.28, based on detailed national assessment of soil carbon stocks in Ireland (Tomlinson et al., 2005). The values of SOC_{ref} appropriate to each soil association may then be assigned using the correspondence to IPCC classes given in Table 6.28. The distribution of CORINE Land Cover over IPCC soil classes was established in the same way to facilitate complete correspondence between land use, soil and SOC_{ref}.

Choice of Methods

Ireland has adopted a Tier 1 approach to reporting greenhouse gas emissions associated with those areas defined as Cropland land use.

Activity data

The primary sources of activity data for Cropland used for the 2024 submission are:

- Central Statistics Office annual statistics of Utilised Agriculture Area (1990-2022);
- Land Parcel Information System data (2000-2022) Maintained by the DAFM. The LPIS is integrated with the forestry, IFORIS data system;
- EPA/Teagasc Indicative Soil Map (2009);
- Activity within the Construction Sector from CSO (1990-2022);
- Fire Information for Resource Management System (FIRMS) NASA;
- National forest fire statistics see Table 6.8;
- Indicative Soil Map (Fealy and Green, 2009) was used to provide indication of soil types

Table 6.28 Soil Class Coverage and Soil Organic Carbon

General Soil Map Soil Association	Proportion of IPCC Soil Class					Proportion of Soil Association in Area of Ireland
	HAC	LAC	Peaty/ Humic	Sandy Soil	Wetlands Soil	
basin peat					0.34	0.06
brown earth		0.19				0.13
brown podzolic		0.21				0.15
Gley		0.30			0.02	0.22
grey brown podzolic		0.30				0.21
Lithosol			0.22	1.00		0.04
lowland blanket peat					0.31	0.05
Podzol			0.78			0.08
Renzinas	1.00					0.01
upland blanket peat					0.33	0.06
Proportion of IPCC Soil Class in Area of Ireland	0.01	0.71	0.10	0.01	0.17	
SOC_{ref} (t C/ha)	95	85	115	71	NA	

6.4.3 Cropland Areas

The area of cropland in a given year is the sum of the area of crops and the area of temporary grassland. The sum can be viewed as the areas of land who's current GHG emissions and removals are influenced by previous and current crop cultivation. The total area of land under crops in any given year is that provided in the CSO national statistics.

In a given year, the area of temporary grassland is estimated as the difference between the CSO estimate of crops in that year, and the total cohort of lands used for cropland as derived from the LPIS.

The LPIS has been used to provide estimates of the area of temporary grassland included under the definition of Cropland land use.

The analysis of the LPIS data from 2000 to 2022 provides robust identification of all parcels used for crops in this period. Figure 6.20 shows the spatial distribution of croplands. They are clearly concentrated within specific geographic regions on a limited range of soil types and similar climatic conditions, as a result of the consolidation processes outline in Section 6.4.1.

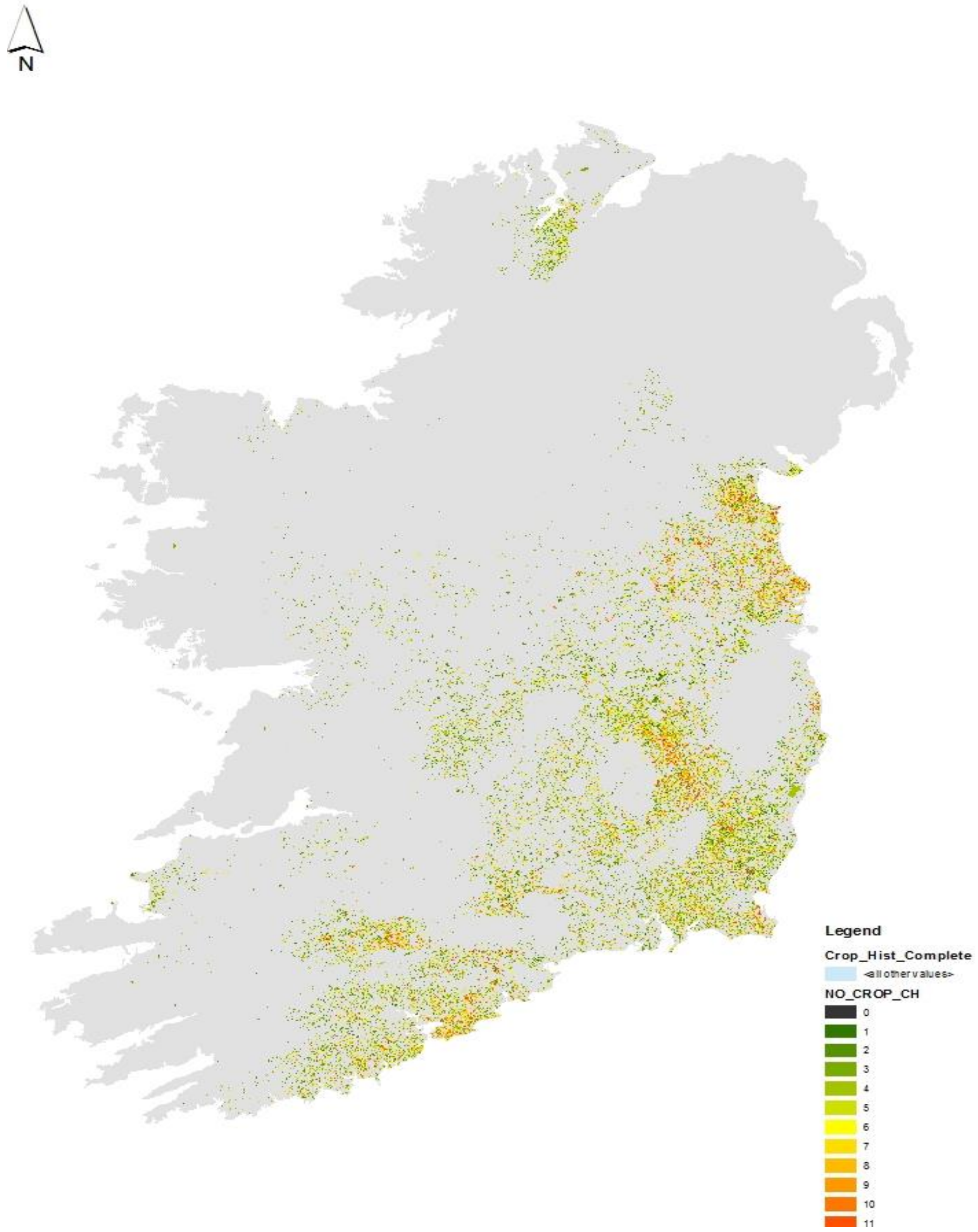


Figure 6.20 Spatial distribution of cropland land parcels in the land parcel information system

During the period 2000-2022, it is possible to explicitly identify parcels converted to Forest land use, as these parcels will either transfer to the IFORIS database, maintain a presence in the LPIS database as Forest, or both.

In order to construct a consistent time series for the period 1990-1999, it is necessary to adjust the area of the cropland cohort to accommodate the known incidences of conversion to Settlement. In order to meet this demand, the cohort of Cropland in 1990 must include those lands which are later converted to Settlement. The demand for settlement on croplands is currently based on estimates of activities in the construction sector which is disaggregated based on the proportion of national land use in forest land, cropland, grassland and other land. See section 6.7 for more detail on the attribution of previous land use for new Settlement. It is assumed; these lands will be excluded automatically from the LPIS dataset and the CSO statistics, or assigned an appropriate attribute: e.g. farm building, dwelling, etc.

There is an important consequence of using this approach for Cropland, which includes all crop and temporary grassland land parcels identified within the 2000-2022 LPIS data, and extrapolation of this area back to 1990 on the basis of known conversion to Settlement. Therefore, by definition, there has been no land converted between Cropland and Grassland land uses, and by corollary all agricultural grasslands within the Grassland land use category are defined as permanent grasslands.

The analysis has not provided evidence of deforestation to Cropland. Likewise, the analysis does not identify an instance of conversion of Wetlands, Settlement or Other Land to Cropland. Therefore, transition of land to Cropland does not occur, and is assigned the notation key “NO” in the CRF tables.

All changes in emissions and removals are associated with short term transitions between crops and temporary grasslands, and are reported as occurring in the Cropland remaining Cropland land use category.

The analysis of the LPIS dataset provides the history of each land parcel. However, it is not feasible to produce estimates of emissions and removals for each parcel. Therefore, it was necessary to devise a consistent approach to summarise the spatial data. To undertake this analysis, the crop types were aggregated into two broad classifications: Crop or Grass. For ease of analysis these where further codified into “0” for Crop and “1” for Grass. This allows the compression of the history of each parcel into a binary code, and for grouping of parcels based on similar patterns of land use history. A total of 133,929 land parcels can be identified as having a complete cropping history. These are condensed into 9,909 management (crop rotation) patterns, plus one pattern of continuous cropping. Table 6.29 shows some examples of this coding and grouping and how it is successful in condensing cropping history data into a more manageable form. Figure 6.21 shows the time series of the inferred proportion of land parcels within the Cropland category which are temporary grassland in a given year.

Table 6.29 Examples of binary coding of cropland parcel history

Pattern Id	Code	Number of Parcels	Sum Area (ha)	Number of years of Grass
A	0000000000000	35897	159930.6	0
B	0000011111111	3558	11180.48	8
C	1101111111111	1511	7695.15	12
D	1100000000000	1431	5569.52	2
E	1111111100111	899	3159.8	11
F	1100111111111	840	3317.04	11
G	1110011111111	824	2880.86	11
H	0000000000100	211	636.19	1
I	1111100000111	127	416.92	8
J	0000011000000	93	295.82	2
K	0000000111100	83	300.05	4
L	1111000000001	83	299.76	5
M	0010000000000	81	341.9	1
N	0001011111111	79	373.34	8
O	0000101111111	77	474.12	7
P	0000001011111	75	210.82	6
Q	0011000000000	73	309.55	2

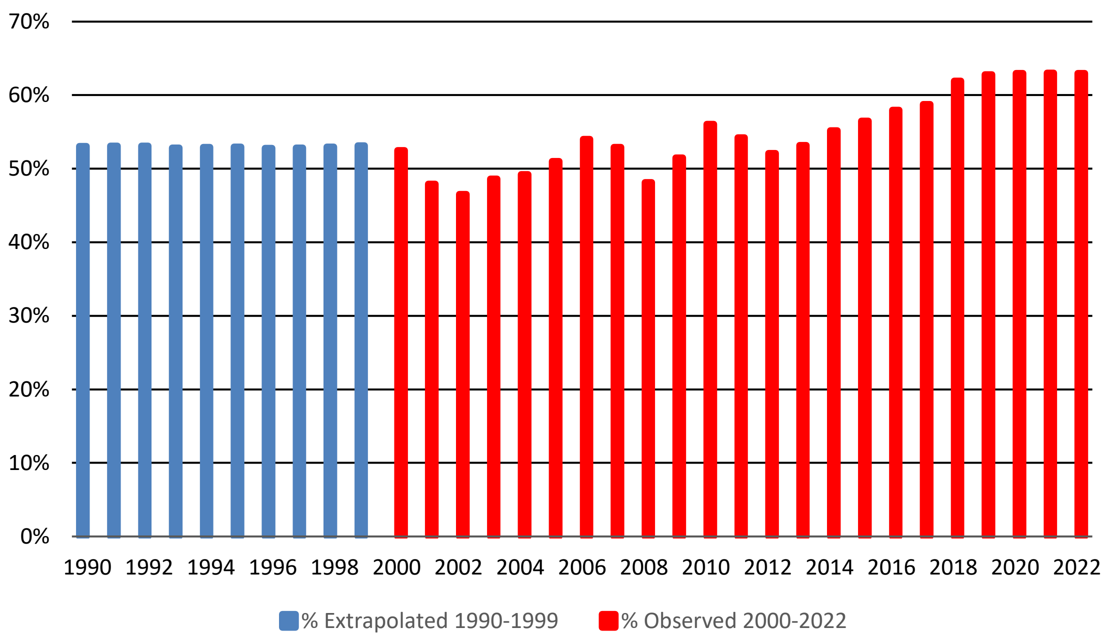


Figure 6.21 Proportion of Cropland cohort which is under temporary grassland each year

It is interesting to note the difference in histories of crop parcels and temporary grassland parcels, shown in Table 6.29. Not surprisingly, if in 2012 a parcel was identified under a crop, then it is more likely to have been under crops in previous years, and spent relatively less time under temporary grass, and vice versa. This reflects the situation that tillage farmers in Ireland will concentrate their efforts on the lands they own, and therefore these lands will spend more time under crops. While, temporary grassland will include a high proportion of lands which are rented or leased for crops on an ad hoc, demand driven, basis, and therefore are less intensively used for crops.

For the period from 1990-1999 the land use pattern is estimated based on a Monte Carlo analysis whereby for each land use pattern 500 simulated times series are constructed for the period 1900 to 1999, constrained by the probability of observed crop/temporary grass for these parcels during the known period from 2000-2022. A run-in period from 1900-to 1989 was used to enable a statistically robust estimate of the initial carbon content associated with long term application of the particular land management/land use pattern prior to the inferred patterns from 1990-1999 and the specific pattern of land use from 2000-2022. However, while this statistical reconstruction approach preserves the specific land use pattern at parcel level, it creates an overall pattern of crop and temporary grassland rotation which has sharply less inter-annual variability than the observed pattern in the period 2000-2022.

The LPIS and Indicative Soil Map (Fealy and Green, 2009) were overlaid to provide an indication of the soil types associated with parcels within the Cropland cohort. The Indicative Soil Map was produced at a resolution of 1:250,000. As such, caution must be taken when attempting to assign additional attributes to the much higher resolution LPIS data. Approximately 98 per cent of parcels associated with crops were associated with Low Activity Clay (LAC) Soils. Approximately 2 per cent were associated with High Activity Soils (HAC) and less than 1 per cent associated with a peat substrate.

Even with the large uncertainty associated with identification of soil type from the Indicative Soil Map, it is possible to estimate the change in carbon pools based on the assumption that all complex crop rotation patterns occur on the low activity soils, without introducing significant bias in the estimation of emissions and removals.

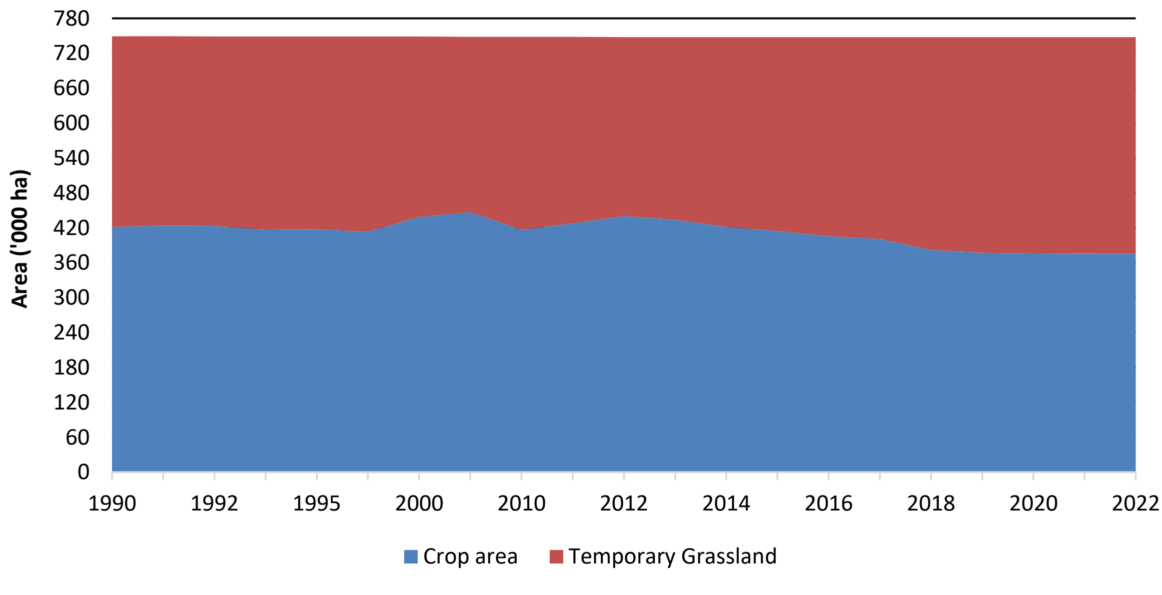


Figure 6.22 Time series of Cropland 1990 to 2022

Figure 6.22 shows the shows the time series of Cropland area from 1990 – 2022, split between the area under crops in a given year, and the area under temporary grassland. The total area decreases slightly over time, reflecting on-going conversion of Cropland to Settlement. Figure 6.17 shows analysis of the long-term trend in croplands in Ireland over the last one and a half centuries shows a steady decline in tillage area (with temporary reversals associated with exceptional measures to address food security concerns during World War I and World War II), and the consolidation of cropping activity to the most suitable soil types and local climate zones in Figure 6.18. From the graph in Figure 6.17, this long-term trend appears to have achieved a steady state, and it is reasonable to assume that no lands were in transition to cropland at the beginning of the reporting period, 1990. Therefore, it is assumed, that with the exception of land conversion between Cropland and Settlement, the Cropland cohort, identified from the analysis of the LPIS data from 2000-2022, has been stable since 1990.

6.4.4 Carbon Stock Change in Biomass

Estimation of changes in above ground biomass is described below. It is assumed, by the Tier 1 methodology that below ground biomass remains constant if there is no change in long term management.

Annual Crops

Changes in above ground biomass are based on the areas transitioning between crops and temporary grassland in the given year. It is assumed there is no significant to change in below ground biomass.

For the period 2000-2021, the area of land converted from crop and temporary grass (and vice versa) is estimated based on the actual parcels reported to undertake the transition in the given year. This has been estimated on an annual basis for all years from 2000-2021 from the LPIS database. It is not possible to adopt this approach for the period 1990-1999 as data at parcel level is not available. Therefore, the average rate of conversion between crop and temporary grass reported from 2000-2021 has been assumed as representative for years 1990-1999.

The biomass stock change and its estimation is based on the difference between initial and final carbon content of biomass for the lands converted. In the conversion of temporary grassland to cropland, it is assumed under the Tier 1 approach that the dominant vegetation from the initial land use is removed entirely. The carbon stock change is then quantified as the net sum of carbon lost on conversion and the carbon added by the first year's growth. It is assumed that temporary grasslands are managed in the same manner as improved permanent grasslands. The dry matter content of grassland is taken as 13.6 tonnes ha^{-1} and the carbon content of dry matter is 0.4 per cent. A value of 5 t dry matter ha^{-1} is adopted for the carbon stock in crop biomass after one year. The carbon stock change in biomass on the area (A) converted to cropland is then calculated using eq 6.4.1, derived from eq 2.15 from Chapter 2 Vol 4 of the 2006 IPCC guidelines as follows:

$$\Delta C = A * [(C_{after} - C_{before}) + DC_{growth}] \qquad \text{(eq 6.4.1)}$$

$$\Delta C = A * [(0.0 - 13.6.0) * (0.4)) + (5.0*0.4)]$$

Where A is the area of crops converted to temporary grassland.

Similarly, the inverse relationship is applied where the transition is from temporary grassland to annual crops. Table 6.30 and Figure 6.23 provide an example of the application of this approach for a specific example of crop and temporary grassland rotation pattern. In total there were 9,909 rotation patterns and plus one pattern of continuous cropping identified, representative of activity on 133,929 parcels of land.

Table 6.30 Example of crop and temporary grassland rotation pattern

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
	Crop	Crop	Crop	Crop	Crop	Crop	Crop	Crop	Crop	Crop	Crop	
Year	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	
	Grass	Grass	Crop	Crop	Crop	Crop	Grass	Grass	Grass	Grass	Grass	

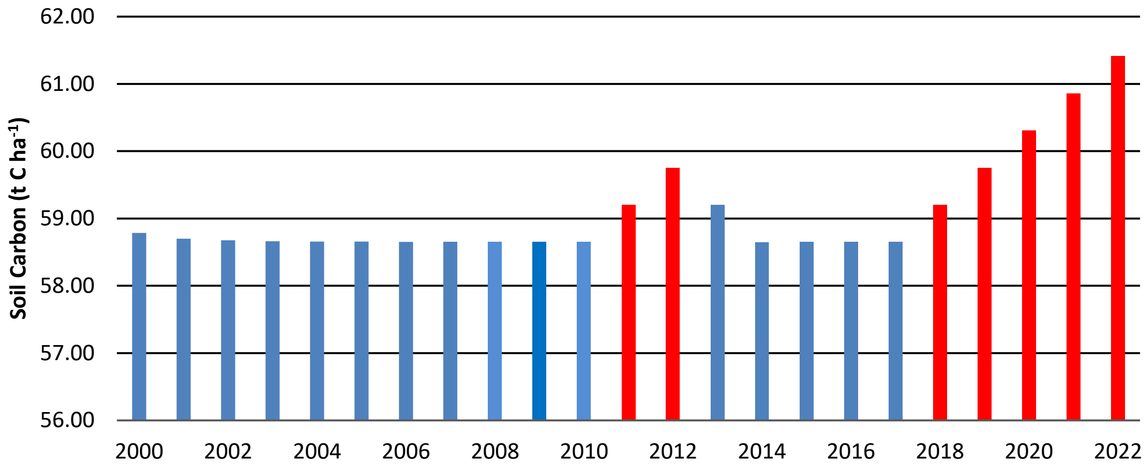


Figure 6.23 Estimated Soil Carbon per hectare based on the crop rotation pattern outlined in Table 6.30 for the period 2000-2021

Perennial Woody Crops

The area of woody crops (including Christmas trees) are included in the CSO "Other Crops" category. However, this category is dominated in the period 1993 to 2007 by the additional reporting of fallow or set-aside lands in this same category.

The areas of fruit orchards are included in the CSO "Fruit" category, however, this category also includes soft, non-woody fruit plants, including the strawberry crop. The area under Fruit is in a long-term decline, which, appears to reflect an industry trend towards indoor, protective environments for strawberry production which have a reduced area footprint. Therefore, the annual CSO statistics are not a suitable data source for perennial woody crops.

A self-consistent time series of activity within the Christmas tree sector is not available either. Christmas trees are defined as a horticultural crop and are therefore included in the CSO annual statistics within the broader horticultural sector. A variety of sources of information have been explored, with some widely different estimates of the national plantation area. There is, however, a high level of consistency in the market for Christmas trees. O'Reilly et al (1997) produced a report for COFORD on opportunities within the Christmas tree sector which estimated a plantation area of 1,500ha to supply a market of 450,000 trees. In 2002, an All-Island report from InterTrade Ireland[8] published estimates from Bord Glas and Goodbody Economic Consultants of some 3,000 ha of plantations in 1998, falling to 2,428 in 2001. In 2006, the Teagasc Fact Sheet on Christmas Tree

[8] http://www.intertradeireland.com/media/A%20Review%20of%20the%20All-Island%20Horticulture%20Industry.pdf

Production estimates between 300,000 and 500,000 trees were planted each year. Bord Bia [9]currently estimates the market for Christmas trees from Irish producers to be between 500,00 and 700,000 plants. Typically, trees are grown at a density of between 4,500 and 7500 plants per hectare. This implies an annual demand for harvesting in the range of 68 to 144 ha of Christmas tree plantation with 2m trees harvested at ages between 7 to 10 years. From this an area, with a estimate of 1,500 ha is calculated. Therefore, it is reasonable to assume that national Christmas tree plantation areas are in long term equilibrium with respect to total area and it is assumed that the area remains constant at 1,500 ha per year (Figure 6.24).

In Ireland, the dominant commercial permanent woody fruit crop is apples. Annual statistics on area of apple orchards are not available. Census of Apple Orchards in Ireland data are available for years 1991, 1997, 2002, 2007, 2012 and 2017.There are estimated to be 45 specialised apple growers in Ireland. There was a significant decline in area under apple orchards during the early 1990's from 732 ha in 1990 to 591 ha in 1997, however, the sector appears to have stabilised, with no significant trend in area under orchard since 1997 (Figure 6.24). The estimated annual areas for years between censuses data has been based on linear interpolation between data points. The estimate of biomass gains and losses associated with transitions between perennial crops and other crop types is based on the Tier 1 approach described in Section 5.2.1.1, Vol 4 of the 2006 IPCC Guidelines.

Biomass in transition from perennial woody crop to annual crops is estimated using eq 2.15 from Chapter 2 Vol 4 of the 2006 IPCC Guidelines.

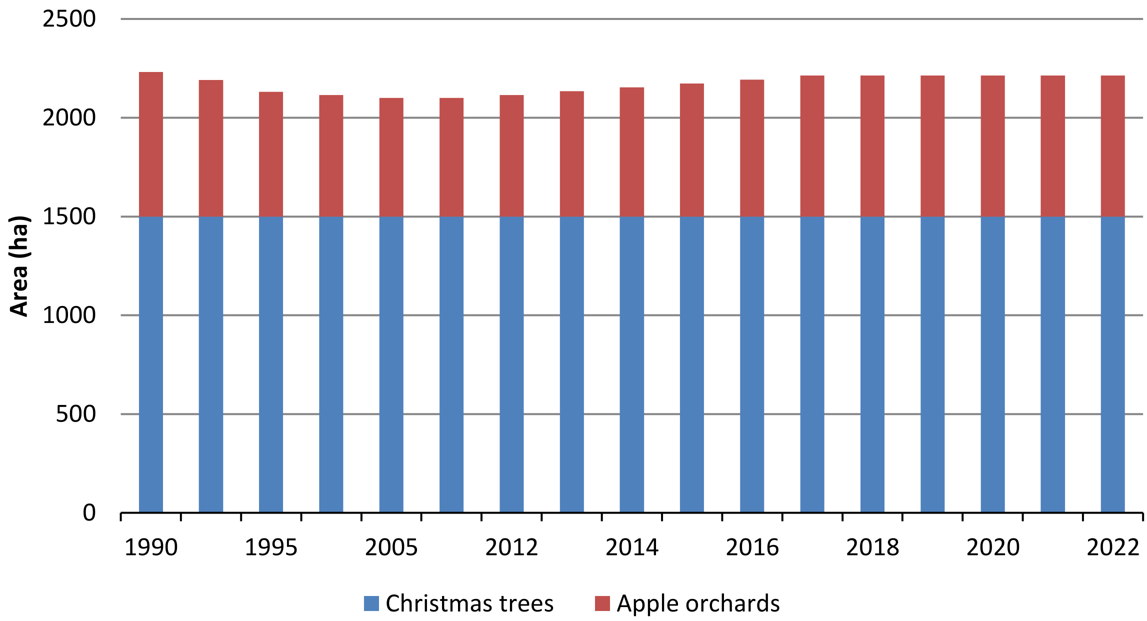


Figure 6.24 Estimated area under Perennial crops 1990-2022

$$\Delta C_B = \Delta C_G + \Delta C_{conversion} - \Delta C_L \quad \text{(eq 6.4.2)}$$

Where DC_B = annual change in biomass stock in perennial crops

[9]http://www.bordbia.ie/industry/manufacturers/insight/publications/MarketReviews/Documents/Export-Performance-and-Prospects-2015.pdf

ΔC_G=annual increase in carbon stocks in biomass under perennial crops. This is assumed to be zero for well-established perennial crop areas. For lands in transition, the accumulation rate is given by the reference carbon stock (63 t C ha^{-1}) divided by a default 30 year period it is assumed it takes for woody crop to reach maturity/equilibrium.

$\Delta C_{conversion}$ = the initial decrease in biomass from perennial woody crops to annual crops. This is equal to the net change due to a loss of 63tC ha^{-1} in the year of transition, from Table 5.1 Chapter 5 Vol 4 of the 2006 IPCC Guidelines, and a gain in biomass due to subsequent growth of crops in the year of transition. This is equal 5.0 t C yr-1, from Table 5.8 of Chapter 5 Vol 4 of the 2006 IPCC Guidelines.

ΔC_L= is the annual loss due to harvesting, fuel wood gathering and disturbance. This is assumed to be zero for well-established perennial crops. The estimated carbon stock change in biomass across the timeseries is presented in Figure 6.25.

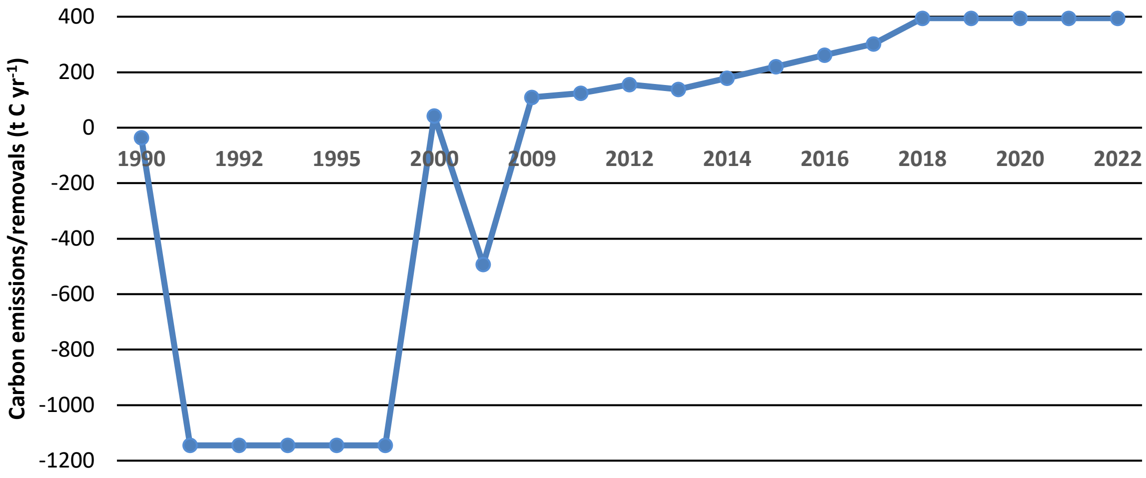


Figure 6.25 Carbon Stock Change in Biomass in Perennial Crops

6.4.5 Cropland Dead Organic Matter/Litter

The tier 1 assumption is applied, with default estimation of zero emissions or removals associated with dead organic matter/ litter.

6.4.6 Carbon Stock Change in Soils

The spatial distribution of cropland areas over IPCC soil class is derived from GIS analysis of the LPIS dataset provided by the Department of Agriculture, superimposed on the Indicative Soils Map of Ireland (Fealy and Green, 2009). The GIS analysis shows that a very high proportion (98 per cent) of croplands are located on Low Activity Clay (LAC) soils. It is assumed that only grasslands on LAC soils are suitable for direct conversion to croplands, which is consistent with the requirement for cropland productivity. It is therefore reasonable to assume that all temporary grassland areas converted to croplands are also on LAC soils.

6.4.7 Estimation of Emissions from Soils

The annual change in SOC in mineral soils over the transition period is based on the Tier 1 methodology, described in Section 2.3.3.1, of the 2006 IPCC Guidelines. Emissions and/or removals are estimated using equation 2.25 of the 2006 IPCC Guidelines, as follows:

$\Delta C = A * (SOC_0 - SOC_{0-T}) / T$ (eq 6.4.3)

$SOC = SOC_{ref} * F_{LU} * F_{MG} * F_I$

where

- ΔC = annual change in carbon stocks
- A = area of land converted from a former land use
- SOC_0 = soil organic carbon stock for current land use
- SOC_{0-T} = soil organic carbon stock for former land use
- SOC_{ref} = reference soil organic carbon under native vegetation for a given soil type in area A
- T = transition period
- F_{LU} = stock change factor for land use or land-use change type
- F_{MG} = stock change factor for management regime
- F_I = stock change factor for organic matter input

The factors F_{LU}, F_{MG} and F_I account for changes in SOC due to management practices that impact on soil carbon. Table 6.32 presents the adjustment factors derived from the product of F_{LU}, F_{MG} and F_I taken from 2019 IPCC Guidelines for the land uses defined for Ireland (Table 6.31). Equation 6.4.3 is the basic Tier 1 methodology used for estimating emissions from mineral soils for all land-use categories as described in the following sections. The default transition period of 20 years is applied for all mineral soils.

Carbon stock changes in mineral soils are estimated using the methodology outlined in Section 6.4.3 and Equation 6.4.3. Farm management and input practices for crop and temporary grasslands are assumed to have been constant over the inventory period for lands within the cropland cohort. Therefore, the SOC will change for mineral soils, only in response to variations in the period lands spend under temporary grasslands.

Table 6.31 Adjustment Factors for SOC

Land Use	**F_{LU}**	**F_{MG}**	**F_I**	**Adjustment factor, AF**
Cropland	0.69	1.0	1.0	0.69
Improved grassland	1.0	1.0	1.14	1.14
Unimproved grassland	1.0	1.0	1	1.0
Temporary grassland	0.82	1.0	1.0	0.82
Rough grazing and other grassland	1.0	1.0	1.0	1

The approach taken to estimate changes in soil carbon stocks is based on the pattern of cropland rotation allowing carbon uptake to soil in years when a land parcel is under temporary grassland, and carbon loss for years under crops. The maximum carbon uptake under grassland is limited to the reference level for improved grassland, while the minimum carbon removal is limited to the reference level for permanent croplands. The initial level of carbon associated with a given pattern of land use is estimated from the average carbon content arising from the Monte Carlo simulation of 500 instances of the pattern populated with random binominal probability equal to the observed proportion of crop years in the period from 2000-2022. In this way, parcels which have a history of mostly temporary grassland will tend to start with high soil carbon stocks, whereas those with a history of mostly crops will tend to start with low soil carbon stocks.

Table 6.32 shows the average carbon stocks for crop and temporary grass parcels based on years spent under grass. Clearly, the more years a parcel spends under a crop, the closer its carbon content is to the reference level for continuous cropping. Likewise, the more years a parcel spend under grass, the closer the carbon levels are to the reference content for permanent grassland.

The incorporation of parcel history into the approach for estimation of soil carbon emissions and removals successfully reflects rotational crop management practices, which developed over time to maintain soil condition and fertility.

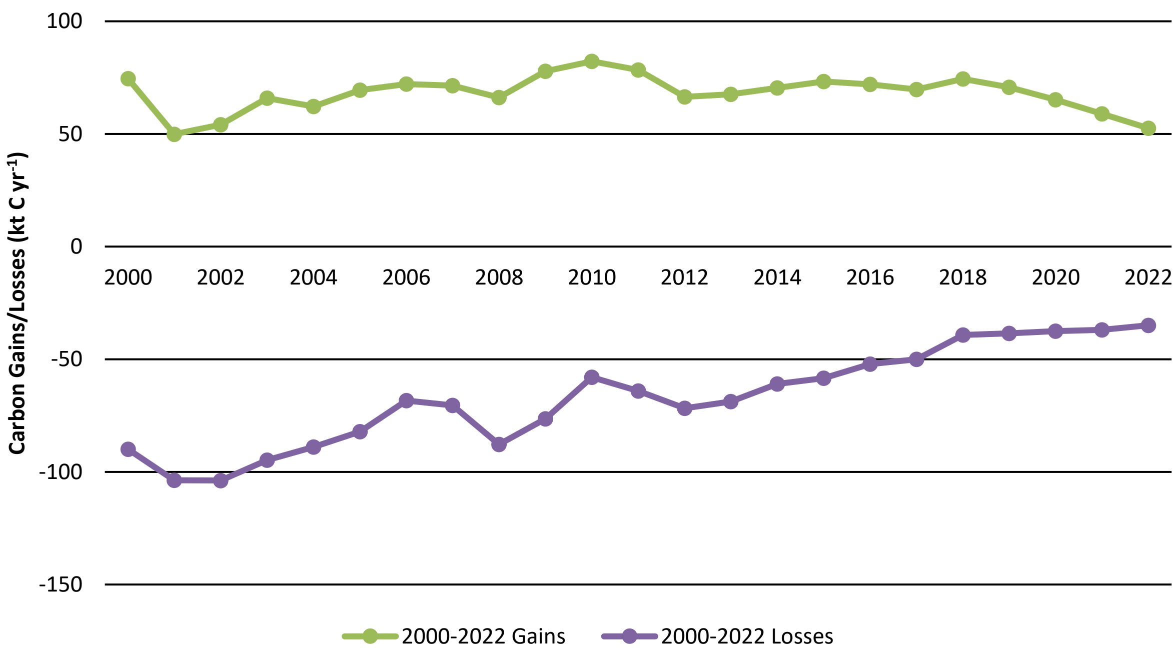


Figure 6.26 Time Series of estimated soil carbon gains and losses associated with rotational patterns of crop production and temporary grassland

Table 6.32 Carbon content of cropland soils as a function of the period under grass or crop over a 20-year period

Carbon content of Soil (tC ha-1)		
Years	Crops Under Grass	Grass under Crop
0	58.7	69.7
1	59.2	69.1
2	59.8	68.6
3	60.3	68.0
4	60.9	67.5
5	61.4	66.9
6	62.0	66.4
7	62.5	65.8
8	63.1	65.3
9	63.6	64.7
10	64.2	64.2
11	64.7	63.6
12	65.3	63.1
13	65.8	62.5
14	66.4	62.0
15	66.9	61.4
16	67.5	60.9
17	68.0	60.3
18	68.6	59.8
19	69.1	59.2
20	69.7	58.7

6.4.8 Cropland emissions due to Biomass Burning

Activity data on the occurrence of fire on cropland is limited but recently developed remote sensing products may yield a better understanding of the occurrence of fires on cropland in the future. Similar to previous submissions the NASA Fire Information for Resource Management System (FIRM) data set for the region of Ireland was interrogated to establish the occurrence of fires on cropland. When overlayed with the CORINE datasets for the years 2000, 2006, 2012 and 2018 it has identified that on average approximately 4 per cent (Table 6.33) of the recorded fire events in any one year coincide with cropland locations. There are however, significant limitations to this approach mainly related to the relatively low spatial resolution and high probability of cloud interference in any signal over Ireland.

Based on the overlay of the NASA FIRMS dataset with CORINE a table of the probability of fire on each land use type for each year 2001 to 2022 was constructed.

The activity data for forest fire is described in section 6.3.4.4 and are therefore known with a greater confidence to the NASA FIRMS/CORINE overlay. This area of forest burnt is then used as a scaling factor to estimate the number of fires on the other land uses based on the relative proportion by land used derived from the GIS overlay of the NASA FIRMS dataset and the CORINE data for the years 2000, 2006, 2012 and 2018.

Meteorological conditions determine the suitable conditions for fire, however remote sensing cannot establish whether the actual fires are due to natural causes or direct human interventions. Although not prohibited by law, it is not common practice to deploy controlled burning as a cropland management tool. Landowners are required to inform local authorities and fire services of their intention of initiating a controlled fire, however this information has not been collated at a national level. Dr Jesko Zimmermann was commissioned in 2012 to provide a review[10] of available data of biomass burning on croplands. The principle findings of this review were "*while single events of crop residue burning cannot be ruled out, it is not common practice in Ireland. Generally, reporting on crop residue burning as part of the national greenhouse gas budget is not feasible, as the available data does not allow distinction between natural and other anthropogenic causes of fire. Furthermore, as the spatial resolution of the fire detection algorithm is 1km^2 fire cannot be associated with a distinct land-parcel. Considering these limitations, any estimate GHG emissions caused by this activity would show high uncertainties*."

Table 6.33 Land Cover/Use associated with NASA FIRMS instances fires and the average proportion of fires detected

Land Use	Proportion of All Fires Detected
Forest	10.6%
Cropland	4.9%
Grassland	20.1%
Wetlands	63.3%
Settlement	1.1%
Other	0.0%

Therefore, the incidence of fires detected on croplands is assumed to be as a result of an accidental fire outbreak. Therefore, all fires on cropland are classified as wildfire, and the notation key "IE" assigned to 4(V) Controlled Fires on Cropland.

The emissions associated with fires are estimated based on the Tier 1 approach outlined in 2006 and 2019 IPCC guidelines Vol 4, Section 2.4 and additional details provided in Vol 4 Chapter 5, Section 5.2.4.2 for cropland remaining cropland.

Note, the Tier 1 approach assumes that there are no long-term losses of biomass carbon due to fires on cropland, and emissions are estimated for CH_4 and N_2O only.

Emissions of CH_4 and N_2O are calculated using eq 2.27 from Chapter 2 Vol 4 of the 2006 IPCC Guidelines, and shown here:

$$L_{fire} = A \cdot M_B \cdot C_f \cdot G_{ef} \cdot 10^{-3} \quad \text{(eq 6.4.4)}$$

Where L_{fire} = amount of greenhouse gas emissions from fire, in tonnes of gas (CH_4, N_2O),

A = area burnt, ha,

M_B = mass of fuel available for combustion, tonnes ha^{-1}. This includes biomass, litter and DOM. For Tier 1 Litter and DOM are assumed zero for croplands remaining croplands.

Cf = combustion factor, dimensionless,

The default value for M_B .C_f is 4.0 from Table 2.4 in the Chapter 2 Vol 4 of the 2006 and 2019 IPCC Guidelines

G_{ef} = is the emission factor, g kg^{-1} dry matter burnt. The default values for cropland are CH_4= 2.7 g kg^{-1} dm_{burnt}, N_20 =0.07 g kg^{-1} dm_{burnt}.

[10] Private communication: Dr Jesko Zimmermann, School of Natural Sciences, Dept. of Botany, Trinity College Dublin, *A review of crop residue burning MODIS Fire detection archive for Ireland* 2013

6.4.9 Uncertainties and time-series consistency in Cropland estimates

Time Series Consistency

The Land Parcel Information System is used to estimate the impact of short-term land management practices and temporary transitions between crop and temporary grassland. The LPIS data from 2000-2022 was used in the analysis presented in this submission. There is inter-annual variation, but no evidence of longer-term trends in this period. This is consistent with the CSO data for crops, which show the period back to 1990 to have a similar trend. However, as noted the CSO data only captures net transitions between crop and grassland and back again.

Uncertainty in Area

The uncertainty in areas for the period 2000-2022 can be estimated from the requirements for submission of data to the DAFM under the various farm payment schemes. The requirement for submitting data to the LPIS is for an accuracy of 0.1 ha for parcels. The mean parcel size is 4.3 ha. Therefore, the average uncertainty for each parcel is of the order of 0.1/4.3, or 2.3 per cent.

Uncertainty in areas for the period 1990-1999 is more difficult to quantify. The uncertainty in areas is based on the uncertainty in the CSO data for that period which is estimated at approximately 2.0 per cent.

Uncertainty in Emissions

The uncertainties associated with estimation of greenhouse gas emissions and removals due to activities under the Cropland land use are based on those appropriate to the adoption of the Tier 1 methodologies, land use and management factors and emission factors set out in the 2006 IPCC guidelines.

6.4.10 Category Specific QA/QC and verification

Standard QA/QC procedures have been applied to the Cropland sector estimates. Details of Ireland's QA/QC process can be found in Chapter 1 of this report.

6.4.11 Cropland recalculations and impact on the emission trend

The recalculations in 4.B Cropland relate to the refinement of LPIS data and the ongoing reanalysis of the full time series as the most recent inventory year is added to the dataset, thus affecting the long term pattern of cropping across the time series and the dynamic of cropping and temporary grassland within the cropland cohort. This has led to recalculation of emissions and removals for all years in the reporting period. Figure 6.27 shows a comparison between 2023 and 2024 submissions of estimated total emissions and removals associated with Croplands.

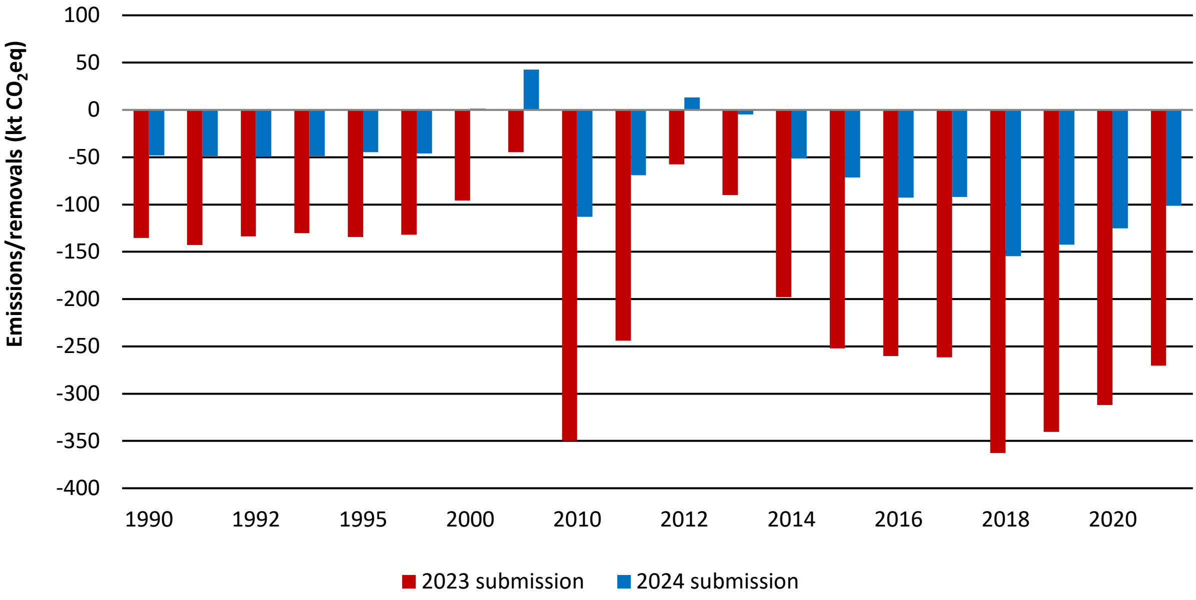


Figure 6.27 Comparison between the 2023 and 2024 submissions of estimated total emissions and removals associated with Cropland

6.4.12 Cropland Category specific planned improvements

The 2015 submission was the first step towards incorporation of the Land Parcel Information System into the reporting methodologies for Croplands. This was re-evaluated for the 2016 submission and all subsequent submissions in the context of a relatively stable Cropland cohort area. The extrapolation of LPIS analysis to the period 1990-1999 presented in this submission is relatively simplistic. Further analysis will be undertaken, including exploration of pre-2000 agricultural spatial databases and ortho photography, to further refine the understanding of land use within Cropland category during this period. The inventory agency aims to enhance this analysis through the development of a national land use map for LULUCF reporting under the LULUCF Regulations (EU) 2018/841 and (EU) 2023/839. A scoping study was completed in this regard in 2019, the results of which has informed the design of a national land use map which is currently under development. The results of this work will be integrated into the Cropland sector methodologies as results become available.

The inventory agency has funded research into remote sensing technologies and analytical techniques for the quantification of non-forest woody biomass in the landscape. In the context of Cropland, this refers to primarily hedgerows. A project (which was completed in 2022) aimed at quantifying the carbon stock in hedgerows and non-forest woody biomass features in the landscape. Hedgerows are an important feature of the Irish landscape. They are traditional means of establishing field and ownership boundaries and protecting crops from livestock incursion. In recent years, environmental payment schemes have included incentives for hedgerow plantation, maintenance and protection. However, while projects such as that described above may be used to estimate the current carbon stock in hedgerows, questions remain in terms of establishing the carbon stock change over past years and also establishing the spatial extent and management of hedgerows in the past. The inventory agency is currently examining techniques to capture the management and extent of hedgerows for historic years.

6.5 Grassland (4.C)

Grassland land use includes improved grasslands, unimproved grasslands and grasslands not currently in use. Improved grasslands include areas identified as lands managed for livestock grazing and grass based feed and winter fodder production (pasture, silage and hay). Unimproved grasslands are identified as rough grazing for livestock, predominantly sheep or low intensity beef farming. Grasslands not in use are those lands identified as dominated by grass habitats, but not currently managed (in any one year) for livestock. The hierarchy of land use identification is outlined in section 6.2.2.1. With this hierarchy, those lands identified as under grass, but with a recent history of crop management, are classified as temporary grassland within the Cropland land use category. All grasslands, including grasslands not in use are considered to be present as the result of land management decisions. The definition of grasslands also includes hedgerows which are an integral part of livestock and land management practice in Ireland.

6.5.1 Grassland Areas

Grassland is the dominant land-use category in Ireland. Anthropogenic management of grasslands is long standing and profound. There has been a long-term trend towards livestock production in Ireland since the mid-1800s. The main driver was an increased demand for dairy and meat products from the industrial population centres in Britain. However, the trend also reflects a response to major changes in rural labour force, and a move to less labour-intensive activities. Between 1850 and 1965 the number of cattle increased from approximately 2.0 million animals to 7.0 million. The reported areas of pasture, silage and hay for this period increased from approximately 3.5 million hectares to a maximum of 4.5 million hectares in the 1900s, and currently approximately 4.2 million hectares. This points to a significant intensification in the management and use of grassland through the 20th century leading to increased productivity.

In recent decades, changes in agriculture, have been driven by measures under the Common Agriculture Policy, where for example the “headage payment” subsidy lead to a very dramatic increase in sheep numbers from 3.5 million animals in the early 1980s to 8.9 million by 1990. This had a severe environmental impact due to over-grazing on hill sides. Reform of the scheme, in the mid-1990s, led to a sharp decline in sheep numbers, and a corresponding decline in the reported area of rough grazing. Similarly, a production quota on milk effectively led to the compression and stagnation of the dairy sector in Ireland up until its removal in 2015.

Choice of Methods

Ireland has adopted both Tier 1 and Tier 2 approaches to reporting greenhouse gas emissions associated with those areas defined as Grassland land use. Estimates for carbon stock change on grasslands on mineral soils are Tier 1 based while those in relation to grasslands on organic soils are Tier 1 and Tier 2 based.

Activity data

The primary sources of activity data for Grassland used for the 2024submission are:

- Central Statistics Office annual statistics of Utilised Agriculture Area (1990-2022);
- Land Parcel Information System data (2000-2022) Maintained by the Department of Agriculture, Food and the Marine, the LPIS is integrated with the Irish FORest Information System data (IFORIS);
- EPA/Teagasc Indicative Soil Map (Fealy and Green 2009);
- Drainage status of grasslands (Tuohy et al., 2023)

- New build activity within the Construction Sector from CSO (1990-2021);
- Fire Information for Resource Management System (FIRMS) NASA;
- National forest fire statistics see Table 6.8;
- National Forest Inventory 2006, 2012, 2017 and 2021

The estimate of the area of grasslands are based on CSO annual agriculture statistics for improved grassland (pastures and areas harvested for silage and hay) and unimproved grassland, which is synonymous with rough grazing, and ancillary data (CORINE) used to estimate the remaining grasslands (grasslands not in use).

The definition of Grassland includes hedgerows and small wooded areas (non-forest), which are maintained as an integral component of livestock management and to establish field boundaries. However, further research is required to complete a robust time series of hedgerow extent and condition in Ireland.

In 2010, the CSO revised the methodology for the estimation of utilised agricultural land. The 2016 submission included a revised analysis based on data from the CSO which includes an estimate of utilised agricultural grasslands for of all years from 2008. In order to achieve long term, forward looking, continuity with the revised CSO methodology, estimates of the pasture area for all years between 1990 to 2007 have been adjusted upward, to account for the stepwise increase in reported utilised grassland areas reported by the CSO.

The CSO had previously changed methodologies for estimation of area under grassland in 1991. The methodology prior to 1991 was not consistent with the methodology used from 1991 to 2007. This resulted in a stepwise break point in the CSO data between 1990 and 1991. The main impact of the change in methodology in 1991 is an increase in the overall grassland area reported. Figure 6.28 shows shows the original data and the impact of the adjustment. It is worth noting, this change in methodology has increased the total area of agricultural grassland to levels similar to those recorded in the pre-1991 methodology, the last major change in methodology.

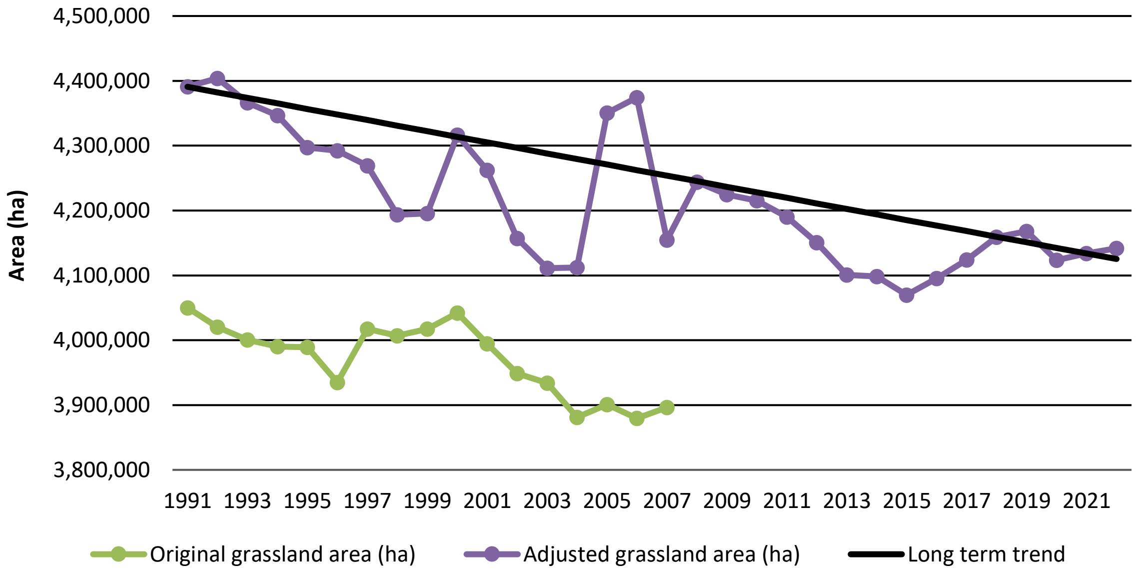


Figure 6.28 Plot of original CSO data for Grassland areas and adjusted data for the years 1991-2007 based on the extrapolation of long-term trends from 1991 to 2007 and 2008-2022

It is important to note that both improved and unimproved grassland areas are estimates of grasslands in use for agricultural purposes in any one year. Rough grazing areas in use are grasslands that are unmanaged with regard to drainage or other factors, such as fertiliser application, but which are grazed by cattle or sheep. The CSO annual statistics for rough grazing exclude other areas of grassland not reported to be in use for agricultural purposes in a particular year. These grasslands are assumed to have limited human management interventions, in a carbon-stable state, with no associated emission or sink activity. However, they do represent a reserve of lands available for conversion to rough grazing as the need arises.

Overall, the area of grassland has decreased in the period since 1990 (see Figure 6.29). The area of improved pasture has been near steady state, while the area of rough grazing, or unimproved grassland has been decreasing. The dominant driver has been the conversion of grassland to Forest Land, and to a lesser extent, conversion to Settlement.

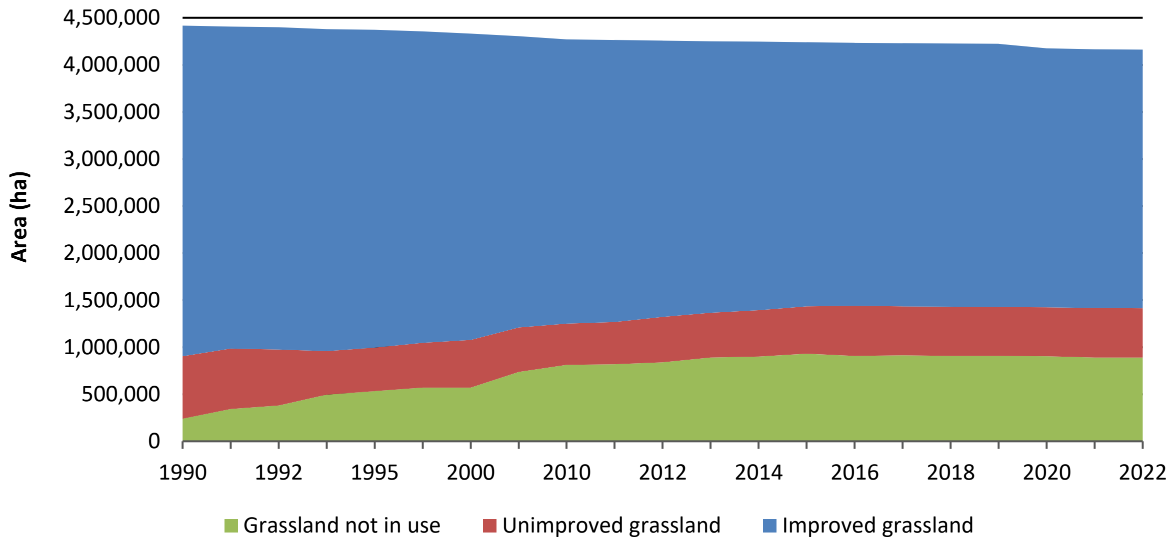


Figure 6.29 Trends in Grassland use 1990-2022

From the data available, it is difficult to determine changes in management practice within the category *4.C.1 Grassland Remaining Grassland*. The annual CSO figures refer to the areas of land that farmers have declared to be "in use" under the specified types of use. Given the economic investment required to maintain "improved" grassland, it is probable that the declared areas are a good indicator of the actual extent of well-maintained managed grasslands. Therefore, significant changes in the improved grassland areas do represent changes in land use management, with lands being under-utilised or intensively managed, depending on the potential for economic return.

Hedgerows are maintained as an integral system of grassland systems to control the movement of livestock, manage grazing fodder stock, and in many cases to define parcel boundaries. There is anecdotal evidence of hedgerow removal to facilitate access, traffic of machinery and deploying alternative methods to management of grazing intensity. However, recent hedgerow surveys across Ireland suggest the removal has not occurred on the same scale as has occurred in other parts of Europe. Additional work is required to quantified change over time in hedgerows in Ireland, both in terms of extent and condition, and the EPA has funded a number of research initiatives on this topic. At present, a consistent time series of changes in hedgerow extent or condition is not available and methodological issues still exist with regard to their mapping especially for past years.

6.5.2 Methodological issues

6.5.2.1 Carbon Stock Changes in Grassland

The relevant carbon stock changes are for living biomass under *4.C.2 Land Converted to Grassland* and for soils under both *4.C.1 Grassland Remaining Grassland* and *4.C.2 Land Converted to Grassland.*

6.5.2.2 Carbon Stock Changes in Living Biomass

The calculation steps for the Tier 1 methodology are described in Section 6.2.1, it assumes that for grassland remaining grassland there is zero biomass carbon stock change. This approach is adopted here, and the notation NO is entered in CRF Table 4.C.

6.5.2.3 Dead Organic Matter/Litter

Tier 1 assumption is applied, with default estimation of zero emissions or removals associated with dead organic matter/ litter.

6.5.2.4 Carbon Stock Changes in Soils

The soil type distribution of grassland areas converted from other land uses over the IPCC soil classes is determined from GIS analysis of CORINE land cover data superimposed on the Indicative Soils Map (Fealy and Green, 2009). Mineral soils as identified from the general soil map were allocated to the five IPCC soil groups and their organic carbon status is established from the soil type and the default reference soil organic carbon stocks. The principal conversion affecting carbon stock change in soils is that from improved grassland to rough grazing, which causes a decrease in soil carbon.

Organic Soils

Carbon emissions and removals are considered from two source activities:

Drainage of organic soil under Grasslands;

Rewetting of previously drained grassland.

Drainage of organic soil under Grasslands

A significant source of carbon emission is the drainage of organic soil types for use as pasture. A proportion of the organic soils under pasture are artificially drained, which enables the emission of carbon from this organic soil type. There are also emissions of CH_4 and N_2O associated with the drainage activity.

Both Tier 1 and Tier 2 emission factors are utilised to estimate emissions from the drainage of organic soils. Recent research has unearthed previously lost historic information on the drainage status of grasslands on organic soils (Tuohy et al., 2023). This provides a country specific assessment of the drainage status for historic years with further analysis undertaken by the authors to establish current practice.

A review of greenhouse gas emissions and removals from Irish Peatlands (Aitova et al., 2023) is the source of country specific emission factors and these are used where possible and appropriate. Where no country specific data exists, Tier 1 emission factors as presented in the 2013 Wetlands Supplement are adopted.

In the estimation of greenhouse gas emissions from drainage both on-site (due to organic matter decomposition) and offsite site losses of dissolved organic carbon in drainage waters are required. In addition, emissions of CH_4 from drainage waters also occur. With respect to N_2O losses these are reported in the Agriculture sector.

For the purposes of estimating on-site CO_2, the area of grassland on organic soils is first disaggregated into the proportion of land which is nutrient rich and nutrient poor based on Hammond (1981) and then further disaggregated into the area drained and the area which is rewet by nutrient status (Tuohy et al., 2023, Tuohy et al. pers comm). The latter which represents those areas previously drained and/or which required intervention by land owners to transform from wetland type condition to land suitable for grass production.

However, it is currently not known the proportion of drains which are shallow and the proportion which are deep. In line with the 2013 Wetlands Supplement, where the drainage depth is not known deep drainage is assumed (i.e. > 30 cm).

Onsite CO_2 emissions are estimated using the following emission factors: For nutrient poor, a value of 1.3 t CO_2-C $ha^{-1}yr^{-1}$ (Table 2 Aitova et al., 2023) is applied and for nutrient rich the default emission factor of 6.1 t CO_2-C ha^{-1} yr^{-1} as presented in table 2.1 Chapter 2 of the 2013 Wetlands Supplement is utilised. Only one study on nutrient rich deep drained grasslands is included in Aitova et al. (2023), the results of which are within the 95% confidence interval of the default 2013 Wetlands Supplement value.

Offsite CO_2 emissions associated with dissolved organic carbon (DOC) are estimated using the Tier 1 approach and default values for the temperate climate zone as presented in equations 2.4 and 2.5 and table 2.2 Chapter 2 of the 2013 Wetlands Supplement where the following values are utilised: $DOC_{FLUX\_Natural}$ (t C ha^{-1} yr^{-1}), 0.21; $\Delta DOC_{DRAINAGE}$, 0.60; $Frac_{DOC\text{-}CO2}$,0.9 and: $EF_{DOC\_DRAINED}$ (t C ha^{-1} yr^{-1}), 0.31. The data presented with respect to fluvial losses in table 3 of Aitova et al. (2023) are for one site only and are thus not representative to be used as country specific values.

Methane emissions from drainage are estimated using equation 2.6 Chapter 2 of the 2013 Wetlands Supplement using a combination of country specific emission factors (Aitova et al., 2023) and default Tier 1 values from Table 2.3 of the 2013 Wetlands Supplement. Default $Frac_{DITCH}$ and EF_{CH4_ditch} values of 0.05 and 1165 (kg CH_4 ha^{-1} yr^{-1}) are utilised with 11.76 kg CH_4 ha^{-1} yr^{-1} (Aitova et al., 2023) utilised for nutrient poor soils and the default value of 16 kg CH_4 ha^{-1} yr^{-1} utilised for nutrient rich soils for EF_{CH4_land}.

The adoption of country specific information on nutrient status and emission factors in this submission has had a profound impact on the estimation of emissions associated with the agricultural use of grasslands. The timeseries of carbon loss from drained organic soils under grassland is presented in Figure 6.30.

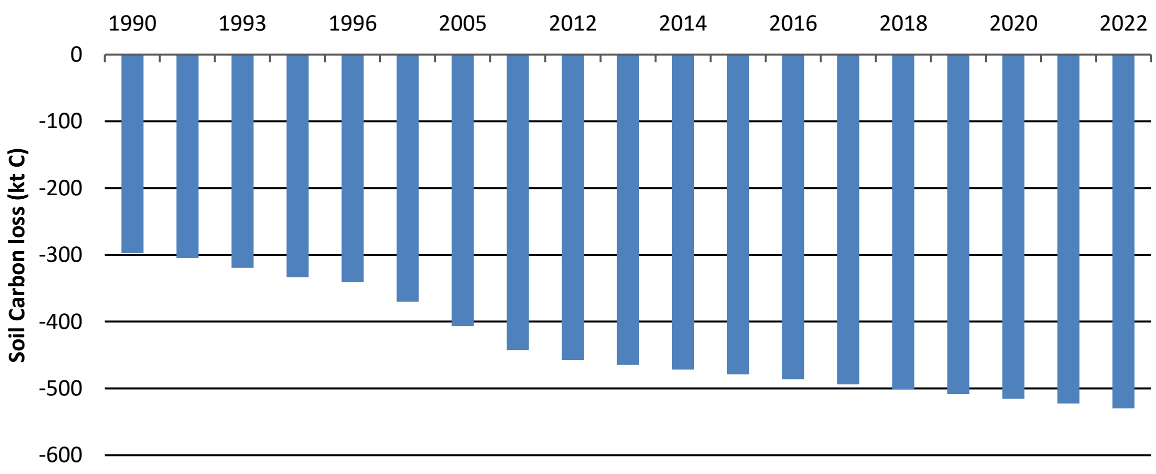


Figure 6.30 Time series of carbon loss from drained organic soils under grassland

Rewetting of previously drained organic soils under grassland area

In order for wetland type conditions to be transformed in those suitable for grass production for grazing and forage harvesting, some form of drainage and/or other management interventions occur. The establishment of drainage at required spacings to effectively drain organic soils is difficult and costly and requires on-going maintenance to remain fully effective. A range of drainage types exist from those with effective in field drains connected to boundary drains to just the installation of boundary drains which have a limited zone of influence and only remove surface water from the field. Based on the work of Tuohy et al (2023) those lands which are not effectively drained had to have some form of intervention to bring them into grass production, however these lands have effectively rewet to some extent and whilst still in use for grass production have reverted to a wet status with the water table at a level higher than that envisaged by the original intervention. It is thus reasonable that these lands are considered to be rewet and still give rise to both on-site and offsite emissions, however at a much lower rate than their drained counterparts.

The estimate of the area of rewetted grassland on organic soils is thus estimated on the basis that if it is not drained that it is in a rewet status. Similar to estimation of emissions for drained organic soils and combination of Tier 1 and country specific Tier 2 emission factors (Aitova et al., 2023) are employed.

Classification of nutrient status and the proportion of lands classified as rewet follows that which is presented for drained soils. For on site CO_2 emissions, an emission factor of 0.85 t C ha^{-1} yr^{-1} (Aitova et al., 2023) for nutrient poor and the default value for the temperate climate zone of 0.5 t CO_2-C ha^{-1} yr^{-1} (Table 3.1 Chapter 3, 2013 Wetlands Supplement) is applied to nutrient rich soils utilising equation 3.4 Chapter 3 of the 213 Wetlands Supplement. Similar to drained soils there is a paucity of data on dissolved organic carbon losses and the default emission factor ($EF_{DOC\_REWETTED}$) 0.24 t CO_2-C ha^{-1} yr^{-1} is for the temperate climate zone and equation 3.5 Chapter 3 of the 2103 Wetlands Supplement are utilised.

CH_4 emissions from rewetted soils are estimated using equation 3.8 Chapter 3 of the 2013 Wetlands Supplement and applying a country specific emission factor of 68.1 kg CH_4-C ha^{-1} yr^{-1} for nutrient poor grasslands and the default value of 216 kg CH_4-C ha^{-1} yr^{-1} for nutrient rich grasslands.

N_2O emissions from rewetted organic soils are reported as not occurring in CRF Table 4(II) in line with the Tier 1 methodology presented in the 2013 Wetlands Supplement which assumes that they are negligible.

6.5.3 Land converted to Grassland

In the period 1990-2022, a limited are of Forest land (*4.A*) has been converted to Grassland.

6.5.3.1 Forest Land converted to Grassland

For details of the analysis of greenhouse gas emissions and removals associated with deforestation and conversion to grassland land use see section 6.3.6.1.2.

6.5.4 Grassland emissions due to Biomass Burning

Activity data on the occurrence of fire on grassland is limited. The NASA FIRMS data set for region of Ireland was interrogated. It identifies that on average approximately 20 per cent of likely fire events coincided with grassland locations. There are significant limitations to the satellite product mainly related to the relatively low spatial resolution and high probability of cloud interference in any signal over Ireland.

The NASA FIRMS data was overlaid on the spatial land cover data CORINE. From this a table of the probability of fire on each land use type was constructed. The analysis suggests a very high proportion of fires are on peatlands. Although peatland fires are a feature of natural fire activity in Ireland, the land cover data has difficulty in distinguishing natural vegetation on peatlands and rough grazing, especially on blanket bog. Therefore, it is assumed that 50 per cent of peatland fires actually occur on managed rough grazing, and are therefore included in the grassland fire area. Therefore, the incidence of grassland fires increases to 50.8 per cent of all fire occurrences on average.

Although meteorological conditions provide suitable conditions for fire, remote sensing cannot establish whether the actual fires are due to natural causes or direct human interventions. Although not encouraged, controlled burning may be deployed, in very limited circumstances, as a grassland management tool, particularly in the control of low-level scrub vegetation on poor or inaccessible grasslands. Landowners are required to inform local authorities and fire services of their intention of initiating a controlled fire, however this information is not collated in any meaningful form at a national level.

As discussed, tt is currently not possible to distinguish between controlled burning and wildfires on grassland, therefore all biomass burning on grassland is included in controlled burning. As a result, emissions from wildfires are reported as "IE" in CRF Table 4 (V).

The emissions associated with fires are estimated based on the 2006 IPCC guidelines Vol 4 Chapter 6, Section 6.2.4 2.

Emissions of CH_4 and N_2O are calculated using eq 2.27 from Chapter 2 Vol 4 of the 2006 IPCC Guidelines, and shown below. There has been no update to any of the following parameters in the 2019 Refinement to the 2006 IPCC Guidelines. The approach requires the area of grassland burnt to be stratified between mineral soils, drained organic soils and undrained organic soils, and provides appropriate default values for each of the parameters shown in eq 6.5.8 and Table 6.34.

$$L_{fire} = A \cdot M_B \cdot C_f \cdot G_{ef} \cdot 10^{-3} \qquad \text{(eq 6.5.8)}$$

Where L_{fire} = amount of greenhouse gas emissions from fire, in tonnes of gas (CH_4, N_2O),

A = area burnt, ha,

MB = mass of fuel available for combustion, tonnes ha^{-1}. This includes biomass, litter and dom. For Tier 1 Litter and DOM are assumed zero for grasslands remaining grasslands.

Cf = combustion factor, dimensionless,

The default values for grassland for MB are from Table 2.4in the Ch 2 Vol 4 2006 IPCC Guidelines, and Table 2.7 in the 2013 Wetlands Supplement. For C_f, it is assumed that all the available fuel is burned, thus the value used is 1.0.

G_{ef} = is the emission factor, g kg^{-1} dry matter burnt. The default values for grassland are CH_4=2.3 g kg^{-1} dm_{burnt}, N_20 =0.21 g kg^{-1} dm_{burnt}.

Table 6.34 Default parameters for use in Equation 6.5.8

	Mineral Soil	**Drained Organic soil**	**Undrained Organic soil**
$M_B \cdot C_F$ (t ha^{-1})	4.1	336	66
G_{ef} CO_2 (g kg^{-1} dm_{burnt})	1613	362	362
G_{ef} CH_4 (g kg^{-1} dm_{burnt})	2.3	9	9
G_{ef} N_2O (g kg^{-1} dm_{burnt})	0.21	0.21	0.21

In the Tier 1 methodology, there are no long-term losses of biomass carbon due to fires on grassland, and emissions are estimated for CH_4 and N_2O only, see Figure 6.32.

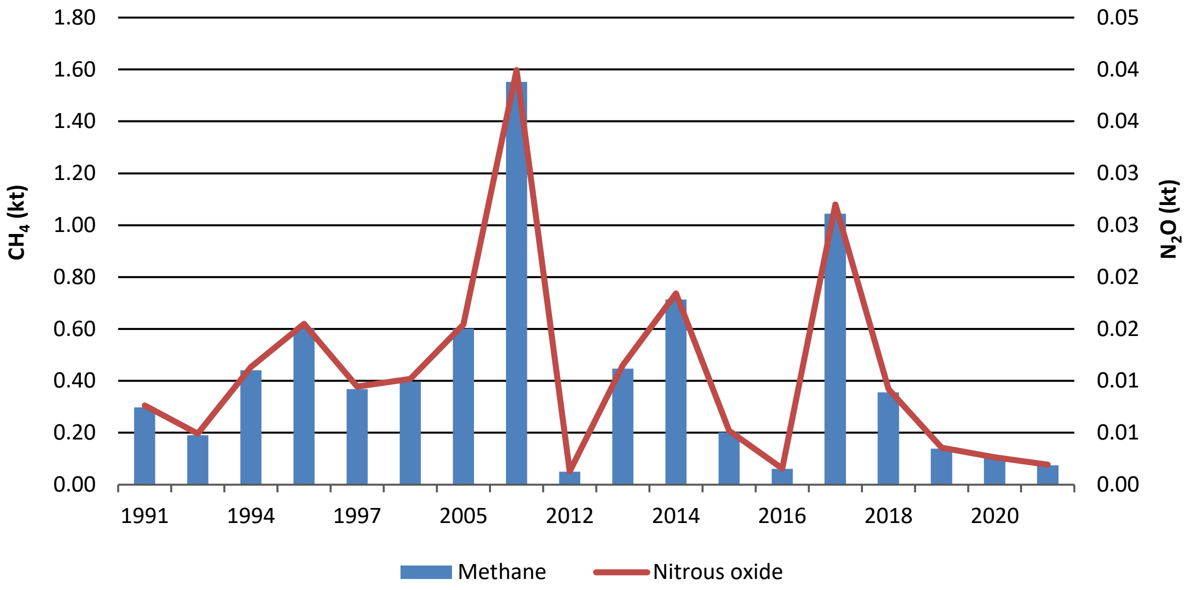


Figure 6.32 Estimated CH_4 and N_2O emissions from biomass burning on Grassland

6.5.5 Uncertainties and timeseries consistency

The dominant uncertainty in relation to Grassland is the history and impact of changes in land management on greenhouse gas emissions. Analysis of the archive of LPIS data for permanent grasslands is not as advanced as that for Cropland (and temporary grassland). The allocation of soil types under each sub category of grasslands is based on extrapolation of the analysis of a single point in time. Therefore, where there are changes reported in the area of grassland, either through the demand from other land uses, or changes in management, it has been assumed that these impact proportionately across all soil types. For example, if there is demand for 1000 ha to transition between improved and unimproved grassland, and 10 per cent of grasslands are on drained organic soils, then 100 ha of the conversion is assumed to related to these drained organic soils.

As discussed above, the time series for agricultural grasslands have been adjusted in response to two discontinuities in the CSO data in 1990/1991 and 2007/2008. These discontinuities arise from known changes in methodology. It is aimed that with the development of a land use map specifically for LULUCF Regulation (EU) 2018/841 and (EU) 2023/839 and on-going research that these uncertainties will be addressed.

6.5.6 Category specific QA/QC and verification

Standard QA/QC procedures have been applied to the Grassland sector estimates. Details of Ireland's QA/QC process can be found in Chapter 1 of this report. During the collation of data for this submission extensive discussions were undertaken with relevant researchers in Ireland with regard to the revised estimates of emissions from grasslands on organic soils as discussed in section 6.5.2.4. These discussion provided a very important element of QA/QC and verification of emission estimates for grasslands on organic soils in this submission.

6.5.7 Grassland category specific recalculations and impact on the emission trend

Significant recalculations have been undertaken in this submission as a result of the publication of two scientific articles in 2023 (Tuohy et al., 2023 and Aitova et al., 2023) in relation to organic soils in Ireland. This research has allowed for the allocation of organic soils to both nutrient poor and nutrient status. It has also allowed for the use of country specific emission factors in conjunction with the use of default emission factors from the 2013 Wetlands Supplement where appropriate. In addition revised land use, land management and input factors from the 2019 Refinement to the 2006 IPCC Guidelines have also been implemented, however the effect of these revised values is minor in comparison to the recalculations associated with organic soils. The net effect of these recalculations are presented in Figure 6.33. Total emissions in kt CO_2 eq have been reduced by on average 3,641.93 kt (range 2651.9 kt to 4,597.36 kt) or 53.2 per cent on average across the timeseries 1990-2021. CO_2 emission have reduced on average by 4,854.26 kt (range 3,964.69 kt to 5,630.87 kt) or 74.6 per cent. Methane emissions in this submission are 43.5 kt CH_4 higher (range 35.20 kt to 48.47) or over four times those reported in the previous submission.

6.5.8 Grassland category specific planned improvements

The inventory agency aims to enhance this analysis presented for the grassland category through the development of a national land use map for LULUCF reporting. A scoping study was completed in this regard in 2019, the results of which has informed the design of a multi-year LULUCF mapping study which is currently ongoing. The results of this work will be integrated into the Grassland sector methodologies as results become available.

The inventory agency has funded research into remote sensing technologies and analytical techniques for the quantification of non-forest woody biomass in the landscape. In the context of Grassland, this refers to primarily hedgerows. The inventory agency has funded a project (completed in 2022) aimed at quantifying the carbon stock in hedgerows and non-forest woody biomass features in the landscape. Hedgerows are an important feature of the Irish landscape. They are traditional means of establishing field and ownership boundaries and protecting crops from livestock incursion. In recent years, environmental payment schemes have included incentives for hedgerow plantation, maintenance and protection. However, while projects such as that described above may be used to estimate the current carbon stock in hedgerows, questions remain in terms of establishing the carbon stock change over past years and also establishing the spatial extent and management of hedgerows in the past. The inventory agency is currently examining approaches to develop knowledge of past hedgerow extent and management.

Furthermore, extensive research has just begun in relation to the further enhancing our knowledge of the nutrient and drainage status of grasslands on organic soils. This project along with the output of an extensive eddy covariance tower network with associated modelling activities (National Agricultural Soil Carbon Observatory) will greatly enhance both the knowledge and understand of emissions and removals from grassland in the coming years.

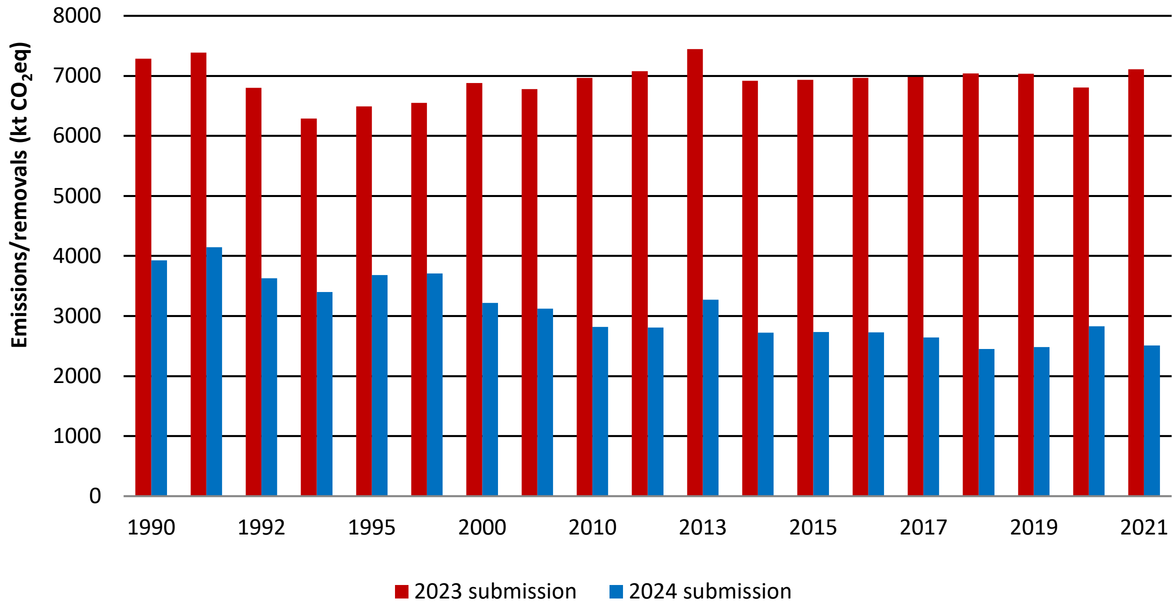


Figure 6.33 Grassland recalculations between the 2023 and 2024 submissions for the period 1990-2021

6.6 Wetlands (4.D)

6.6.1 Wetland Areas

The term Wetlands as applied to Ireland refers to those areas of peatland that have not been reported under another land use (i.e. forestry and grassland on organic soil) and that are either in a near-natural or some form of exploited status. This exploitation has occurred to provide a source of fuel for the Residential (1.A.4.b), Commercial/Institutional (1.A.4.a), Public Electricity and Heat Production (1.A.1.a) and Manufacture of Solid Fuels and Other Energy Industries (1.A.1.c) sectors and in addition a source of peat products for horticultural uses. In the context of the definition of Wetlands described in the 2006 IPCC Guidelines and the 2019 refinement to those guidelines it also includes inland marshes, salt marshes, moors and heathland and intertidal flats. For the purposes of reporting unmanaged wetlands includes the inland marshes, salt marshes, moors and heathland and intertidal flats which are unmanaged and only the area of these lands is reported. The remaining exploited and near-natural status wetlands are therefore managed having experienced anthropogenic interventions and emissions are reported for these lands. With respect to near-natural status wetlands the National Peatlands Strategy (NPWS, 2015) suggests that peatlands in Ireland can be considered as "humanised landscapes" that have evolved and or originated in close association with land use systems and that it would be impossible to find an Irish peatland that has never been grazed or used in some way by humans. Additionally, Aitova et al (2023) argue that in the context of peatlands in Ireland, (near-natural" is a more accurate description of those peatlands not commercially exploited as all Irish peatlands have experienced anthropogenic pressure to some extent. This definition is adopted for reporting purposes.

The 2015 submission included an estimate of emissions and removals associated with activities of enterprises engaged in the drainage of peat for extraction for horticulture use. The estimate was based on analysis of export and domestic sales and back calculation of the area of peatland required to meet this demand. This submission updates this analysis.

There is a long history of peatland drainage for peat extraction over the centuries, (Clarke 2006). In general, methods of peat extraction culminate in the abandonment of a peat body once the level of peat extraction reaches the water table maintained by the series of drainage ditches constructed to enable extraction. Thereafter the drainage ditches will fall into disrepair (if not actively managed), and gradually rewetting of the abandoned extraction site occurs. Therefore, it is reasonable that where a reduction in exploited peat areas occurs that these areas become rewetted where no further information exists as to their status. Where there is an increase in exploited peat areas (outsisde of those areas managed by Bord na Mona), this demand is met by those lands within the near-natural status reflecting the stated intent of exploiting further areas of peat.

A limited area of forest land on peat have been deforested and rewetted as part of a wetland restoration project supported by the EU LIFE programme.

6.6.2 Unmanaged Wetland Areas

The initial 1990 unmanaged wetland area is based on the total area of peatland (excluding exploited areas) and other wetland habitats estimated from the CORINE 1990 land cover map classifications.

6.6.3 Managed Wetland Areas

Managed wetland areas encompass those area actively exploited or harvested for fuel and horticultural products and those in a near-natural status.

The commercial exploitation of peatlands has been dominated by Bord na Mona (BnM, the Irish Peat Board) since the 1940's until recent years. In addition to those lands that Bord na Mona have rewetted in the past a large scale, Peatland Climate Action Scheme (PCAS) also referred to as the Enhanced Decommissioning, Rehabilitation and Restoration Scheme was established in 2020 targeting c. 33,000 ha of land previously harvested for peat extraction for electricity generation. Work under the scheme begun in 2021 with a completion of mid-2026. Additional actions are being undertaken through an EU LIFE funded project, Peatlands and People.

Commercial extraction proceeds in three separate stages, all of which can lead to changes in carbon stocks. Drainage is the first management activity, followed after several years by removal of the top layers of plant growth in the first season of peat extraction and then by the industrial extraction and harvesting of a layer of 10 to 15 cm of peat annually. The average working life of commercially developed Irish peatland is of the order of 30-50 years. Conversion to forest land has been the historically favoured afteruse of cutaway peatland. However, in recent years wetland restoration and rehabilitation are currently the preferred options. Bord na Mona manages its peat reserves to meet demand and therefore progressing to extract peat from new sites only when an older field is exhausted. It is assumed that the decrease in reserved area of peatland indicate new extraction areas, and therefore they are an estimate of the area from which biomass has been removed

In comparison to current activities by Bord na Mona smaller areas of exploited wetland have been restored to ecosystem function through drainage management and rewetting in the past. These areas continue to emit greenhouse gases, but at a much reduced level than exploited peat. For these areas the tier 1 approach as described in the 2013 IPCC Wetlands Supplement is applied.

Bord na Mona provides an annual update of their activities including estimates of area for the company's commercial peat harvesting activities. The data is commercially sensitive, and therefore not presented in this report. For the period from 1990 to 2011, the data for BnM commercial peat extraction areas are given as totals for consecutive five-year periods for a variety of peatland categories. Thereafter, BnM has provided annual statistics.

Domestic harvesting of peat bogs by private landowners for their own household use is a strong tradition in many parts of Ireland, and although well documented in a social and cultural context, the volume and extent of such peat extraction activity has shown wide ranging estimates of the areal extent. The development of a national landcover map and its publication in 2023 and based on the year 2018 has however provided further insight. This map covering 36 different land cover classifications specifically designed for Ireland and at a resolution of at least 0.1 ha, makes it 250 time more detailed than CORINE. The classification cutover bog largely agrees with the data for the same classification in the NFI, with the latter being used to assign lands to domestic harvesting as a time series exists from the NFI and consistency is maintained with the data source for category 4.A. Of note however is that the areas identified in the both the NFI and the National Landcover map do not distinguish between areas harvested by private landowners for fuel and those non-Bord na Mona areas commercially exploited for horticultural products. Thus the estimated area of land for horticultural products is deducted from the total domestic cutover area to derive the area of land harvested for use as a fuel by private landowners.

All submissions since 2015 include an analysis of GHG emissions and removals associated with peat extraction and use of peat in Horticultural products. BnM was until recent years also one of the companies which supply this market, and most of the area of peatland exploited for extraction of horticultural peat is included in the annual statistics supplied by BnM. However, an additional area of drained peat is required in order to take account of the activities of non-BnM commercial enterprises. This estimate is based on estimates of market share from trade statistics.

In communication with industry experts, it is estimated that 85 per cent of horticultural peat products are exported. The quantity of peat exported is captured in the national imports and exports trade figures as provided by the CSO to the UN Commodity Trade Statistics Database and the equivalent commodity exports reported to Eurostat, http://comtrade.un.org/db/default.aspx. The export figures are scaled to include domestic use of products.

6.6.4 Carbon Stock Changes in Wetland

6.6.4.1 Biomass

Carbon stock changes in biomass are determined by the balance between carbon loss due to the removal of vegetation on preparation for peat harvesting and gain on areas of restored peatland. These changes have been estimated on the basis that the entire cover of vegetation is removed to prepare for peat harvesting and that an equivalent amount of biomass is returned on restoration of cutaway areas. In discussions with peatland experts a transition period of 5 years for biomass re-establishment used, which is supported by findings from restored peatlands sites managed by Bord na Mona (Wilson et al., 2012).

The vegetation is removed from an area of the peatland reserve that is drained to come under production annually and the restoration area is taken as the annual increase in cutaway wetland. The vegetation is typically heather-dominated bog or heathland cover for which a biomass carbon content of 3 t C ha^{-1} is adopted (Cruickshank et al, 2000). The vegetation types differ from pristine peatland due to the influence of drainage systems developed by BnM.

Table 6.18 in Section 6.3.6 6 provides the area of forest land converted to wetlands for the years 1990-2022. The immediate oxidation of biomass, litter and dead wood for years prior to 2006 were derived using the mean IEF for 2006 to 2010 (see section 6.3.3). Similar to re-establishment on cutaway peatland, it is assumed that natural vegetation cover will gradually recover over a period of five years at the rate of 0.6 t C $ha^{-1}yr^{-1}$ up to an equilibrium of 3 t C ha^{-1}.

DOM and Litter emissions and removals

DOM and Litter are indistinguishable from organic matter in organic soils. Therefore, it is assumed to be included in the assessment of carbon emissions and removals estimated for soils. It is also worth noting that the material removed from peat extraction sites for energy purposes incorporates DOM and litter, and therefore the carbon losses in these off-site activities are included in the Energy sector.

6.6.4.2 Soils

There is a loss of carbon associated with drainage and the exposure of the peat surface annually after harvesting takes place. The annual activity data are the active production areas of Bord na Mona bog, together with the areas of peatland in use by private commercial enterprises and by domestic users. Additional areas drained for the extraction of peat to supply the horticultural market, as outlined in Section 6.4.4, are included in the total area drained.

As a result of the reclassification of lands within the wetland land use category (sections 6.6.1, 6.6.2 and 6.6.3) and the publication of a review of greenhouse gas emissions and removals from Irish Peatlands (Aitova et al., 2023), this submission contains revised methodologies and the application of country specific emission factors where appropriate and are applied as follows.

Industrial Peat Extraction (Bord na Mona & private horticultural peat operators)

Similar to previous submissions the emission factors applied to the two types of industrial scale harvesting (for electricity generation and horticultural products) for both onsite and offsite emissions are the same. On site CO_2 emissions are estimated using a country specific emission factor of 1.7 t CO_2-C ha^{-1} yr^{-1} (Wilson et al., 2015). Offsite emissions of CO_2, similar to previous submissions are based on the Tier 1 methodology provided in equation 7.5, Chapter 7 Vol. 4 of the 2006 IPCC Guidelines and adopting the default carbon factor for nutrient poor sites. It is noted that this value is considered by national experts to be quite high and may not be consistent with the Tier 1 methodology provided for carbon loss by volume of product. The total tonnage of horticultural product exported is derived from national statistics and market share information which is then used to estimate off site emissions from industrial scale harvesting. For the purposes of estimating non-CO_2 emissions from horticultural products a conversion is undertaken using a typical bulk density value to derive a harvested area.

Emissions of CO_2 from dissolved organic carbon in drainage waters are based on the areal extent of industrial scale harvesting and utilises equation 2.5 and the default values for $DOC_{FLUX\_NATURAL}$, $\Delta DOC_{DRAINAGE}$, $Frac_{DOC\_CO2}$ presented in Table 2.2 Chapter 2 of the 2013 Wetlands Supplement.

Both CH_4 and N_2O emissions are estimated utilise the Tier 1 approaches as outlined in the 2013 Wetlands Supplement for drained organic soils. The default emission factors of 6.1 kg CH_4 ha^{-1} yr^{-1}, $Frac_{DITCH}$ value of 0.05 and EF_{CH4_ditch} 542 kg CH_4 ha^{-1} yr^{-1} for Boreal/Temperate climate zones are used to estimate CH_4 emissions. N_2O emissions are estimated using the Tier 1 approach and default emission factor of 0.3 kg N_2O-N ha^{-1} yr^{-1} for peatlands managed for extraction in the Boreal/Temperate Climate zone.

Large scale rewetting of industrially harvested peatlands is currently being undertaken in Ireland, however historically smaller scale rewetting has occurred both intentionally through engineering works and unintentionally through abandonment of lands post harvesting. The default emission factors of 0.5 t CO_2-C ha^{-1} yr^{-1} and 0.24 t CO_2-C ha^{-1} yr^{-1} for CO_2 emissions from both on-site and offsite sources are utilised. Rewetted soils are also a substantial source of CH_4 for an emission factor of 216 kg CH_4 $ha^{-1}yr^{-1}$ is applied (Table 3.3 Chapter 3, 2013 Wetlands Supplement). N_2O emission are assumed to be negligible.

Domestic Peat Extraction

Domestic harvesting of peat bogs by private landowners for their own household use is a strong tradition in many parts of Ireland. The derivation of the area associated with this activity is discussed in section 6.6.3. Onsite CO_2 emissions are estimated using equation 2.3 Chapter 2 of the 2013 Wetlands Supplement and a country specific emission factor 1.59 t CO_2-C ha^{-1} yr^1.

Emissions of CO_2 from dissolved organic carbon in drainage waters utilises equation 2.5 and the default values for $DOC_{FLUX\_NATURAL}$, $\Delta DOC_{DRAINAGE}$, $Frac_{DOC\_CO2}$ presented in Table 2.2 Chapter 2 of the 2013 Wetlands Supplement.

Both CH_4 and N_2O emissions are estimated utilise the Tier 1 approaches as outlined in the 2013 Wetlands Supplement for drained organic soils. The default emission factors of 6.1 kg CH_4 ha^{-1} yr^{-1}, $Frac_{DITCH}$ value of 0.05 and EF_{CH4_ditch} 542 kg CH_4 ha^{-1} yr^{-1} for Boreal/Temperate climate zones are used to estimate CH_4 emissions. N_2O emissions are estimated using the Tier 1 approach and default emission factor of 0.3 kg N_2O-N ha^{-1} yr^{-1} for peatlands managed for extraction in the Boreal/Temperate Climate zone.

A reduction in the areal extent of domestic cutover implies that the area involved is no longer harvested, is abandoned and in terms of its drainage status returns to a rewetted status. Similar to Industrial Peat Extraction the default methodologies are applied for onsite and offsite CO_2 emissions and CH_4 emissions.

Near Natural Wetlands

As discussed in section 6.6.3, the term “near natural” is a more accurate description of unmanaged peatlands in Irish context given that all Irish peatlands have experienced anthropogenic pressure to some extent (Aitova et al., 2023). As reported by Aitova et al (2023), near-natural peatlands are a net CO_2 sink, a source of CH_4 emissions and also give rise to C loss via surface runoff. The emission factors values proposed by Aitova et al (2023) are used in the estimation of emission and removals from this category of wetland. On site removals of 0.33 t CO_2-C ha^{-1} yr^{-1}, C loss in surface runoff of 0.17 t C ha^{-1} yr^1 and CH_4 emissions of 54.7 kg CH_4-C ha^{-1} yr^1 are utilsied.

6.6.5 Emissions due to Biomass Burning on Wetlands

Activity data on the occurrence of fire on wetlands is limited. The NASA FIRMS data set for region of Ireland was interrogated and overlaid on the spatial land use dataset CORINE. It identified that on average 61.0 per cent of likely fire events coincided with wetland locations. There are significant limitations to this satellite based product mainly related to the relatively low spatial resolution and high probability of cloud interference in any signal over Ireland.

Peatland fires tend to spread over larger areas than other fires. The areas in which fires occur tend to be under populated, with limited infrastructure at risk. Therefore, fires can grow to impact larger areas, before being noticed, and therefore more readily detected with remote sensing. The analysis suggests a very high proportion of fires are on peatlands. Although peatland fires are a feature of natural fire activity in Ireland, the land cover data (CORINE) has difficulty in distinguishing natural vegetation on peatlands and rough grazing, especially on blanket bog. Therefore, it is assumed that 50 per cent of peatland fires are actually occurring on grassland and are therefore included in the grassland fire area. As a result, the revised proportion of fires on wetlands decreases to 31.0 per cent on average.

Although meteorological conditions provide suitable conditions for fire, remote sensing cannot establish whether the actual fires are due to natural causes or direct human interventions. Unlike in other regions, such as Scotland, it is not common practice to deploy controlled burning as a peatland/heathland management tool to maintain game habitat. However, these areas, especially in mountain areas, are of high amenity value, and attract numerous visitors during fine weather, which can give rise to accidental or malicious fire setting.

Therefore, the incidence of fires on wetlands is assumed to be accidental, and all fires on wetland are classified as wildfire (Figure 6.34).

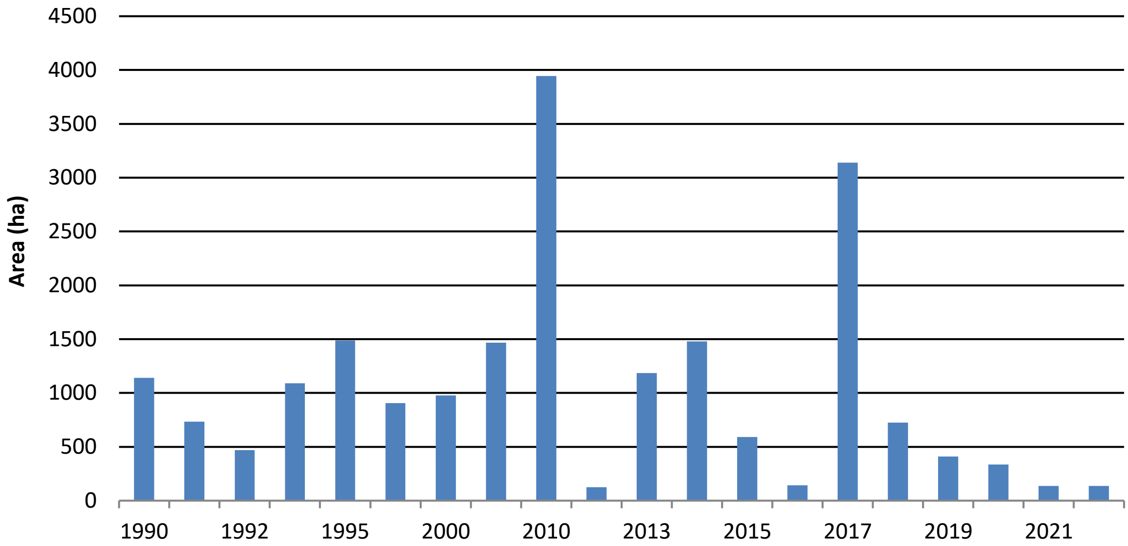


Figure 6.34 Estimate of the area of wetland subject to biomass burning

The emissions associated with fires are estimated based on the 2006 IPCC guidelines and relevant sections of the 2013 Wetlands Supplement to the 2006 IPCC guidelines.

Emissions of CO_2, CH_4 and N_2O are calculated using eq 2.27 from Chapter 2 Vol 4 of the 2006 IPCC Guidelines, and are shown in Figure 6.35 respectively.

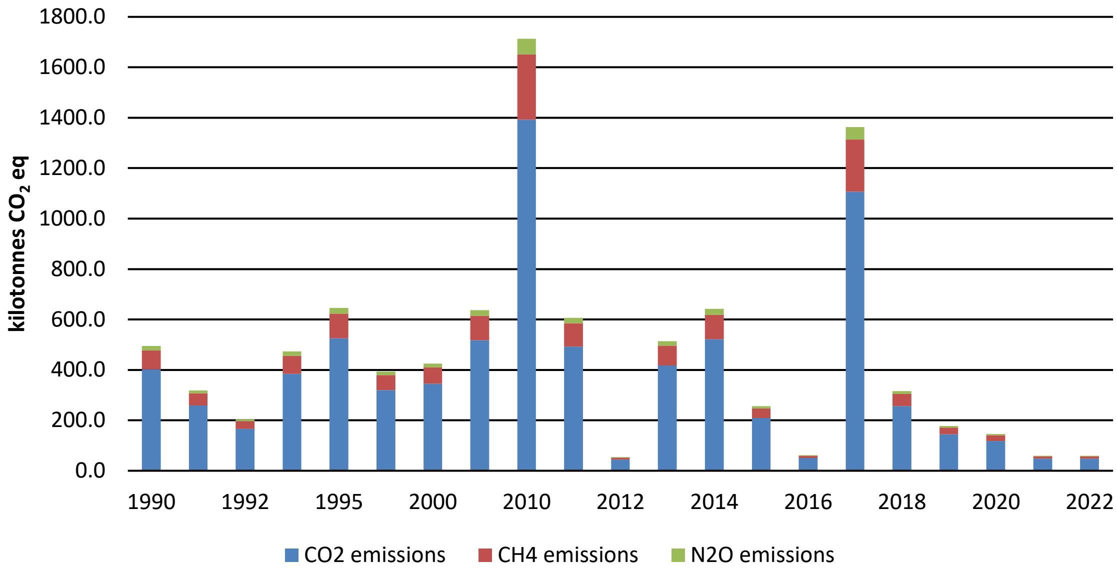


Figure 6.35 Estimate emissions (kt CO_2eq) due to biomass burning on wetlands

The approach requires an estimate of the area burnt and provides appropriate default values for each of the parameters.

$$L_{fire} = A \cdot M_B \cdot C_f \cdot G_{ef} \cdot 10^{-3} \qquad \text{(eq 6.6.1)}$$

Where L_{fire} = amount of greenhouse gas emissions from fire, in tonnes of gas (CH_4, N_2O),

A = area burnt, ha,

M_B = mass of fuel available for combustion, tonnes ha^{-1}. This includes biomass, litter and DOM. For Tier 1 Litter and DOM are assumed zero for wetland remaining wetlands.

Cf = combustion factor, dimensionless,

The default value for M_B .C_f is 336 t dm ha^{-1} from Table 2.4 in the Chapter 2 Vol 4 2006 IPCC Guidelines.

G_{ef} = is the emission factor, g kg^{-1} dry matter burnt. A country specific emission factor for CO_2 =342 gkg^{-1} dm_{burnt} (Wilson et al., 2015) and CH_4= 8.35 g kg^{-1} dm_{burnt};(Wilson et al., 2015), in conjunction with the default emission for N_2O =0.21 g kg^{-1} dm_{burnt}. are utilised.

6.6.6 Uncertainty in Wetlands

Drainage of organic soils within the Wetland land use category is significant by virtue of uncertainty in areal extent and emission factors used.

The area of peatland drained for peat extraction has been dominated by the activities of the semi state commercial company Bord na Mona (BnM) There are a number of smaller commercial enterprises, mainly involved in peat extraction for horticulture which competed in the export market with BnM. There is uncertainty in the conversion of volume of sales of peat to an equivalent area of drained lands to meet horticultural product demand. It is assumed that the competitive operators employ similar extraction methods as BnM and therefore require an area of land in proportion to their market share. This is likely an overestimate of area drained as the extraction methods deployed are likely to be more vigorous than the approach taken by BnM but little information is available.

In the analysis of carbon losses due to the use of horticultural peat, Ireland has adopted the Tier 1 approach based on an estimate of production from figures available in units of weights of product exported. It has been noted that the default emission factor for this approach is relatively high, and national export opinion suggests this should be verified by country specific analysis. Therefore, at present Ireland considers the estimate of losses due to this source highly uncertain. The recent publication of a review of greenhouse gas emissions and removals from Irish Peatlands (Aitova et al., 2023) provides an analysis of country specific research results and further refines emission and removal estimates for the wetland land use category. Further research is underway which will improve knowledge and understanding in future submissions.

6.6.7 Wetlands recalculations and impact on emission trend

Significant recalculations have been undertaken in this submission on the basis of a reclassification of wetland subcategories and recently published research (e.g. Aitova et al., 2023) and national land cover map developments. These have a significant impact on the both the level and trend in emissions and removals.

Total greenhouse gas emissions from wetlands have increased by 2,108.3 kt CO_2 eq (range 1, 847.1 kt CO_2 eq to 2,293.3 kt CO_2 eq) or 88.1 per cent annually across the timeseries 1990-2021. CO_2 emissions have increased by 17.5 kt CO_2 (range -203.0 kt CO_2 to 106.8 kt CO_2) annually with CH_4 emissions increasing by 74.3 kt CH_4 (70.7 t CH_4 to 79.9 kt CH_4). N_2O emissions have increased by 45.6 per cent (0.02 kt N_2O to 0.05 kt N_2O) annually.

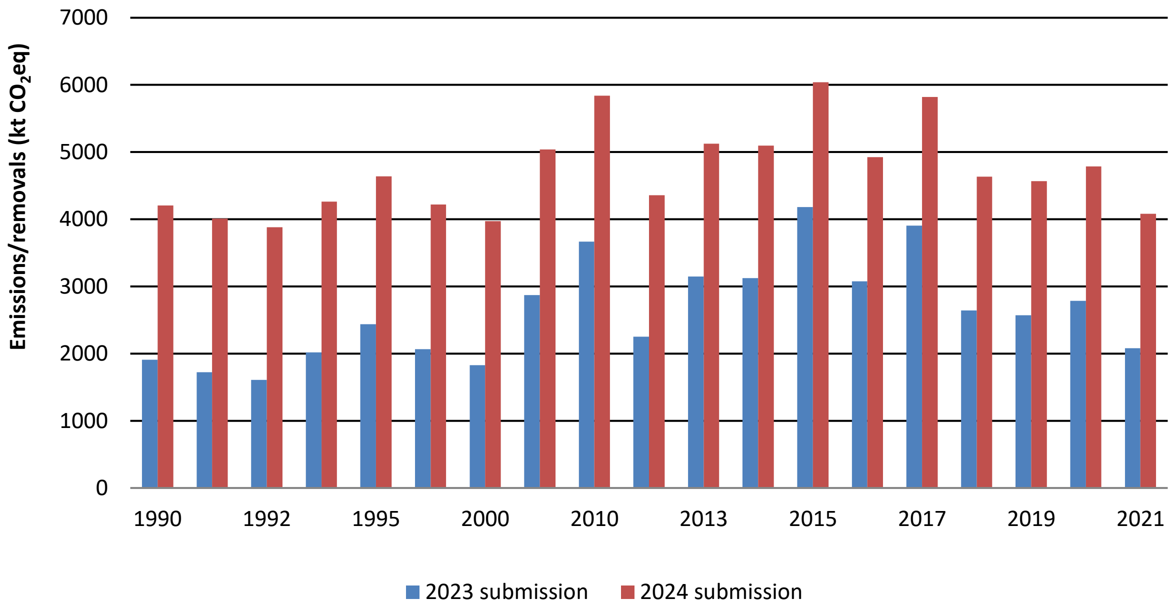


Figure 6.36 Comparison between the 2023 and 2024 submissions of estimated total emissions associated with the Wetlands category

6.6.8 Wetlands category specific planned improvements

The inventory agency continues to fund a number of projects aimed at investigating the peatland properties influencing greenhouse gas emissions and removals from peatlands in Ireland with three projects (one for each of the greenhouses gases CO_2, CH_4 and N_2O funded under the EU-LIFE program as highlighted earlier. The results recently published data (Aitova et al, 2023) have been integrated into methodological approaches for the sector as part of a wider redevelopment of emissions and removals from LULUCF in this submission. Spatial land use mapping aimed at developing a robust approach for LULUCF Regulation requirements are underway. Additionally, as of 2021, Bord Na Mona have begun a large-scale peatland rewetting and restoration program on c. 33 kha of exploited peatland, which is to be progressed in the period to 2026. Data on the extent of activities is being collated and will be incorporated along with relevant research studies to assess these actions as they occur in future submissions.

During the collation of data for this submission extensive discussions were undertaken with relevant researchers in Ireland with regard to the revised estimates of emissions from wetlands. These discussion provided a very important element of QA/QC and verification of emission estimates for grasslands on organic soils in this submission.

6.7 Settlements (4.E)

6.7.1 Area of Settlements

The area of settlements in 1990 base year is estimated from the urban categories within the CORINE 1990 database for Ireland. Land converted to settlements is the area demanded for new road building, available from national road building statistics, and the area covered by new residential, commercial and industrial construction based on CSO and Department of Housing, Planning and Local Government annual construction statistics, which also report floor area of development projects.

With the exception of Forest converted to Settlement, the identification of previous land use from which settlement areas are converted is based on an analysis of the distribution of land use classes given by CORINE 1990. The extent of deforestation associated with conversion to settlement has been independently assessed, and is outlined in section 6.3.2. The remaining change in Settlement area is assumed to have occurred in proportion to the respective categories in CORINE 1990, with the exclusion of land cover types which are unsuitable for development e.g. water bodies, beaches, etc. The time series for Settlement land use is shown in Figure 6.37.

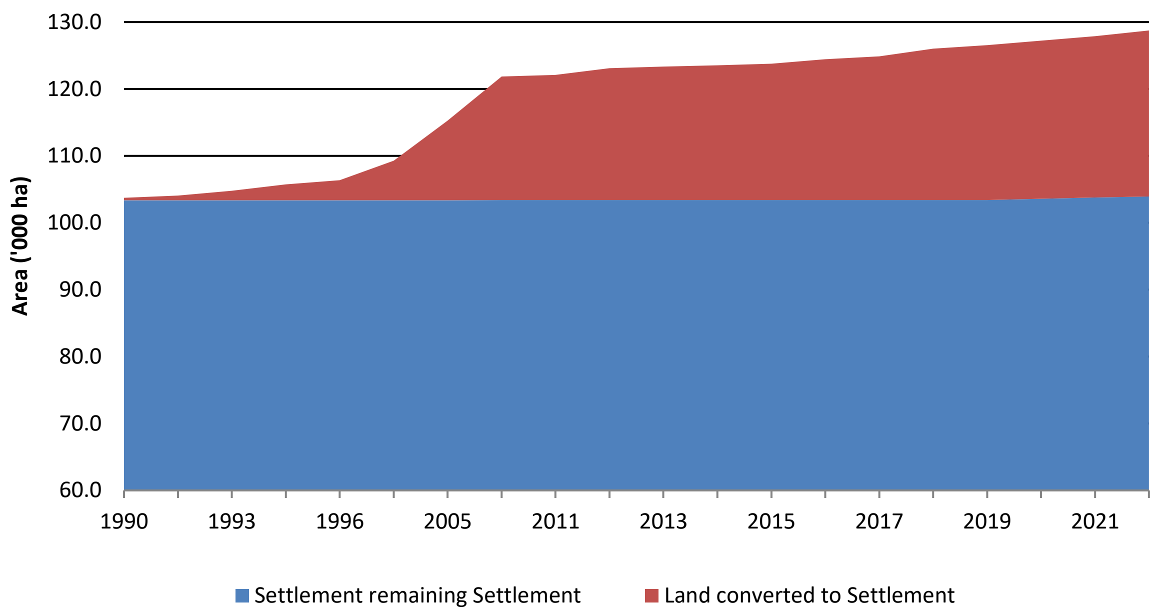


Figure 6.37 Estimated area of Settlements 1990 to 2022

6.7.2 Carbon Stock Changes in Settlements

6.7.2.1 Biomass

The assumption is made of complete removal of biomass in the year of conversion. The biomass loss from grassland and cropland is as per the 2006 IPCC guidelines using the Tier 1 approach. It is assumed that those lands converted from "Other Land" had a biomass equivalent to natural vegetation. The relative loss of biomass from forest per hectare is large. No account has been made of the potential increased carbon stock in biomass in urban areas, e.g. in parks or roadside planting. This may be a significant carbon sink, especially under the policy of actively encouraging urban tree planting along new roads and in new housing developments, but no data is currently available on its extent.

Table 6.18 includes the area of forest land converted to settlements for the years 1990-2022. The immediate oxidation of biomass, litter and dead wood for years prior to 2006 were derived using the mean IEF for 2006 to 2009 (see section 6.3.3). It is assumed there is no recovery of biomass in these areas deforested to Settlement.

6.7.2.2 Soils

With the exception of Forest land converted to Settlement the estimate of change in soil carbon during conversion to settlement is based on a review of approaches taken by other reporting parties. The 2006 IPCC guidelines also provide some additional insight into this potential source of emissions. It is assumed that 50 per cent of the soil carbon present in the soil prior to conversion to Settlement is lost to the atmosphere, and this occurs in the year of conversion. A 100 per cent uncertainty is attached to this emission factor. The methodology applied to Forest converted to Settlement is outlined in section 6.3.6.

The estimate of soil types under settlement is based on the national distribution of soil types associated with the previous land use. It is assumed that Wetland is unsuitable for conversion to Settlement, and therefore conversion from Wetlands to Settlement is reported as not occurring "NO" in the CRF tables.

6.7.2.3 Direct N_2O emissions from soils due to nitrogen fertiliser application

Inorganic Fertiliser:

Nitrous oxide emissions associated with use of artificial fertilisers on Settlement soils is included in emission estimates for 3.D Agriculture Soils, which includes all sales of N-fertiliser in the state.

Organic Fertiliser:

Nitrous oxide emissions associated with use of organic fertilisers on Settlement soils is estimated based on statistics on the home composting of organic/food waste. Other organic fertiliser which is available for sale at most gardening supply outlets is not included, as it has not been possible to identify a source of robust data on the volume of sales to generate a complete time series of this type of organic fertiliser use within Settlement.

A national report "*Market Report on Irish Organic Compost Production and Use*" [11] in 2012 suggested a nitrogen content of between 7.5 kg $t^{-1,}$ for home composted organic waste which is used to estimate N_2O emissions from organic N fertilizers.

6.7.2.4 Biomass Burning in Settlements

See section 6.4.9 for a detailed discussion of the analysis of areas of biomass burning. Only a very small proportion of burnt areas have been identified as occurring on Settlement by this remote sensing approach. This finding includes a very high uncertainty. Given the assumption that Settlement would have low level of biomass available for burning, it is assumed that the GIS analysis which assigned detected fires to Settlement is inconclusive given that the minimum mapping area of CORINE is large at 25ha, and the fires detected are likely to have occurred on adjacent Grassland. Therefore, there are no emissions associated with Biomass Burning in Settlement, and the notation key "NO" has been assigned. In support of this assumption, it is worth noting that it is illegal in Ireland to burn waste or biomass in the open within settlement areas.

6.7.3 Uncertainty in Settlements

The area of settlement in the 1990 base year is based on the CORINE 1990 estimate of urban, industrial and other manmade environments. Change in settlement area since 1990 are based on construction statistics, national road infrastructure development and specific deforestation activities identified in earlier sections of this chapter.

There is a critical assumption which limits the potential for carbon stock change to only the specific footprint of the buildings, i.e. the sealed area, as captured in the planning permission declarations, with additional assumptions with respect to minimum new paving requirements and hedgerow removal required for new builds. This means there is an implicit assumption of no carbon stock change in lands adjacent to new constructions (green areas, etc.) relative to previous land use. Additional analysis is required to address this issue, however it is unlikely that this analysis would elevate land use change to Settlement to key category status. It is worth noting that these lands are reported as part of the "Other Land" category by default as they would not be captured in Cropland, Grassland, Forestry or Wetland statistics.

Reporting of potential change in soil carbon during conversion to settlement is based on a review of approaches taken by other reporting parties. The revised 2006 IPCC guidelines also provide some additional insight into this potential source of emissions. It is assumed that 50 per cent of the soil

[11] http://www.rx3.ie/MDGUploadedFiles/file/rx3publications/rx3%20Organics%20Market%20Report%20300%20dpi.pdf

carbon present in the soil prior to conversion to Settlement is lost to the atmosphere, and this occurs in the year of conversion. A 100 per cent uncertainty is attached to this emission factor.

6.7.4 Settlements recalculations and impact on the emission trend

Figure 6.38 presents a comparison between the 2023 and 2024 submissions of estimated total emissions associated with Settlements. Recalculations occur (for CO_2 only) for all years as a results of the revised estimates of soil carbon lost from other land uses as presented in the 2019 update to the 2006 IPCC guidelines. Revised areas for conversion from forest land for the years 2016 and 2018 are included in this submission as a result of updated analysis in the last NFI. On average emissions have decreased by 11.73 kt CO_2 eq or 2.9 per cent annually (-80.43 kt CO_2 eq to 386.26 kt CO_2 eq) across the timeseries 1990-2021. For the years 2016 and 2018 there is a 258.3 per cent and 186.7 per cent increase, respectively in those years.

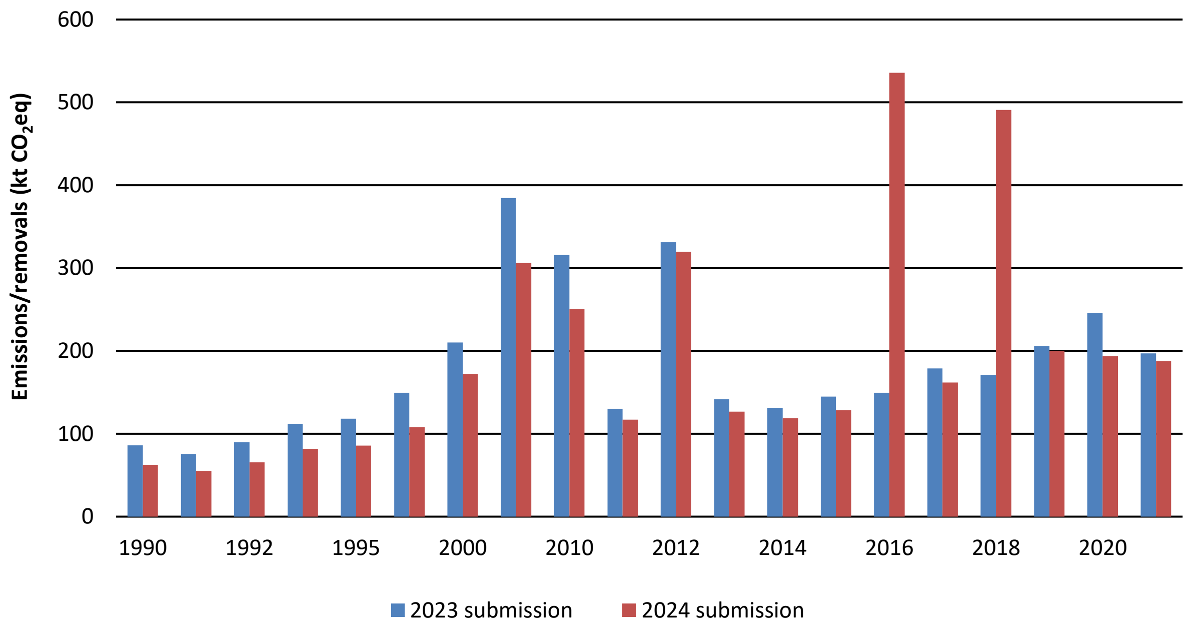


Figure 6.38 Comparison between the 2023 and 2024 submissions of estimated total emissions associated with Settlements

6.8 Other land (Category 4.F)

6.8.1 Other Land area

The category *4.F Other Land* includes all lands not classified under the categories 4.A through 4.E. It represents the difference between the sum of categories 4.A through 4.E and the total land area of Ireland. A large part of *4.F Other Land* is not active in terms of potential for emissions or removals.

6.8.2 Carbon Stock Changes in Other Land

It is assumed that Other Land remaining Other Land is in equilibrium across all carbon pools, and not subject to anthropogenic change. Table 6.18 shows the transition of forest land to other land, which are not classified as crop, grassland, settlements or wetlands for the years 1990-2021. These forest conversions are small areas being converted to quarries or the footprints of telecommunication masts. More recently, these areas also include forest conversions into windfarms, but these are only the areas for roads and turbine platforms. Areas in the turbulence zone are generally clearfelled and replanted.

The immediate oxidation of biomass, litter and dead wood for years prior to 2006 were derived using the mean IEF for 2006 to 2009 (see section 6.3.3). It is assumed that these deforested lands revert to a natural grassland state, and recover an above ground biomass of the order of 6 t C ha^{-1} in the year of conversion.

6.8.3 Biomass Burning on Other Land

See section 6.4.9 for a detailed discussion of the analysis of areas of biomass burning. Only a very small proportion of burnt areas have been identified as occurring on Other Land by this remote sensing approach. This finding includes a very high uncertainty. Given the assumption that Other Land would have low level of biomass available for burning, it is assumed that the GIS analysis which assigned detected fires to Other Land is inconclusive given the minimum mapping unit of CORINE is 25ha, and the fires detected are likely to have occurred on adjacent Grassland. Therefore, there are no emissions associated with Other Land Biomass Burning, and the notation key "NO" has been assigned.

6.8.4 Uncertainty in Other Land

In the absence of a "wall to wall" land use mapping system in Ireland, the Other Land area is estimated from the residual area required to maintain a reporting of constant total national land area once estimates for all other land use categories have been taken into account. As such, this category will be subject to the cascade of uncertainty in estimates of land use area from the other land use categories.

6.8.5 Other Land recalculations and impact on emission trend

Estimates of emissions from Other Land are by default directly affected by changes in the areas and revisions to the areas associated with all the other land uses. Given the low level of emissions from this land use category for most years, the absolute values of recalculations are in general small (average 1990 to 2021 timeseries is 0.19 kt CO_2 eq per annum).

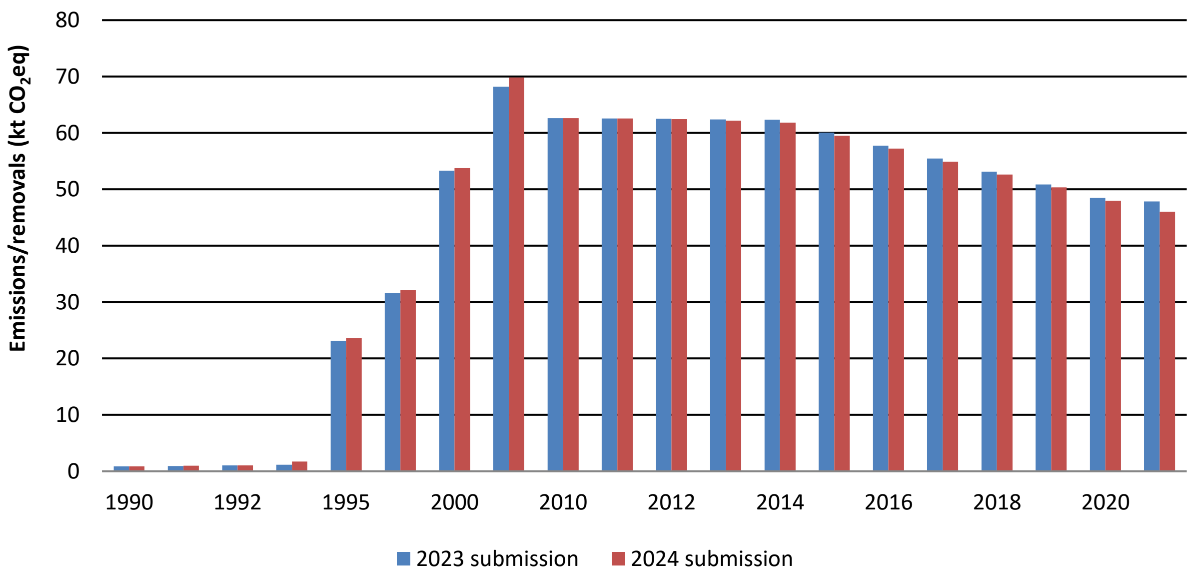


Figure 6.37 Comparison between the 2023 and 2024 submissions of estimated total emissions for Other Land

6.9 Summary of uncertainty in non-Forest Land LULUCF categories

The purpose of uncertainty analysis is to identify those key categories which contribute significantly to the uncertainty in the overall estimate emissions and removals. The results of the formal Tier 1 approach to uncertainty analysis are presented in Table 6.36. These are consistent with the findings of the qualitative discussion provided here.

Categories of land use can be identified as potential key categories for uncertainty in the estimate of greenhouse gas emissions and removals within LULUCF by virtue of uncertainty in the activity data or uncertainty in the emission factor, or a combination of both.

6.10 Overall LULUCF Quality Assurance and Quality Control

The entire compilation for the LULUCF sector were reviewed externally by an independent consultant, qualified as a UNFCCC expert reviewer for LULUCF/KP-LULUCF in March 2012. Furthermore, activities under Article 3.3 of the Kyoto Protocol were externally reviewed by a separate independent consultant in late 2017. These independent assessments provide an important element of quality assurance for this submission. Following the findings of these independent peer reviews, this chapter was substantially improved to provide additional transparency and consistency and this has been maintained in this submission.

6.10.1 Category specific QA/QC for Forest Lands (4.A)

Category specific QA/QC plans and documentation for forest land are carried out by FERS Ltd on behalf of the DAFM and EPA using 2006 IPCC Guidelines (Chapter 6) and are outlined in the following sections.

6.10.1.1 QA/QC plan for activity data for Forest Lands (4.A)

- Evaluation of required data from external sources (Forest service, Collite);
- Set up of memoranda of understanding between DAFM, EPA and data providers including:
    - Deadlines for data delivery;
    - Internalised QA/QC checks and procedures;
    - Metadata;
    - Notification of changes to methods used for collecting activity data;
    - Identification of contact points and responsible parties.
- Correspondence with data providers 2 months before agreed delivery dates to notify of new requirements, request notification of changes to any activity data and to remind providers of deadlines;

Table 6.35 Summary of Uncertainty analysis

	IPCC Source Category	Gas	Activity Data (AD) Uncert.	Emission Factor (EF) Uncert.	Reference Activity Data	Reference Emission Factor
	Category/ Sub-category		**%**	**%**		
4.A	Forest land	CO_2	51.0	114.0	See Sections 6.3.4.7 and 6.3.5.7	Country Specific value cf Chapter 6.3
4.B.1	Cropland Remaining Cropland	CO_2	7.2	69.1	Teagasc Soil and Sub-soil Map 2009, Trend analysis of LPIS and CSO UAA areas	Default value from IPCC Guidelines
4.B.2	Cropland In Transition	CO_2	7.2	69.1	Teagasc Soil and Sub-soil Map 2008, Trend analysis of LPIS and CSO UAA areas	Default value from IPCC Guidelines
4.C.1	Grassland remaining Grassland	CO_2	12.2	30.2	Teagasc Soil and Sub-soil Map 2008, Trend analysis of LPIS and CSO UAA areas	Default value from IPCC Guidelines
4.C.2	Grassland in Transition	CO_2	666.7	401.8	Teagasc Soil and Sub-soil Map 2008, Trend analysis of LPIS and CSO UAA areas	Default value from IPCC Guidelines
4.D.1	Wetlands remaining wetlands	CO_2	6.1	26.7	CORINE, BnM, SEAI, Expert opinion	Default value from IPCC Guidelines
4.D.2	Land Converted to Wetland	CO_2	2.5	50.0	Deforestation data, Chapter 6.3	Country Specific value cf Chapter 6.3
4.E.1	Settlement remaining Settlement	CO_2	40.4	75.0	Expert assessment of national statistics, CORINE	Default value from IPCC Guidelines
4.E.2	Settlement in Transition	CO_2	40.4	92.5	Expert assessment of national statistics, CORINE	Default value from IPCC Guidelines
4.F.1	Other Land remaining Other Land	CO_2	30.9	90.0	Uncertainty in Other Land Area based on combined uncertainty of land use change in other land use categories	Default value from IPCC Guidelines
4.F.2	Lands converted to Other Land	CO_2	136.8	75.0	Uncertainty in Other Land Area based on combined uncertainty of land use change in other land use categories	Default value from IPCC Guidelines
4.A	Forest Land	CH_4	30.0	100.0		
4.B	Cropland	CH_4	100.0	39.1	Uncertainty in area of burning, scaled by reported Forest fire	Default value from IPCC Guidelines
4.C	Grassland	CH_4	96.4	91.2	Uncertainty in area of burning, scaled by reported Forest fire	Default value from IPCC Guidelines
4.D	Wetland	CH_4	86.0	66.5	Uncertainty in area of burning, scaled by reported Forest fire	Default value from IPCC Guidelines
4.E	Settlement	CH_4	0.0	0.0	Uncertainty in area of burning, scaled by reported Forest fire	Default value from IPCC Guidelines
4.F	Other Land	CH_4	0.0	0.0	Uncertainty in area of burning, scaled by reported Forest fire	Default value from IPCC Guidelines
4.A	Forest Land	N_2O	30.0	100.0		Default value from IPCC Guidelines
4.B	Cropland	N_2O	75.0	100.0	N2O emissions associated with burning only, Activity data same as CH4 emissions for Burning	Default value from IPCC Guidelines
4.C	Grassland	N_2O	17.4	100.0	Combined uncertainty in carbon loss from drained organic soils under grassland. The uncertainty from the carbon estimate cascades to the Activity Data Uncertainty in this approach	Default value from IPCC Guidelines
4.D	Wetland	N_2O	56.8	92.7	Combined uncertainty in carbon loss from drained organic soils within Wetlands. The uncertainty from the carbon estimate cascades to the Activity Data Uncertainty in this approach	Default value from IPCC Guidelines
4.E	Settlement	N_2O	45.2	54.7	Combined uncertainty in carbon loss from drained organic soils within Wetlands. The uncertainty from the carbon estimate cascades to the Activity Data Uncertainty in this approach	Default value from IPCC Guidelines

- QC checks of reference sources for national activity data by evaluation of documentation with regard to activity data. For example, is data collection or sampling regimes adequate and un-bias? Does the agency have any information on uncertainties?
- Comparisons of input data with independent data sets such as harvest statistics (FAO/Eurostat), land cover data such as CORINE (see Black et al., 2009a);
- Time series consistency checks of activity data;
- Collation and initial completeness checks of activity data required;
- Pre-processing activity data and compiling data bases to be used by CBM-CFS3.

6.10.1.2 Emission Factors, Models and Calculations

QC checks on the background data used to develop emission factors: assessment of the adequacy of the emission factors and the QA/QC performed during their development. (e.g. Byrne and Farrell, 2005-organic soil emissions; Tobin et al 2007-litter turnover).

Model selection

CBM-CFS3 is an international recognised forest carbon budget model. Numerous papers describe the model, model validation and application (see Kurz et al., 2009, Grassi et al., 2018, Pilli et al., 2013, 2016). QC checks on Models**:** Both the FORCARB and CBM-CFS3 models were developed specifically for GHG inventory reporting. When these models were designed and developed the following was considered;

- Appropriateness of model assumptions, extrapolations, interpolations;
- Model calibration: models have been calibrated (see Annex 3.4.A.5) using NFI data (see Annex 3.4);
- Calibration of the age class distributions used in the FORCARB model was checked against independently derived information (Black et al., 2012);
- If model descriptions, assumptions, rationale, and scientific evidence and references supporting the approach and parameters used for modelling have not been published, detailed descriptions are supplied in the Annex 3.4;
- Models are re-evaluated and updated annually using any new research information or if uncertainty analysis and validations indicate large uncertainties of bias in the assessment of any pool of forest subcategory.
- All pools are included in the models, so are complete in relation to the IPCC source/sink categories. Where categories or pools are not reported, this is justified in chapter 11.
- The calibrated CBM-CFS3 model has been cross compared with the previous CARBWARE model and is shown to improve CSC estimates for Irish forestry (section 6.10.1.3)
- CBM-CFS3 has been validated against real time eddy covariance data and show good agreement in net ecosystem change estimates (section 6.10.2)

QA/QC is improved by using a widely used software (CBM-CFS3) together with archive (AIDB) and simulation databases. This reduces the risk of calculation errors or manual error over the time series.

Cross comparison of CBM-CFS3 and CARBWARE

The CBM-CFS3 model compares well with the previous tier 3 model (CARBWARE) used for reporting from 2008-2017. We refer to Figures 6.12 and associated text in NIR 2019 where we see good agreement between different models (CARBWARE and CBM-CFS3). CARBWARE was extensively validated against independent data sources (see NIR 2018). The observed differences are clearly explained in the text relating to the figures. We consider that CBM-CFS3 performs better than CARBWARE in relation to modelling of the dead organic matter pool and the ability to estimate mineral soil stock changes (see Figure 9.12, NIR 2019).

For the afforestation (4A2) we refer to Figure 6.15 and related text of NIR 2019, which compared CBM-CFS3 and CARBWARE trends, again there is excellent agreement with the extensively validated CARBWARE model.

6.10.1.3 Validation of CBM-CFS3 with research data

Validation against real time forest NEE estimates

Eddy covariance measures the exchange of CO_2 between a forest and the atmosphere. This is the only available real time measurement of forest net ecosystem exchange (NEE, see Black et al., 2007). CBM-CFS3 provides estimates of NEE (biomass and DOM pools), which, in theory should agree with eddy covariance estimates, if models are properly calibrated. Eddy covariance data from the literature (Black et al., 2007) and additional data provided by Prof M Saunders (TCD) from the COFORD funded CARBIFOR2 project, were used for cross comparison with CBM-CFS3 model outputs for corresponding species, age and yield classes. Validation of CBM-CFS3 forest removals (i.e. NEE) against eddy covariance show good agreement (r^2= 0.84, Figure 6.38).

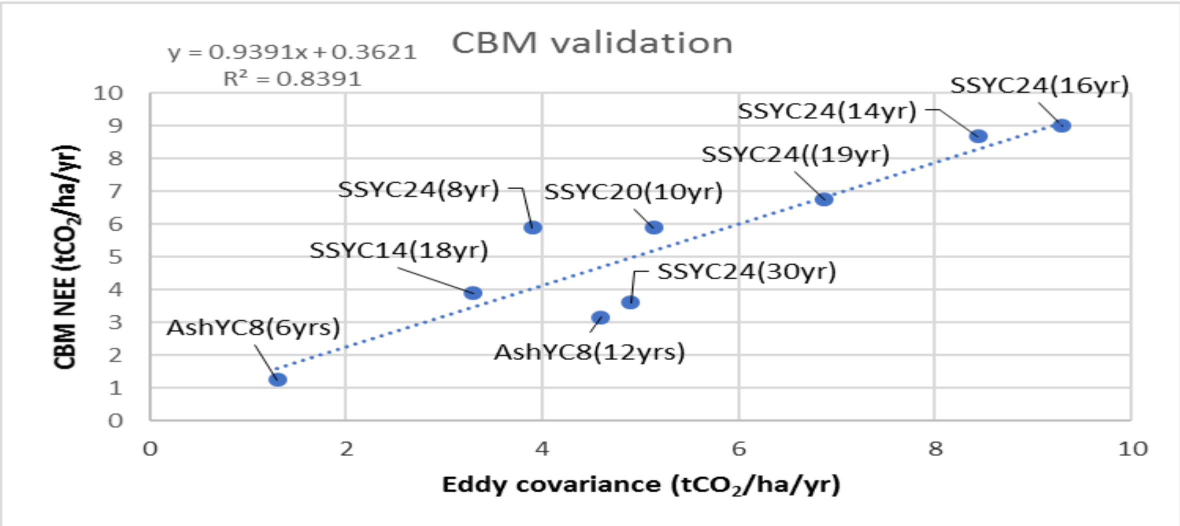


Figure 6.38 Validation of NEE estimated form CBM-CFS3 and eddy covariance data for different aged a Sitka spruce (SS) and Ash stands

Validation of CBM-CFS3 biomass stock estimates

Research data from the COFORD research program (provided by Prof B Tobin (UCD) was used to validate CBM-CFS3 C stock estimates, derived from corresponding species, yield class and silvicultural intervention categories (Table 6.36). The NFI estimated biomass stock values for Irish forests vary from

0 to 568 t C ha^{-1} (mean value 72 t C ha^{-1}) for the species types listed in Table 6.36. The research dataset contains the three most representative forest types in Ireland and generally concentrated on younger age classes, because research was aimed at investigating C stock in afforested stands planted since 1990.

Table 6.36 A summary of the experimental validation dataset

Species	**C stock range (t C ha^{-1})**	**Yield class range (m^3 ha^{-1} yr^{-1})**	**Age range (years)**	**Number of sites (N)**	**Corresponding CBM-CFS3 model**
Sitka spruce	8.9-147.4	10-24	9-21	37	Sitka spruce thinned
Ash	1.2-193.1	6-8	6-50	24	FGB thinned
Mixed Sitka spruce lodgepole pine	0.9-20.8	10-14	3-14	18	Cmix no thin

The performance of the CBM-CFS3 estimate of biomass C stocks was assessed using various statistical measures including:

- Adjusted r^2 and P value
- Percentage bias (Bias per cent)
- Root mean square error (RMSE)
- Percentage error at the 95 per cent confidence interval (Error %)
- Students T test P value, where P values < 0.05 suggest that CBM-CFS3 and validation data are significantly different.

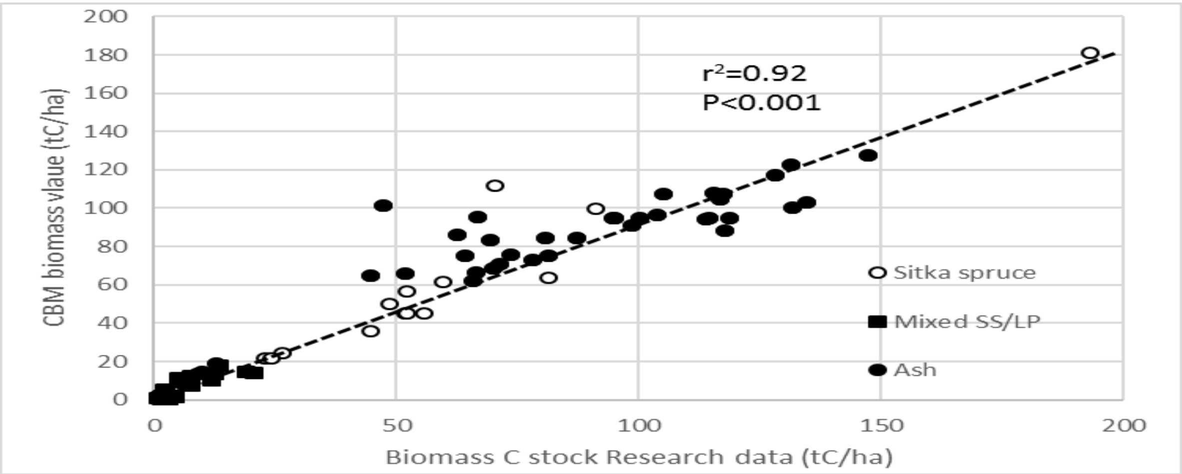


Figure 6.39 Validation of total biomass estimates from CBM-CFS3 and research data plots for different aged Sitka spruce, mixed Sitka spruce and Lodgepole pine (SS/LP)) and Ash stands.

Table 6.37 Independent cross validation statistics for modelled CBM-CFS3 and research plot total biomass stock estimates

Species	Corresponding CBM-CFS3 model	RMSE (tC/ha)	Error %	Bias %	T test P value
Sitka spruce	Sitka spruce thinned	17.4	6.6	2.16	0.79ns
Ash	FGB thinned	10.54	10.8	0.6	0.60ns
Mixed Sitka spruce lodgepole pine	Cmix no thin	3.5	23.9	-4.45	0.89ns
Total	**All**	**13.1**	**5.5**	**1.6**	**0.89ns**

Based on the statistical test carried out (see Figure 6.39 and Table 6.37) CBM-CFS3 predicts total biomass C stock for different forest types at a high degree of accuracy. The overall prediction error at the 95 per cent confidence interval is 5.5 per cent.

6.10.2 Completeness and error checks in the compilation of the CRF tables

Transcription of data to the CRF and compilation of data in the required format can result in inconsistencies. A check on the final CRF table is performed on completion of data transcription. Following recommendations from previous ARRs corrections or adjustments are made and documented in the NIR. A QA/QC check list is documented every year to record problems detected and corrective actions.

6.10.2.1 Validation and QA/QC links to Uncertainty Analysis

Comparisons of emission factors between countries: this is carried out for forest remaining forest land and land converted to forests (Table 6.38 and Table 6.39). Uncertainty analysis or validation is used to identify where improvements should be made to pool or categories estimates and methods. For example, improvements are planned following the identified issue bias in estimating broadleaf biomass changes.

Uncertainty analysis includes trend analysis to determine if there are any time series inconsistencies.

Time series adjustments are applied if there are fundamental differences in the activity data being used or methods applied over a time series.

6.10.2.2 Validation of Reported Estimates in Category 4.A.1

In addition, model uncertainty and model validations shown in Annex 3.4, IEFs reported in the CRF table 4.A were compared to other countries with similar forest characteristics by using the Locator Tool (Table 6.38). It is important to note that changes in methodology due to the introduction of new pools and EFs as part of the 2006 IPCC Guidelines, the 2013 Wetland Supplement and the 2013 KP Supplementary Guidance has resulted in significant differences in IEFs for drained organic soils and N_2O from drainage. These comparisons do not take these changes into account. The same methodologies for LB and DOB are applied in the current submission. Irelands IEF for LB is comparable to the UK and within the observed range (Table. 6.38). DOM EFs agree slightly higher than the UK but again within the expected range. The reported IEF from organic soils are within the ranges reported. The IEFs for wildfires in Ireland is the highest reported.

Table 6.38 Comparison of 2015 inventory year IEF's reported for other countries and those reported for category 4.A.1

Pool	IEF (Mg/ha)			
	Ireland	EU28	UK	Range
LB net	1.07	0.58	1.08	-0.3 to 1.7
DOM	0.43	-0.001	0.22	-0.23 to 0.51
Organic Soils	-0.45	-0.41	6.06	-0.71 to 6.06
Fire CO_2	260.64	IE,NO,NA	Mg/kg biomass	8.3 to 260.64
Fire CH_4	1.14	IE,NO,NA	Mg/kg biomass	0.03 to 1.14
Fire N_20	0.01	IE,NO,NA	Mg/kg biomass	<0.001 to 0.3008

6.10.2.3 Validation of Reported Estimates in Category 4.A.2

IEFs reported in the CRF table 4A2 were compared to other countries with similar forest characteristics for the inventory year 2010 in the 2012 submission (Table 6.39). All of the reported IEFs for all pools are within the ranges reported for other countries.

Table 6.39 Comparison of IEFs reported for other countries and those reported by Ireland for category 4.A.2

Pool	IEF (Mg/ha)			
	Ireland	EU28	UK	Range
LB net	3.12	1.34	0.91	-0.187 to 8.79
DOM	0.82	0.21	0.03	-0.22 to 2.55
Organic Soils	-0.73	-0.65	2.77	-10.8 to 2.8
Fire CO_2	151.8	IE,NO,NA	Mg/kg biomass	0.0009 to 151.8
Fire CH_4	0.66	IE,NO,NA	Mg/kg biomass	0.29 to 0.03
Fire N_20	0.003	IE,NO,NA	Mg/kg biomass	0.008 to <0.001

6.10.2.4 Independent External Review

The use of the CBM-CFS3 model for reporting forest emissions and removals for the EU LULUCF regulation was carried out in March/April 2019 (see NFAP, 2020). There was an independent external review of the Kyoto Protocol elements of the LULUCF inventory in 2017. This review was funded by COFORD, DAFM.

Chapter 7 Waste

7.1 Overview of the Waste Sector

The list of activities under *Waste* in the IPCC reporting format is given in Table 7.1 below. A summary of emissions from these activities are given in Table 7.2, Figure 7.1 and Figure 7.2.

Solid waste disposal in landfill sites, *biological treatment of solid waste, waste incineration* and *wastewater treatment* are the main activities that give rise to greenhouse gas emissions in the *Waste* sector (Table 7.1).

The largest of these sources is usually *solid waste disposal* on land where CH_4 is the gas concerned. Landfills represent a key emission category in Ireland and the emission estimates of CH_4 are considered to be well quantified in the national inventory.

7.1.1 Emissions Overview

A summary of emissions from these activities are given in Table 7.2.

There is one key category in this sector, which is both a trend and level key category:

- ***5.A Solid Waste Disposal (CH_4)*** at solid waste disposal sites (SWDS) is a significant activity in Ireland. Emissions from this source include both historical unmanaged and currently well managed sites.

Other categories present in this sector include:

- ***5.B.1 Composting*** consisting of household organic waste collected at kerbside and brought to civic amenity/temporary collection sites, as well as organic material composted at households;
- ***5.B.2 Anaerobic digestion at biogas facilities (CH_4)*** is a relatively recent new treatment of organic wastes for biogas recovery and is estimated for 2010 to 2022;
- ***5.C.1 Waste Incineration*** includes emissions from clinical waste up to 1997 when all hospital waste incinerators were closed, and industrial/hazardous waste which covers emissions from incineration of solvents or liquid/vapour destruction in thermal oxidisers at chemical and pharmaceutical plants. All solid waste incineration in Ireland is for electricity production and therefore is accounted for in *1.A.1.a Energy Industries*;
- ***5.C.2 Open Burning of Waste*** includes the combustion of unwanted combustible materials such as paper, wood, plastics, textiles, rubber, waste oils and other debris in nature (open-air) and domestic fireplaces.
- ***5.D Wastewater Treatment and Discharge*** includes treatment of wastewater and human sewage.

The greenhouse gases relevant to *Waste* are as follows:

- ***Carbon dioxide*** emissions originate from *5.C.1 Waste Incineration* and *5.C.2 Open Burning of Waste;*

- ***Methane*** emissions originate from *5.A.1 Managed Waste Disposal Sites, 5.A.2 Unmanaged Waste Disposal Sites, 5.B.1 Composting, 5.B.2 Anaerobic digestion, 5.C.1 Waste Incineration, 5.C.2 Open Burning of Waste,* and *5.D.1 Domestic Wastewater;*
- ***Nitrous Oxide*** emissions originate from *5.B.1 Composting, 5.C.1 Waste Incineration, 5.C.2 Open Burning of Waste,* and *5.D.1 Human Sewage.*

The 2024 submission shows total GHG emissions of 877.9 kt CO_2 equivalent in the Waste sector in 2022, of which *5.A Solid waste disposal* accounts for 72.2 per cent, *5.B Biological treatment of solid waste* 5.8 per cent, *5.C Incineration and open burning of waste* 4.1 per cent and *5.D Wastewater treatment and discharge* 17.8 per cent. The latest estimates show that emissions in the *Waste* sector have decreased by 48.6 per cent from 1990 to 2022 mainly due to a 57.0 per cent decrease in CH_4 emissions from *5.A solid waste disposal*.

7.1.2 Methodology Overview

A summary of the Tier methods consistent with the 2006 IPCC Guidelines is provided in Table 7.1 below, along with a summary of the activities applicable to Ireland.

Ireland's first waste to energy municipal solid waste (MSW) incinerator commenced operation in 2011 and its second commenced in 2017 and emissions from these new plants have been reported under public electricity and heat production (1.A.1.a) in chapter 3 in accordance with the 2006 IPCC guidelines.

Table 7.1 Level 3 Source Methodology for Waste

5. Waste	**CO_2**	**CH_4**	**N_2O**
A. Solid Waste Disposal*			
1. Managed Waste Disposal Sites	NA	NA, T2	NA
2. Unmanaged Waste Disposal Sites	NA	NA, T2	NA
B. Biological Treatment of Solid Waste			
1. Composting	NA	NA, T1	NA, T1
2. Anaerobic Digestion at Biogas Facilities	NA	NA, T1	NA, T1
C. Incineration and Open Burning of Waste			
1. Waste Incineration	T1	T1	T1
2. Open Burning of Waste	T1	T1	T1
D. Wastewater Treatment and Discharge			
1. Domestic Wastewater	NA	T1, T2	T1
2. Industrial Wastewater	NA	NA	NA
E. Other	NA	NA	NA

*Key Category by level and trend in 2021 (including and excluding LULUCF)
T1, 2, 3: Tier 1, Tier 2, Tier 3 as described in the 2006 IPCC Guidelines;
NA: "not applicable" because no emissions of the gas occur in the source category.

Table 7.2 Emissions from Waste 1990-2022

IPCC	Category	Gas	Unit	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
5.A.1	Managed Waste Disposal Sites	CH_4	kt CO_2eq	NO	NO	1420.3	1139.9	336.7	525.5	721.7	792.5	803.2	756.0	714.0	664.6	643.8	589.6	634.1
5.A.2	Unmanaged Waste Disposal Sites	CH_4	kt CO_2eq	1476.2	1783.9	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
5.B.1	Composting	CH_4	kt CO_2eq	NO	NO	NO	30.4	31.9	29.0	26.8	25.9	25.6	28.5	27.4	29.0	27.7	24.2	29.1
5.B.1	Composting	N_2O	kt CO_2eq	NO	NO	NO	17.3	18.1	16.5	15.2	14.7	14.5	16.2	15.5	16.5	15.7	13.7	16.5
5.B.2	Anaerobic digestion at biogas facilities	CH_4	kt CO_2eq	NO	NO	NO	NO	0.1	0.3	0.4	1.0	0.9	2.1	2.9	3.9	4.7	5.3	5.4
5.C.1	Waste incineration	CH_4	kt CO_2eq	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.C.1	Waste incineration	N_2O	kt CO_2eq	0.74	0.74	0.53	0.96	0.48	0.38	0.35	0.35	0.20	0.22	0.18	0.25	0.25	0.29	0.32
5.C.1	Waste incineration	CO_2	kt CO_2eq	83.0	83.0	58.7	106.3	53.5	42.4	38.5	39.0	22.0	24.2	20.1	27.3	28.0	31.7	35.0
5.C.2	Open burning of waste	CH_4	kt CO_2eq	1.17	1.42	1.94	2.60	0.47	0.16	0.15	0.16	0.15	0.16	0.19	0.25	0.15	0.13	0.06
5.C.2	Open burning of waste	N_2O	kt CO_2eq	0.24	0.29	0.39	0.52	0.10	0.03	0.03	0.03	0.03	0.03	0.04	0.05	0.03	0.03	0.01
5.C.2	Open burning of waste	CO_2	kt CO_2eq	12.62	15.19	18.08	22.23	7.52	2.18	2.64	2.86	2.69	2.87	3.41	4.65	2.74	2.51	0.97
5.D.1	Domestic wastewater	CH_4	kt CO_2eq	68.4	70.2	69.9	55.3	56.3	56.6	58.6	58.4	56.5	57.1	56.7	57.3	59.5	60.1	58.7
5.D.1	Domestic wastewater	N_2O	kt CO_2eq	66.8	65.0	73.5	79.0	83.8	82.2	84.8	85.5	90.2	91.5	92.9	94.1	95.2	95.9	97.6
	Total Waste		**kt CO_2eq**	**1709.2**	**2019.8**	**1643.4**	**1454.4**	**588.9**	**755.1**	**949.2**	**1020.4**	**1015.9**	**979.0**	**933.3**	**897.9**	**877.8**	**823.4**	**877.9**

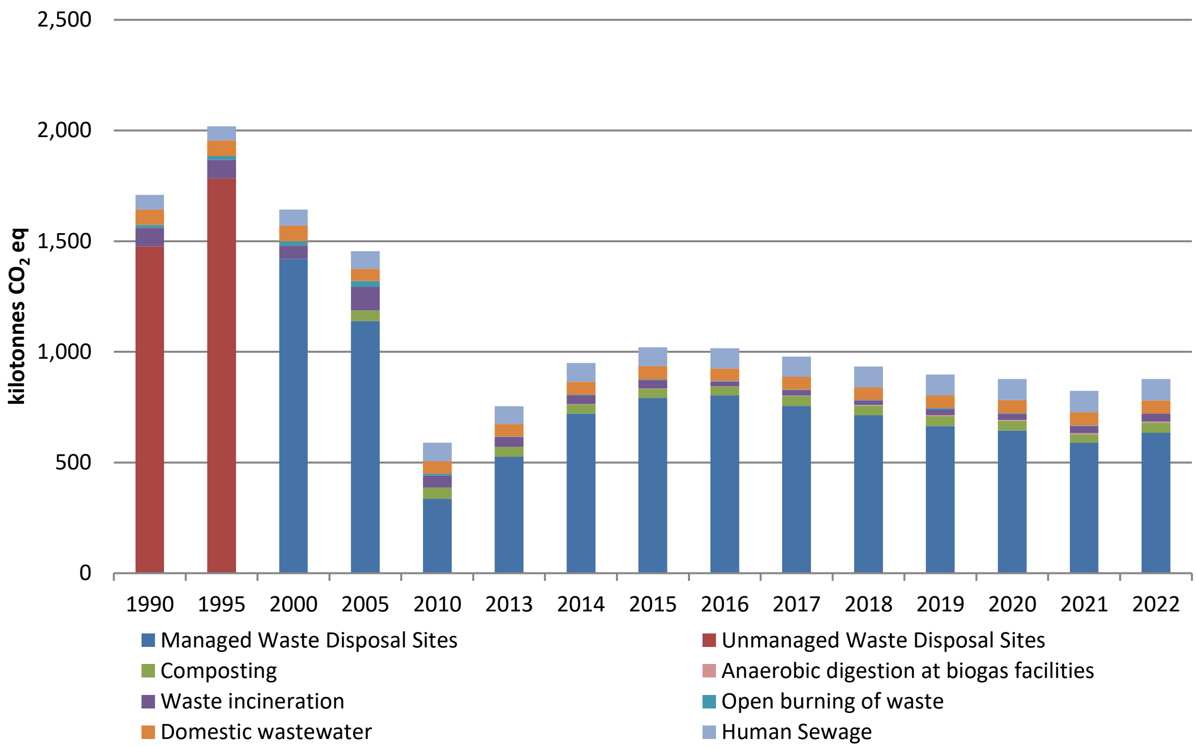


Figure 7.1 Total Emissions from Waste by Sector, 1990-2022

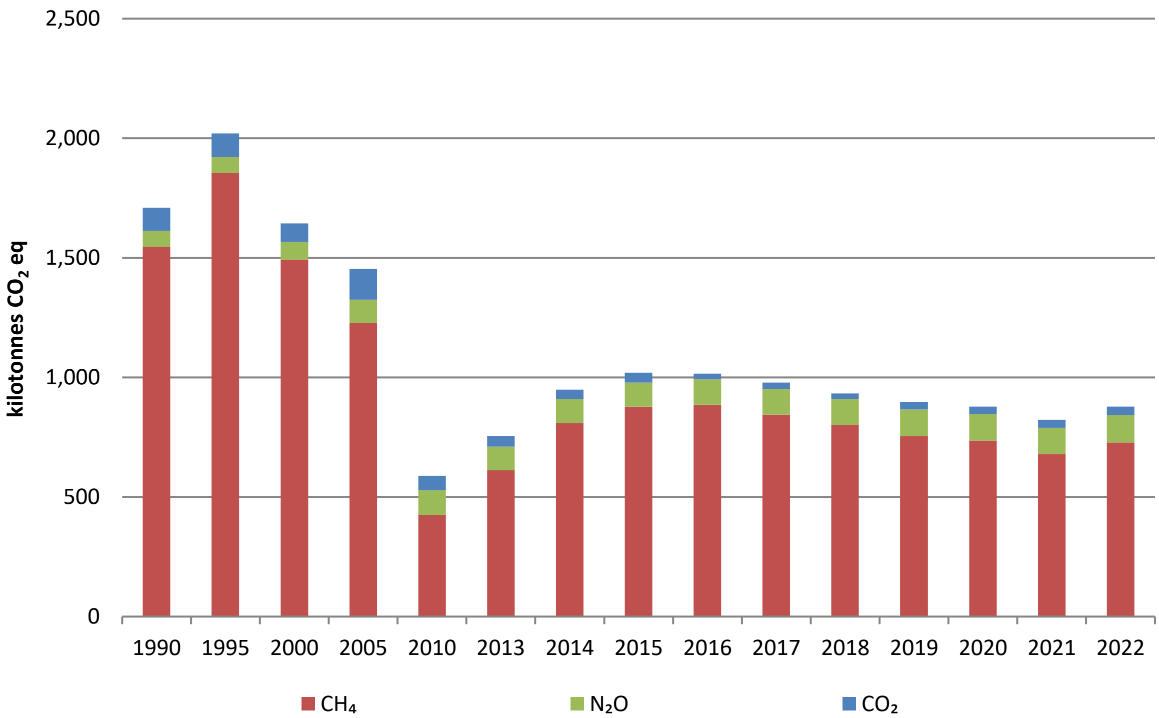


Figure 7.2 Total Emissions from Waste by Gas, 1990-2022

7.2 Emissions from Solid Waste Disposal (5.A)

The IPCC Level 3 emission source categories relevant under *5.A Solid Waste Disposal* in 2022 are *5.A.1 Managed Waste Disposal Sites* and *5.A.2 Unmanaged Waste Disposal Sites*. Total CH_4 emissions from these activities amounted to 634.1 kt CO_2eq in 2022.

7.2.1 Managed Waste Disposal Sites (5.A.1)

7.2.1.1 Category Description

Treatment and disposal of municipal, industrial and other solid waste at solid waste disposal sites (SWDS) produces significant amounts of methane (CH_4). In addition to CH_4, SWDS also produce biogenic carbon dioxide (CO_2) and non-methane volatile organic compounds (NMVOCs) as well as smaller amounts of nitrous oxide (N_2O), nitrogen oxides (NOx) and carbon monoxide (CO). Waste minimisation and recycling/reuse policies (DECLG, 1998, 2002, 2004(a), 2004(b), 2012) have been introduced to reduce the amount of waste generated in Ireland, and increasingly, alternative waste management practices to solid waste disposal on land have been implemented to reduce the environmental impacts of waste management. Also, landfill gas recovery is now commonplace as a measure to reduce CH_4 emissions from SWDS.

7.2.1.2 Methodological Issues

The Tier 2 approach in the 2006 IPCC Guidelines is used for both *Unmanaged* and *Managed Waste Disposal Sites*. The model is a simple first-order decay spreadsheet model that keeps a running total of the amount of degradable organic carbon (DOC) available in a landfill as the basis for calculating the amount of DOC converted to CH_4 and CO_2 annually. Analyses undertaken, as part of the improved methodology introduced in the 2010 submission, shows annual Methane Correction Factor (MCF) values increasing over time to reflect the change from generally shallow, poorly-managed landfills before 1998 (and therefore pre-landfill licensing) to well controlled and engineered managed landfills in subsequent years. Whilst individual landfill data is collated and analysed for MSW constituent breakdowns and CH_4 recovery statistics, the first order decay model is used at a national level (i.e. assuming all waste in one landfill).

The EPA commenced the development of the National Waste Database (NWD) in the early 1990s to address a severe lack of information on waste production and waste management practices in Ireland. The database was needed to support radical reform of national policy and legislation on waste pursuant to the Waste Management Act of 1996 and subsequent Government strategies on sustainable development (DELG, 1997) and waste management (DELG, 1998). National statistics generated from this database published on a three-year cycle, and interim reports published on a yearly basis since 2001 by the EPA are the primary basis for establishing the historical time-series of municipal solid waste (MSW) placed in landfills from 1995 onwards. These reports include:

- Carey et al, 1996;
- Crowe et al, 2000;
- Meaney et al, 2003;
- Collins et al, 2004a; Collins et al, 2004b; Collins et al, 2005;
- Le Bolloch et al, 2006; Le Bolloch et al, 2007; Le Bolloch et al, 2009;
- McCoole et al, 2009; McCoole et al, 2011; McCoole et al, 2012; McCoole et al, 2013; McCoole et al, 2014a; McCoole et al, 2014b.

- More recent datasets have been published on the internet only and can be accessed at http://www.epa.ie/nationalwastestatistics/

The inventory agency also utilises individual reports by landfill operators on the quantities of biodegradable municipal waste (BMW) accepted at landfill sites. Landfill operators are required to provide this information to the EPA so that national BMW reduction targets set under the Landfill Directive (1999/31/EC) can be assessed and complied with and that guidance on MSW Pre-Treatment and Residuals Management (EPA, 2009) is adhered to.

Identification and risk assessment of historical landfills under S.I. No. 524 of 2008 (DEHLG, 2008) serves as the main source of information on landfilling of waste prior to 1995. The results of other surveys undertaken in previous years (Boyle, 1987, ERL, 1993, MCOS, 1994 and DOE, 1994) have also been used to some extent in compiling the MSW time-series.

The NWD reports, published since 1995, provide a good starting point for assigning waste quantities to SWDS and provide a representation of waste composition. However, knowledge of waste quantities and composition are still required to establish the basic historical information, given the extended timeframe that must be taken into account in the IPCC waste model. The waste quantities for model analyses are determined by adding up the amounts of household and commercial waste for the relevant landfills for each year where this is given by the NWD. The quantities of waste for other years, which are not available from the NWD, are estimated by using the documents and published reports referred to above (Boyle, 1987, ERL, 1993, MCOS, 1994 and DOE, 1994).

Wastepaper products are the key determinant of degradable carbon in landfills. The NWD shows a significant decline in the proportion of wastepaper products in waste going to landfills which reflects the increase in recycling of paper. The NWD is used to give the values for all years in the period 1995 to 2010 after which BMW reports are utilised. In the analysis for historical years, the paper content was fixed at 40 per cent for 1980 (and previous years and decreases linearly from 40 per cent in 1980 to 30.2 per cent in 1995 (Boyle, 1987, Carey et al., 1986). The proportion of organics, the other principal constituent of waste, was estimated in the same way for each year.

In response to a recommendation from a previous review, organic waste is now separated into food and garden waste. Additional information on the composition of solid waste disposed at landfills is provided in Annex 3.5, Table 3.5.A.

The waste constituents of MSW that contribute to DOC, food waste, waste paper, wood, textiles and disposable nappies, are identified in the available NWD breakdown for 1995, 1998, 2001 through 2010 and BMW reports for 2011 to 2022. The IPCC default proportions of DOC content are used for all these constituents (Annex 3.5). In addition, a DOC content of 5 per cent has been assumed for sewage sludge.

The 2006 IPCC Guidelines provide narrow ranges for the value of decay rate constant appropriate to the individual waste components under different climatic zones. Ireland has chosen the highest values given for the Western Europe wet temperate conditions for all waste constituents, as the value of the ratio MAP:PET (Mean Annual Precipitation: Potential Evapotranspiration) is greater than 2 in Ireland.

The default value of 0.5 is utilised for the fraction of DOC dissimilated (DOC_f)

The choice of MCF is made by assigning individual landfills or groups of landfills to the IPCC management categories (Table 3.1 Volume 5 2006 IPCC Guidelines) which reflect the applicable level of management for each year of their lifetime. The licensing of landfill sites came into effect around 1998, which ultimately resulted in the closure of approximately 250 sites (mainly shallow unmanaged sites). All landfills that continued in operation under licence after 1998, together with all new sites, are assumed to come within the IPCC description of a managed site and the MCF of 1.0 applies. The licensing of landfills is a requirement under the Waste Management Act 1996 (DECLG. 1996) as amended and associated regulations. The larger landfills that were in existence prior to the introduction of waste licensing were subject to some level of management but not to the extent of fully managed licensed sites after 1998. These large sites are assigned to the IPCC category of unmanaged deep sites for the years up to 1998 with a MCF of 0.8 and to the managed category with a MCF of 1.0 for the remainder of their lifetime post 1998. The 250 sites (approximately) that operated primarily as small open town dumps and shallow uncontrolled disposal sites with significant aerobic conditions up to the introduction of waste licensing are assigned to the IPCC category of unmanaged shallow sites up to 1998, for which the appropriate MCF is 0.4. A transition from unmanaged shallow classification in 1960 to one-third unmanaged shallow and two-thirds unmanaged deep sites in 1998 is applied to the remainder of sites, giving an increasing MCF from 0.4 to 0.68 over this period. MCFs for the time series are available in Table 3.5.B of Annex 3.5.

Information on the number of flares in use, together with data relating to flare capacity, run time and performance is used to estimate the volume of landfill gas flared at each site. The inventory agency undertakes an annual survey of landfill gas recovery at landfill sites. The first such survey was undertaken in 2008 covering the period 1996 (year in which landfill gas recovery begun in Ireland) to 2007. Annual surveys have been undertaken since then. The tonnage of CH_4 flared and or utilised in engines for electricity production is calculated from the landfill gas volume extracted by accounting for methane concentration, gas temperature (assumed to be ambient air temperature) and suction pressure (provided in survey returns) and by using methane destruction efficiencies of 50 per cent for open flares and 98 per cent for enclosed flares and utilisation engines. Data from utilisation plants is validated against electricity output data provided by EIRGRID (Electricity Transmission System Operator) to SEAI for inclusion in the national energy balance.

The survey of landfill gas recovery in 2022 found that there were 57 flares on 51 SWDS with 13 methane utilisation plants housing a total of 26 engines. The overall results of CH_4 production, utilisation and flaring are presented in Table 7.3.

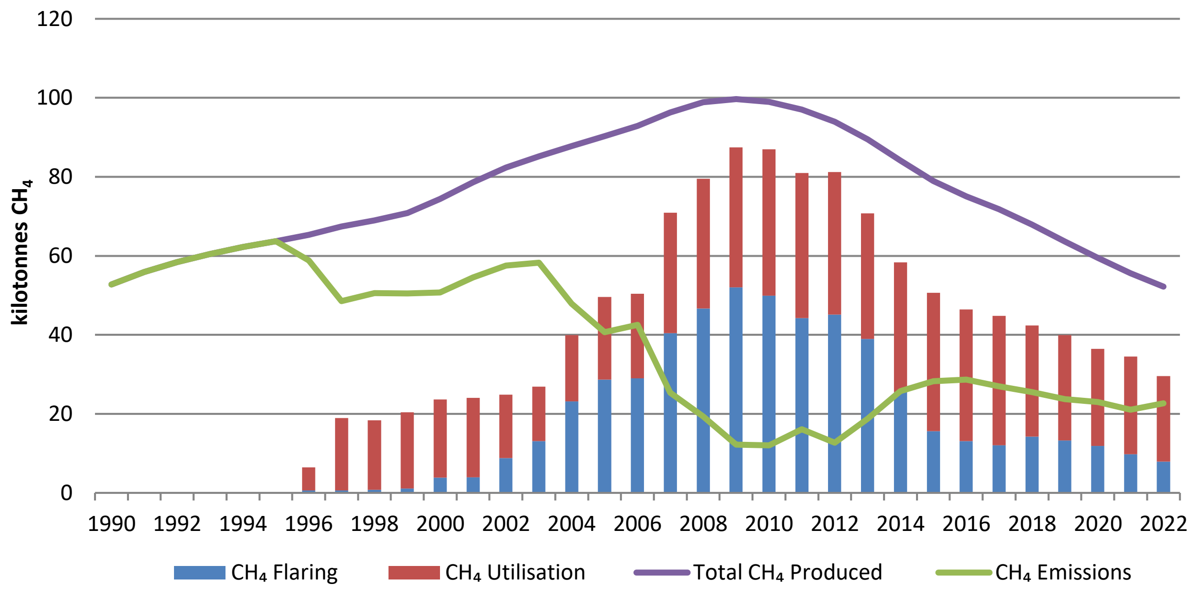


Figure 7.3 Methane Emissions from Solid Waste Disposal 1990-2022

Table 7.3. Methane Emissions from Solid Waste Disposal 1990-2022

	Methane Generation (tonnes)	Methane Flaring (tonnes)	Methane Utilisation (tonnes)	Methane Recovery (tonnes)	Percent Methane Recovery (%)	Methane Emissions (tonnes)	Methane Emissions (kt CO_2eq)
1990	52,723.00	-	-	-	0%	52,723.00	52.72
1995	63,710.36	-	-	-	0%	63,710.36	63.71
2000	74,400.15	3,855.11	19,818.49	23,673.60	32%	50,726.55	50.73
2005	90,296.24	28,638.38	20,947.12	49,585.50	55%	40,710.74	40.71
2010	99,003.27	49,886.65	37,090.88	86,977.53	88%	12,025.73	12.03
2013	89.497.71	38,988.32	31,742.57	70,730.89	79%	18,766.82	18.77
2014	84,128.73	25,538.51	32,814.48	58,352.99	69%	25,775.82	25.78
2015	78,982.88	15,619.44	35,058.52	50,677.96	64%	28,304.93	28.30
2016	75,078.32	13,076.51	33,316.55	46,393.06	62%	28,685.26	28.69
2017	71,791.16	12,043.13	32,747.10	44,790.24	62%	27,000.92	27.00
2018	67,905.76	14,240.19	28,166.73	42,406.92	62%	25,498.84	25.50
2019	63,658.73	13,236.95	26,684.88	39,921.83	63%	23,736.90	23.74
2020	59,462.78	11,861.16	24,609.74	36,470.90	61%	22,991.87	22.99
2021	55,565.27	9,812.35	24,697.27	34,509.62	62%	21,055.65	21.06
2022	52,208.17	7,903.84	21,656.25	29,560.09	57%	22,648.07	22.65

Table 7.3 and Figure 7.3 present the results for methane emissions from *5.A Solid Waste Disposal*. These estimates of CH_4 generation obtained using the model in the IPCC 2006 Guidelines are considered more robust than estimates developed before the 2010 submission. The estimates show a steady increase in CH_4 production over the period 1990-2009, reflecting Ireland's strong dependence on solid waste disposal to landfills over that period. Subsequently individual landfill specific and national BMW targets (EPA, 2009) along with increased recycling rates have led to a reduction in CH_4 generation. The utilisation of CH_4 remained generally constant up to 2006 since becoming established in 1996. The quantity of CH_4 utilised subsequently almost doubled in the period to 2012 with the installation of engines at a number of the newer larger landfills and expansion at other sites. The quantity of CH_4 flared increased sharply from 2003 to 2012 (with interannual variability in later years). This reflects the proliferation of the use of enclosed flares as a means of odour and landfill gas control at landfills throughout the country, all of which operate under EPA waste licence and stringent environmental controls. Reductions in the quantities of landfill gas recovered in recent years are the combined result of reductions in the quantities of CH_4 generated and landfill gas management issues. Methane recovery through flaring and utilisation peaked in 2010.

Table 7.4 Information related to Managed Waste Disposal (5.A.1)

IPCC category	Category Description	Method used	CH_4 Emission Factor	Emission Factor Reference
5.A.1	Managed Waste Disposal	T2	First Order Decay (FOD) model	2006 IPCC Guidelines

7.2.1.3 Uncertainties and Time-series Consistency

The methodologies used in the derivation of emissions estimates from the waste sector are consistent over the time-series. In the case of category 5.A, this consistency applies to all three components that determine the ultimate emissions, i.e. CH_4 generation, CH_4 flared and CH_4 utilised.

Despite continuous improvements in national data, the overall uncertainty associated with estimating CH_4 emissions from source category 5.A is high at 49.0 per cent. This uncertainty is primarily due to the length of the historical period that must be taken into account. Uncertainty estimates for the source category are calculated using equations 3.1 and 3.2, Volume 1 of the IPCC Good Practice Guidance. Uncertainties of 20 per cent are assumed in relation to the quantity of MSW, its composition and DOC contents, giving a combined uncertainty of 34.6 per cent for activity data. The emission factor uncertainty is also 34.6 per cent, when 20 per cent is taken as the uncertainty for the fraction of DOC dissimilated, MCF and decay rate constant. This gives an uncertainty of 49.0 per cent for CH_4 generation which is combined with uncertainties of 30 per cent and 10 per cent for CH_4 flaring and utilisation, respectively to give an uncertainty of 40.1 per cent for emissions. The Tier 1 uncertainty analysis is presented in Annex 2 of this report.

7.2.1.4 Category-specific QA/QC and verification

The inventory agency intends to continue its annual surveys of landfill operators to determine landfill gas flaring and utilisation statistics. All survey returns with respect to landfill gas flaring and utilisation that was undertaken as part of this submission were reviewed by a member of the inventory team and clarifications were sought directly from landfill operators.

7.2.1.5 Category-specific Recalculations

There were significant recalculations for the years 2004 to 2021 due to a revision of activity data. The composition of MSW going to Solid Waste Disposal Sites was revised as increasingly significant amounts of MSW were allocated to inert/bio-stabilised instead of biodegradable wastes. This change revised the inert composition share in recent years from < 30 per cent bio-stabilised to over 60 per cent bio-stabilised and consequently resulted in less methane generation. Emissions decreased significantly from 2016 onwards, from -4.3 per cent to -16.2 per cent in 2021. See table 7.11.

7.2.1.6 Category-specific Planned Improvements

The inventory agency intends to undertake a review of the data collected in respect of landfill gas flaring and utilisation to ensure that there is consistent reporting with annual environmental reports and E-PRTR into the future.

7.2.2 Unmanaged Waste Disposal Sites (5.A.2)

7.2.2.1 Category Description

Solid waste disposal sites that are unmanaged are typically open dump sites or shallow uncontrolled disposal sites with significant aerobic conditions.

7.2.2.2 Methodological Issues

The Tier 2 approach in the 2006 IPCC Guidelines is used for *Unmanaged Waste Disposal Sites* as described in section 7.2.1.2. The 250 sites that operated primarily as small open town dumps and shallow uncontrolled disposal sites with significant aerobic conditions up to the introduction of waste licensing are assigned to the IPCC category of unmanaged shallow sites up to 1998, for which the appropriate MCF is 0.4. A transition from unmanaged shallow classification in 1960 to one-third unmanaged shallow and two-thirds unmanaged deep sites in 1998 is applied to the remainder of sites, giving an increasing MCF from 0.4 to 0.68 over this period.

Table 7.5 Information related to Unmanaged Waste Disposal Sites (5.A.2)

IPCC category	Category Description	Method used	CH_4 Emission Factor	Emission Factor Reference
5.A.2	Unmanaged Waste Disposal	T2	First Order Decay (FOD) model	2006 IPCC Guidelines

7.2.2.3 Uncertainties and Time-series Consistency

The uncertainties applicable to *Unmanaged Waste Disposal Sites* are provided in Annex 2. The emission time series for 1990-2021 is consistent.

7.2.2.4 Category-specific QA/QC and verification

Standard QA/QC procedures have been applied to *Unmanaged Waste Disposal Sites*. Details of Ireland's QA/QC process can be found in Chapter 1 of this report.

7.2.2.5 Category-specific Recalculations

There is no category-specific recalculation this year for *5.A.2*.

7.2.2.6 Category-specific Planned Improvements

There are no planned improvements for this category.

7.3 Emissions from Biological Treatment of Solid Waste (5.B)

Composting (5.B.1) and *Anaerobic digestion* (5.B.2) are sources of emissions in this category. Total CH_4 and N_2O emissions from these activities amounted to 51.1 kt CO_2eq in 2022.

7.3.1 Composting (5.B.1)

7.3.1.1 Category Description

Composting is an aerobic process and a large fraction of the degradable organic carbon (DOC) in the waste material is converted into carbon dioxide (CO_2). CH_4 is formed in anaerobic sections of the compost, but it is oxidised to a large extent in the aerobic sections of the compost. The estimated CH_4 released into the atmosphere ranges from less than 1 percent to a few per cent of the initial carbon content in the material (Beck-Friis, 2001; Detzel et al., 2003; Arnold, 2005).

Composting can also produce emissions of N_2O. The range of the estimated emissions varies from less than 0.5 percent to 5 percent of the initial nitrogen content of the material (Petersen et al., 1998; Hellebrand 1998; Vesterinen, 1996; Beck-Friis, 2001; Detzel et al., 2003). Poorly working composts are likely to produce more of both CH_4 and N_2O (e.g., Vesterinen, 1996).

Data for 2022 is estimated based on per capita emissions in 2021 and population data for 2022, as it is not yet available. In this submission, this category includes household and commercial organic waste collected and treated at composting facilities in Ireland. Activity data is provided in Table 3.5.E of Annex 3.5.

7.3.1.2 Methodological Issues

The Tier 1 approach in the 2006 IPCC guidelines is used for *Composting* using equations 4.1 and 4.2 in the guidelines. Tonnage of composting material (on a dry matter basis) is obtained each year including household and commercial organic wastes brought to civic amenity/temporary collection sites. Wastes imported and treated at facilities in Ireland are also included, and wastes generated in Ireland but treated in another country are excluded. Activity data has been obtained from 2001 onwards, before which emission estimates are reported as Not Occurring (NO).

Equation 4.1;

$$CH_4\ Emissions = \sum(M_i * E_{i,CH4}) * 10^3 - R$$

Where:

CH_4 Emissions = total CH_4 emissions in inventory year, kt CH_4

M_i = mass of organic waste treated by biological treatment type *i*, kt

$E_{i,CH4}$ = EF for treatment (composting) *i*, g CH_4/kg waste treated

R = total amount of CH_4 recovered in inventory year, kt CH_4

Equation 4.2;

$$N_2\,O\ Emissions = \sum(M_i * E_{i,N2O}) * 10^3$$

Where,

$E_{i,N,o}$ = EF for treatment (composting) *i*, g N_2O/kg waste treated.

Emission estimates are made for CH_4 and N_2O in line with the 2006 IPCC guidelines. The EFs used are presented in Table 7.6 below.

Table 7.6 Information related to Biological Treatment of Solid Waste (5.B)

IPCC category	Category Description	Method used	CH_4 Emission Factor	N_2O Emission Factor	Emission Factor Reference
5.B.1	Composting	T1	10 g CH_4/kg	0.6g N_2O/kg	2006 IPCC Guidelines Table 4.1
5.B.2	Anaerobic digestion	T1	2 g CH_4/kg	NA	2006 IPCC Guidelines Table 4.1

7.3.1.3 Uncertainties and Time-series Consistency

The uncertainties applicable to *Composting* are provided in Annex 2. The emission time series for composting 2001–2022 is consistent.

7.3.1.4 Category-specific QA/QC and verification

Standard QA/QC procedures have been applied to *Composting*. Details of Ireland's QA/QC process can be found in Chapter 1 of this report.

7.3.1.5 Category-specific Recalculations

Composting data has been recalculated for the year 2021 only, as new data is available. See table 7.11.

7.3.1.6 Category-specific Planned Improvements

There are no planned improvements for this category.

7.3.2 Anaerobic Digestion at Biogas Facilities (5.B.2)

7.3.2.1 Category Description

Estimates of methane emissions are quantified for Anaerobic digestion at biogas facilities using data provided by the EPA's Waste Statistics team. This activity data only includes wastes treated by anaerobic digestion and does not include agricultural slurries or plant material as these are not classified as wastes. The generated CH_4 used to produce heat and/or electricity is reported in the Energy Sector while emissions of CH_4 from such facilities due to unintentional leakages during process disturbances or other unexpected events are reported here. Data for 2010 to 2021 was provided by the EPA's Waste Statistics team. Activity data is provided in Table 3.5.E of Annex 3.5.

7.3.2.2 Methodological Issues

Emission estimates are made for CH_4 in line with the 2006 IPCC guidelines and the CH_4 EF used is presented in Table 7.6. The Tier 1 approach in the 2006 IPCC guidelines is used for *Anaerobic digestion at biogas facilities* using equation 4.1 in the guidelines. Tonnage of material (on a dry matter basis) is obtained each year. Wastes imported and treated at facilities in Ireland are also included, and wastes generated in Ireland but treated in another country are excluded. Activity data has been obtained for 2010 to 2021 and 2022 data is estimated based on per capita rates in 2021 and population data for 2022. Emissions from 1990 to 2009 are reported as Not Occurring (NO).

Equation 4.1;

$$CH_4\ Emissions = \sum (M_i * E_{i,CH4}) * 10^3 - R$$

Where:

CH_4 Emissions = total CH_4 emissions in inventory year, kt CH_4

M_i = mass of organic waste treated by biological treatment type *i*, kt

$E_{i,CH4}$ = EF for treatment (composting) *i*, g CH_4/kg waste treated

R = total amount of CH_4 recovered in inventory year, kt CH_4

7.3.2.3 Uncertainties and Time-series Consistency

The uncertainties applicable to Anaerobic digestion are provided in Annex 2. The emission time series for Anaerobic digestion 2010–2021 is consistent.

7.3.2.4 Category-specific QA/QC and verification

Standard QA/QC procedures have been applied to Anaerobic Digestion. Details of Ireland's QA/QC process can be found in Chapter 1 of this report.

7.3.2.5 Category-specific Recalculations

Activity data has been recalculated for the year 2021 only, as new data is available. See table 7.11.

7.3.2.6 Category-specific Planned Improvements

There are no planned improvements for this category.

7.4 Emissions from Incineration and Open Burning of Waste (5.C)

The emission categories relevant under *5.C Incineration and Open Burning of Waste* are *5.C.1 Waste Incineration* and *5.C.2 Open Burning of Waste.* Total emissions from these activities amounted to 34.6 kt CO_2 eq in 2022.

7.4.1 Waste Incineration (5.C.1)

7.4.1.1 Category Description

Waste incineration is defined as the combustion of solid and liquid waste in controlled incineration facilities. Modern refuse combustors have tall stacks and specially designed combustion chambers, which provide high combustion temperatures, long residence times, and efficient waste agitation while introducing air for more complete combustion. Types of waste incinerated include municipal solid waste (MSW), industrial waste, hazardous waste, clinical waste and sewage sludge. The practice of MSW incineration is currently more common in developed countries, while it is common for both developed and developing countries to incinerate clinical waste.

Emissions from waste incineration without energy recovery are reported in the Waste Sector, while emissions from incineration with energy recovery are reported in the Energy Sector, both with a distinction between fossil and biogenic carbon dioxide (CO_2) emissions.

The category of *Waste Incineration* in Ireland encompasses emissions from **clinical waste** incineration and **hazardous waste** (solvent waste) incineration from industry. The incineration of clinical waste was discontinued after 1997. Ireland's first waste to energy MSW incinerator commenced operation in 2011 and another commenced in 2017, emissions from these plants are reported under Public Electricity and Heat Production (1.A.1.a) in chapter 3.

7.4.1.2 Methodological Issues

The Tier 1 approach in the 2006 IPCC Guidelines is used for *Waste Incineration*.

In the early 1990s, the majority of hospitals operated on-site incinerator units where hazardous **clinical waste** was incinerated. A number of hospitals operated the practice of incinerating both hazardous and non-hazardous waste. Due to the implementation of stricter standards on incineration and the requirement for facilities to be licensed by the EPA, all incinerators were closed by the mid- to late-1990s. National waste database reports and Government records contain some information on the quantity of health-care waste incinerated during the period of operation of the incinerators. From these sources, it was determined that an estimated 4,000 tonnes of health-care waste were incinerated per annum. This value was used across the time series for the period 1990-1997, after which negligible quantities of health-care waste were incinerated up until the closure of the two remaining incinerators in 2000. Since 1997, the bulk of clinical waste in Ireland is treated using non-incineration technologies (namely sterilisation and shredding), with the remaining waste disposed of through landfilling, exported for incineration or used as a fuel in cement kilns.

Emissions from clinical waste incineration (biogenic and non-biogenic) are estimated using the tier 1 method and equation 5.1 from the 2006 IPCC guidelines.

Equation 5.1;

$$CO_2 Emissions = \sum_i (SW_i * dm_i * CF_i * FCF_i * OF_i) * 44/12$$

Where:

CO_2 Emissions = CO_2 emissions in inventory year, kt/yr

SW_i = total amount of solid waste of type *i* (wet weight) incinerated or open-burned, kt/yr

dm_i = dry matter content in the waste (wet weight) incinerated or open-burned, (fraction)

CF_i = fraction of carbon in the dry matter (total carbon content), (fraction)

FCF_i = fraction of fossil carbon in the total carbon, (fraction)

OF_i = oxidation factor, (fraction)

44/12 = conversion factor from C to CO_2

i = type of waste incinerated/open-burned specified as follows:

ISW: industrial solid waste, SS: sewage sludge, HW: hazardous waste, CW: clinical waste, others (that must be specified).

Parameters values are taken from the 2006 IPCC guidelines and are presented in Table 7.7 below. Methane (CH_4) and nitrous oxide (N_2O) emission factors are taken from Tables 5.3, 5.4 and 5.6 of the 2006 IPCC guidelines. Additional information on emissions, EFs and parameters used is available in Table 3.5.C of Annex 3.5.

Table 7.7 Information related to Waste Incineration (5.C.1)

IPCC category	Category Description	Method used	Gas	Emission Factors	Emission Factor Reference
5.C.1	Clinical Waste	T1	CH_4	60 kg/kt waste (wet)	2006 IPCC Guidelines Table 5.3
				100% oxidation factor	2006 IPCC Guidelines Table 5.2
			N_2O	20 g/t waste (wet)	2006 IPCC Guidelines Table 5.4
				100% oxidation factor	2006 IPCC Guidelines Table 5.2
			CO_2	40% fossil carbon (as % of total carbon)	2006 IPCC Guidelines Table 5.2
				60% C content of waste (dry)	2006 IPCC Guidelines Table 5.2
5.C.1	Solvent (liquid/ vapour) waste	T1	CH_4	0.56 g/t (wet)	2006 IPCC Guidelines section 5.4.2
				100% oxidation factor	2006 IPCC Guidelines Table 5.2
			N_2O	100 g/t waste (wet)	2006 IPCC Guidelines Table 5.46
				100% oxidation factor	2006 IPCC Guidelines Table 5.2
			CO_2	100% fossil carbon (as % of total carbon)	2006 IPCC Guidelines Table 5.2
				80% C content of waste	2006 IPCC Guidelines Table 5.2

There are currently only a small number of facilities based in the pharmaceutical and chemical sectors that operate incinerators or thermal oxidisers for the treatment of **hazardous waste**, mainly for solvent or liquid/vapour destruction. The facilities that operate these units report emissions to the atmosphere to the EPA as part of IPPC licensing requirements. Estimates of the quantity of hazardous waste incinerated at the relevant facilities are determined from returns to the National Waste Database (Carey et al, 1996; Crowe et al, 2000; Meaney et al, 2003; Collins et al, 2004a; Collins et al, 2004b; Collins et al, 2005; Le Bolloch et al, 2006; Le Bolloch et al, 2007; Le Bolloch et al, 2008; McCoole et al, 2009; McCoole et al, 2010; McCoole et al, 2011; McCoole et al, 2012 ;McCoole et al, 2013 and McCoole et al, pers comm).

Emissions from solvent waste incineration are estimated using the tier 1 method and equation 5.3 from the 2006 IPCC guidelines. Additional information on emissions, EFs and parameters used is available in Table 3.5.D of Annex 3.5.

Equation 5.3;

$$CO_2 Emissions = \sum_i (AL_i * CL_i * OF_i) * 44/12$$

Where:

CO_2 Emissions = CO_2 emissions in inventory year, kt/yr

AL_i = amount of incinerated fossil liquid waste type *i*, kt

CL_i = carbon content of fossil liquid waste type *i*, (fraction)

OF_i = oxidation factor for fossil liquid waste type *i*, (fraction)

44/12 = conversion factor from C to CO_2

7.4.1.3 Uncertainties and Time-series Consistency

The uncertainties applicable to *Waste Incineration* are provided in Annex 2.

7.4.1.4 Category-specific QA/QC and verification

Standard QA/QC procedures have been applied to *Waste Incineration*. Details of Ireland's QA/QC process can be found in Chapter 1 of this report.

7.4.1.5 Category-specific Recalculations

There was a minor recalculation for the year 2021 for *Waste Incineration* (5.C.1) due to updated activity data. See table 7.11.

7.4.1.6 Category-specific Planned Improvements

There are no planned improvements for this category.

7.4.2 Open Burning of Waste (5.C.2)

7.4.2.1 Category Description

Open Burning of Waste in Ireland consists of open burning of household waste and farm plastics.

7.4.2.2 Methodological Issues

A combination of Tier 1 and Tier 2 approaches in the 2006 IPCC guidelines is used for *Open Burning of Waste*. Statistics on open burning of household waste are not available in Ireland and estimates are made based on data for uncollected household waste. Data on uncollected household waste are sourced from the EPA national waste statistics publications[12]. Activity data is given in Annex 3.5.F Open Burning MSW 5.C. Statistics on farm film placed on the market and farm film waste collected for recycling is obtained from the Irish Farm Film Producers Group. The emission factors used to estimate emissions from open burning of waste are presented in Table 7.8.

Table 7.8 Information related to Open Burning of Waste (5.C.2)

Method used	Gas	Material	Emission Factors	Emission Factor Reference
T1, T2	CH_4		6.5 kg/t waste (wet)	2006 IPCC Guidelines section 5.4.2
			58% oxidation factor	2006 IPCC Guidelines Table 5.2
	N_2O		150 g/t waste (dry)	2006 IPCC Guidelines Table 5.6
			58% oxidation factor	2006 IPCC Guidelines Table 5.2
	CO_2	Plastics	100% fossil carbon (as % of total carbon)	2006 IPCC Guidelines Table 2.4
			75% C content of Waste	2006 IPCC Guidelines Table 2.4
		Textiles	20% fossil carbon (as % of total carbon)	2006 IPCC Guidelines Table 2.4
			50% C Content of Waste	2006 IPCC Guidelines Table 2.4

7.4.2.3 Uncertainties and Time-series Consistency

The uncertainties applicable to *Open Burning of Waste* are provided in Annex 2.

7.4.2.4 Category-specific QA/QC and verification

Standard QA/QC procedures have been applied to *Open Burning of Waste*. Details of Ireland's QA/QC process can be found in Chapter 1 of this report.

[12] https://www.epa.ie/our-services/monitoring--assessment/waste/national-waste-statistics/

7.4.2.5 Category-specific Recalculations

There was a minor recalculation for the year 2020 for *Open Burning of Waste* (5.C.2) due to updated activity data. See table 7.11.

7.4.2.6 Category-specific Planned Improvements

There are no planned improvements for this category.

7.5 Emissions from Wastewater Treatment and Discharge (5.D)

The IPCC Level 3 emission source categories relevant under *5.D Wastewater Treatment and Discharge* in 2021 are *5.D.1 Domestic Wastewater* (CH_4) and (N_2O). Total CH_4 and N_2O emissions from these activities amounted to 156.2 kt CO_2eq in 2022.

7.5.1 Domestic Wastewater (5.D.1)

7.5.1.1 Category Description

Wastewater can be a source of methane (CH_4) when treated or disposed anaerobically. It can also be a source of nitrous oxide (N_2O) emissions. Carbon dioxide (CO_2) emissions from wastewater are not considered in the 2006 IPCC guidelines because these are of biogenic origin and should not be included in national total emissions. Domestic wastewater is defined as wastewater from household water use. Domestic wastewater is either treated in centralized treatment plants or in septic tanks. Centralised wastewater treatment plants also treat commercial and industrial wastewater and for that reason emissions from *Industrial Wastewater (5.D.2)* are included in *Domestic Wastewater (5.D.1).* Information on Ireland's wastewater flows is provided in Annex 3.5.G.

7.5.1.2 Methodological Issues

A combination of Tier 1 and Tier 2 approaches in the 2006 IPCC guidelines is used for *Domestic* and *Industrial Wastewater*.

Based on the available data on wastewater treatment in Ireland the inventory agency considers that all wastewaters are accounted for in its approach. Approximately two-thirds of the population in Ireland is served by centralized sewerage treatment plants, the remaining one-third of the population uses septic tanks to treat wastewater mainly for individual houses in non-urban areas (Smith et al., 2004). There are an estimated 489,069 (CSO 2016) domestic wastewater treatment systems treating wastewater from single houses in Ireland that are not connected to a public sewer system which utilise conventional septic tanks. These households' systems are in rural areas and therefore not connected to urban centralised wastewater treatment systems which cater for urban domestic, commercial and industrial wastewaters.

National statistics on household occupancy suggest a value of approximately 3 persons per household (CSO, 2016), therefore these domestic septic tanks service approximately 1.5 million people or one third of Ireland's population.

Sludge is produced in all of the primary, secondary and tertiary stages of wastewater treatment. The anaerobic stabilisation of sludge makes it safe for disposal and is a source of CH_4 in Ireland. The amount of wastewater sludge produced in Ireland is available from biennial reports on urban wastewater treatment.

The sludge arising from the secondary treatment of over half of the population equivalent served by urban wastewater treatment plants is anaerobically digested. It is reported that approximately three per cent of this sludge is treated anaerobically (O' Leary et al. 1997, 2000; O'Leary and Carty, 1998; Smith et al. 2003; 2004, 2007; Monaghan et al. 2009). The CH_4 produced at these plants is used for electricity and heat generation since 2003. There are 16 urban wastewater treatment plants with biogas recovery for heat only or CHP, and of these 16 plants 10 were operational for part or all of 2021.

The average biochemical oxygen demand (BOD) of industrial wastewater sludge is 60 kg/t (40 per cent of the typical BOD content of treated industrial wastewater) and DOC is estimated as the product of average BOD content and tonnes of dry solids of sludge.

Information on the population equivalent of wastewater untreated would potentially result in emissions below the threshold of significance in 2018, 2019, 2020 and 2021 77,000 pe, 78,000, 77,406 and 61,263 pe which are collected in closed sewers and discharged mostly to coastal waters. In the IPCC 2006 Guidelines, wastewater discharged to the ocean is not a source of CH_4, except maybe in estuaries or "peaceful" coastal areas with high organic load. Estimated emissions of N_2O from untreated wastewater for 2018, 2019, 2020 and 2021 (77,000, 78,000, 77,406 and 61,263 p.e.) would be 1.47, 1.49, 1.48 and 1.17 kt CO_2 equivalent, significantly below the threshold of significance for 2018-2021.

The sludge from wastewater treatment is disposed of in landfills, used as organic fertiliser on agricultural lands or in composting. The quantity of sludge that is disposed of in landfills contributes to CH_4 emissions from SWDS and is accounted for in *5.A Solid Waste Disposal*. The sludge applied to agricultural land contributes to N_2O emissions from soils and is included in emission estimates for *3.D.1 Direct Emissions to Soil*. The total emissions of CH_4 from wastewater are estimated using equation 6.1 from the 2006 IPCC guidelines.

Equation 6.1;

$$CH_4\ Emissions = [\sum (U_i * T_{i,j} * EF_j)]\ (TOW - S) - R$$

Where:

CH_4 Emissions = CH_4 emissions in inventory year, kg CH_4/yr
TOW = total organics in wastewater in inventory year, kg BOD/yr
S = organic component removed as sludge in inventory year, kg BOD/yr
U_i = fraction of population in income group *i* in inventory year
$T_{i,j}$ = degree of utilisation of treatment/discharge pathway or system, *j*, for each income group fraction *i* in inventory year
$_i$ = income group: rural, urban high income and urban low income
$_j$ = each treatment/discharge pathway or system
EF_j = emission factor, kg CH_4 / kg BOD
R = amount of CH_4 recovered in inventory year, kg CH_4/yr
The total organics in wastewater (TOW) in Ireland is estimated based on population equivalent data from urban waste discharge reports (equation 6.3 from the 2006 IPCC guidelines) and is disaggregated by the degree of utilisation of treatment/discharge pathway or system ($T_{i,j}$) as follows;

1. Organically degradable material in wastewater at treatment plant with biogas facility (kg BOD y^{-1})
2. Organically degradable material in wastewater at treatment plant without biogas facility (kg BOD y^{-1})
3. Organically degradable material in wastewater in septic tanks (kg BOD y^{-1})

Equation 6.3;

$$TOW = P * BOD * 0.001 * I * 365$$

Where:

TOW = total organics in wastewater in inventory year (for 365 days), kg BOD/yr

P = country population in inventory year, (person)

BOD = country-specific per capita BOD in inventory year, g/person/day, 60 g (Europe)

I = correction factor for additional industrial BOD discharged into sewers (for collected the default is 1.25, for uncollected the default is 1.00.); and a conversion factor of 0.001 to convert kg BOD from grams BOD was applied in the equation.

On-site domestic septic tanks consist of an underground tank (over 1 metre deep) and a percolation area for the treatment of the resultant effluent. Prevailing soil temperatures at the depths where methanogenesis is assumed to occur (i.e. the bottom of the septic tank) only exceed 15°C for two months of the year in Ireland according to long term trends in soil temperatures available from Ireland's national meteorological service https://www.met.ie/climate/available-data/monthly-data. Thus, the low prevailing temperatures in septic tanks means that the CH_4 correction factor (MCF) based on the 2006 IPCC guidelines default value, has been revised down from 0.5 to 0.083. The CH_4 emission factor for septic tanks is estimated based on equation 6.2 from the 2006 IPCC guidelines and an EF of 0.05 kg CH_4/kg BOD.

Equation 6.2;

$$EF_j = B_o * MCF_j$$

Where:

EF_j = emission factor for treatment/discharge pathway or system j, kg CH_4/kg BOD (Table 7.9)

B_o = maximum CH_4 producing capacity, kg CH_4/kg BOD (0.6 kg CH_4/kg BOD)

MCF_j = methane correction factor (fraction), (0.5*2/12 = 0.083)

The CH_4 emission factor for urban wastewater treatment plants without biogas recovery is also estimated using equation 6.2 from the 2006 IPCC guidelines and an EF of 0.018 kg CH_4/kg BOD; based on a MCF of 0.03 (assumed some anaerobic) and a B_o 0.6 kg CH_4/kg BOD.

Table 7.9 Information related to Domestic Wastewater (5.D.1)

IPCC category	Category Description	Method used	Gas	Emission Factor	Emission Factor Reference
5.D.1	Septic tank	T1, T2	CH_4	0.05 kg CH_4/kg BOD	2006 IPCC Guidelines Table 6.2, Modified for Ireland's cold climate
5.D.1	Urban wastewater treatment plant (without biogas facility)	T1, T2	CH_4	0.018 kg CH_4/kg BOD	2006 IPCC Guidelines Table 6.2, Monaghan et al. 2009
5.D.1	Sewage	T1	N_2O	3.2 g N_2O/person	2006 IPCC Guidelines Table 6.11

Wastewater treatment plants with heat or CHP account for on average over 45 percent of the BOD loading in Ireland since 2003. Emissions resulting from the biogas use/recovery are reported in the Energy sector under CRF category 1.A.4.a Commercial/Institutional.

Human consumption of food results in the production of sewage, which is processed in septic tanks or in wastewater treatment facilities. This treated waste is disposed of directly onto land, into the soil through percolation areas or discharged to a water body. N_2O can be produced during these processes through nitrification and denitrification. N_2O emissions are estimated using equation 6.7 and 6.8 of the 2006 IPCC guidelines. Parameter values and emission estimates of N_2O are provided in Table 7.10.

Equation 6.7;

$$N_2O\ Emissions = N_{EFFLUENT} * EF_{EFFLUENT} * 44/28$$

Where:

N_2O emissions = N_2O emissions in inventory year, kg N_2O/yr

$N_{EFFLUENT}$ = nitrogen in the effluent discharged to aquatic environments, kg N/yr

$EF_{EFFLUENT}$ = emission factor (0.005 kg N_2O-N/kg N) for discharge to wastewater (Table 6.11),

The factor 44/28 is the conversion of kg N_2O-N into kg N_2O.

$N_{EFFLUENT}$ is estimated from equation 6.8.

Equation 6.8;

$$NE_{FFLUENT} = P \cdot Protein \cdot F_{NPR} \cdot F_{NON-CON} \cdot F_{IND-COM} - N_{SLUDGE}$$

Where:

$N_{EFFLUENT}$ = total annual amount of nitrogen in the wastewater effluent, kg N/yr

P = human population

Protein = annual per capita protein consumption, kg/person/yr

F_{NPR} = fraction of nitrogen in protein, default = 0.16, kg N/kg protein

$F_{NON-CON}$ = factor for non-consumed protein added to the wastewater, 1.1 (Table 6.11)

$F_{IND-COM}$ = factor for industrial and commercial co-discharged protein into the sewer system, 1.25 (Table 6.11)

N_{SLUDGE} = nitrogen removed with sludge (default = zero), kg N/yr

Table 7.10 Estimates of N_2O emissions from human sewage 1990-2022

Year	Pop (million)	Days	Per capita protein consumption (g/day)	N fraction in protein (IPCC default)	Effluent EF kg N_2O-N/kg-N (IPCC default)	Non-consumed protein (IPCC default)	Industrial co-discharge (IPCC default)	N_2O * (kt)
	A	B	C	D	E	F	G	
1990	3.506	365	114.0	0.16	0.005	1.1	1.25	0.252
1995	3.601	365	108.0	0.16	0.005	1.1	1.25	0.245
2000	3.790	365	116.0	0.16	0.005	1.1	1.25	0.277
2005	4.134	365	114.3	0.16	0.005	1.1	1.25	0.298
2010	4.555	365	110.0	0.16	0.005	1.1	1.25	0.316
2013	4.593	365	107.0	0.16	0.005	1.1	1.25	0.310
2014	4.610	365	110.0	0.16	0.005	1.1	1.25	0.320
2015	4.635	365	110.3	0.16	0.005	1.1	1.25	0.323
2016	4.762	365	113.3	0.16	0.005	1.1	1.25	0.340
2017	4.785	365	114.4	0.16	0.005	1.1	1.25	0.345
2018	4.857	365	114.4	0.16	0.005	1.1	1.25	0.351
2019	4.922	365	114.4	0.16	0.005	1.1	1.25	0.355
2020	4.977	365	114.4	0.16	0.005	1.1	1.25	0.359
2021	5.012	365	114.4	0.16	0.005	1.1	1.25	0.362
2022	5.100	365	114.4	0.16	0.005	1.1	1.25	0.368

*emissions calculated as A * B * C * D * E * F * G * 44 / 28000

7.5.1.3 Uncertainties and Time-series Consistency

Uncertainties in estimates of emissions from the source category 5.D arise due to the quality of source data, wastewater production estimates, its chemical parameters in terms of COD or BOD, the methane producing capacity and its treatment. Uncertainty estimates of 10 per cent and 30 per cent are assigned to the activity data and emission factor used, respectively.

The uncertainties applicable to *Domestic Wastewater* are provided in Annex 2.

7.5.1.4 Category-specific QA/QC and verification

Standard QA/QC procedures have been applied to *Domestic Wastewater*. Details of Ireland's QA/QC process can be found in Chapter 1 of this report.

7.5.1.5 Category-specific Recalculations

There were slight recalculations for this category for years 2001-2009 and 2018 due to updated activity data (population statistics) and per capita protein consumption sourced from FAOSTAT. See table 7.11.

7.5.1.6 Category-specific Planned Improvements

There are no planned improvements for this category.

7.5.2 Industrial Wastewater (5.D.2)

Emissions from *Industrial Wastewater (5.D.2)* are included in *Domestic Wastewater (5.D.1).* This category is reported as Included Elsewhere (IE). On site wastewater treatment at industrial facilities where they exist are aerobic systems, therefore no CH_4 emissions occur from these sites.

7.6 Emissions from Other Waste Sources (5.E)

No activities have been identified in Ireland for inclusion under this category. This category is reported as Not Occurring (NO).

Table 7.11(a) Previous and current emission estimates in the Waste Sector (1990-2021)

	2023 Submission	Units	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021
5.A.1	Managed Waste Disposal Sites	kt CO_2e	NO	NO	1,420.3	1,127.8	312.1	516.3	725.9	814.2	839.5	804.1	775.8	742.4	738.7	703.2
5.A.2	Unmanaged Waste Disposal Sites	kt CO_2e	1,476.2	1,783.9	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
5.B.1	Treatment of solid waste- composting	kt CO_2e	NO	NO	NO	47.6	50.0	45.5	42.0	40.6	40.1	44.7	42.9	45.5	43.4	44.7
5.B.2	Anaerobic digestion at biogas facilities	kt CO_2e	NO	NO	NO	NO	0.1	0.3	0.4	1.0	0.9	2.1	2.9	3.9	4.7	4.8
5.C.1	Waste Incineration-Biogenic	kt CO_2e	0.0	0.0	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5.C.1	Waste Incineration-Fossil	kt CO_2e	83.7	83.7	59.2	107.2	54.0	42.8	38.8	39.3	22.2	24.4	20.3	27.6	28.3	31.9
5.C.2	Open Burning of Waste-Biogenic	kt CO_2e	0.6	0.8	1.2	1.8	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.C.2	Open Burning of Waste-Fossil	kt CO_2e	13.4	16.1	19.2	23.6	8.0	2.3	2.8	3.0	2.8	3.0	3.6	4.9	2.9	2.8
5.D.1	Domestic Wastewater	kt CO_2e	68.4	70.2	69.9	55.3	56.3	56.6	58.6	58.4	56.5	57.1	56.7	57.3	59.5	60.1
5.D.1	Domestic Wastewater	kt CO_2e	66.8	65.0	73.5	79.0	83.8	82.2	84.8	85.5	90.2	91.5	92.9	94.1	95.2	95.9
5.D.2	Industrial Wastewater	kt CO_2e	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
	Total Waste	**kt CO_2e**	**1,709.2**	**2,019.8**	**1,643.4**	**1,442.3**	**564.2**	**745.9**	**953.4**	**1,042.1**	**1,052.2**	**1,027.0**	**995.1**	**975.7**	**972.8**	**943.4**
	2024 Submission	**Units**														
5.A.1	Managed Waste Disposal Sites	kt CO_2e	NO	NO	1,420.3	1,139.9	336.7	525.5	721.7	792.5	803.2	756.0	714.0	664.6	643.8	589.6
5.A.2	Unmanaged Waste Disposal Sites	kt CO_2e	1,476.2	1,783.9	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
5.B.1	Treatment of solid waste- composting	kt CO_2e	NO	NO	NO	47.6	50.0	45.5	42.0	40.6	40.1	44.7	42.9	45.5	43.4	37.9
5.B.2	Anaerobic digestion at biogas facilities	kt CO_2e	NO	NO	NO	NO	0.1	0.3	0.4	1.0	0.9	2.1	2.9	3.9	4.7	5.3
5.C.1	Waste Incineration-Biogenic	kt CO_2e	0.02	0.02	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5.C.1	Waste Incineration-Fossil	kt CO_2e	83.7	83.7	59.2	107.2	54.0	42.8	38.8	39.3	22.2	24.4	20.3	27.6	28.3	31.9
5.C.2	Open Burning of Waste-Biogenic	kt CO_2e	0.6	0.8	1.2	1.8	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.C.2	Open Burning of Waste-Fossil	kt CO_2e	13.4	16.1	19.2	23.6	8.0	2.3	2.8	3.0	2.8	3.0	3.6	4.9	2.9	2.7
5.D.1	Domestic Wastewater	kt CO_2e	68.4	70.2	69.9	55.3	56.3	56.6	58.6	58.4	56.5	57.1	56.7	57.3	59.5	60.1
5.D.1	Domestic Wastewater	kt CO_2e	66.8	65.0	73.5	79.0	83.8	82.2	84.8	85.5	90.2	91.5	92.9	94.1	95.2	95.9
5.D.2	Industrial Wastewater	kt CO_2e	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
	Total Waste	**kt CO_2e**	**1,709.2**	**2,019.8**	**1,643.4**	**1,454.4**	**588.9**	**755.1**	**949.2**	**1,020.4**	**1,015.9**	**979.0**	**933.3**	**897.9**	**877.8**	**823.4**

Table 7.11(b) Absolute and relative recalculations in the Waste Sector (1990-2021)

	Absolute change	Units	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021
5.A.1	Managed Waste Disposal Sites	kt CO_2e	-	-	-	12.06	24.64	9.18	-4.15	-21.62	-36.32	-48.03	-61.87	-77.72	-94.96	-113.63
5.A.2	Unmanaged Waste Disposal Sites	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5.B.1	Treatment of solid waste- composting	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	-6.78
5.B.2	Anaerobic digestion at biogas facilities	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	0.59
5.C.1	Waste Incineration-Biogenic	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5.C.1	Waste Incineration-Fossil	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5.C.2	Open Burning of Waste-Biogenic	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	-0.01
5.C.2	Open Burning of Waste-Fossil	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	-0.10
5.D.1	Domestic Wastewater	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5.D.1	Domestic Wastewater	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5.D.2	Industrial Wastewater	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total Waste	**kt CO_2e**	**0.00**	**-**	**-0.00**	**12.06**	**24.64**	**9.18**	**-4.15**	**-21.62**	**-36.32**	**-48.03**	**-61.87**	**-77.72**	**-94.96**	**-119.93**
	Relative change	**Units**														
5.A.1	Managed Waste Disposal Sites	kt CO_2e	-	-	-	1.1%	7.9%	1.8%	-0.6%	-2.7%	-4.3%	-6.0%	-8.0%	-10.5%	-12.9%	-16.2%
5.A.2	Unmanaged Waste Disposal Sites	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5.B.1	Treatment of solid waste- composting	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	-15.2%
5.B.2	Anaerobic digestion at biogas facilities	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	12.4%
5.C.1	Waste Incineration-Biogenic	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5.C.1	Waste Incineration-Fossil	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5.C.2	Open Burning of Waste-Biogenic	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	-40.8%
5.C.2	Open Burning of Waste-Fossil	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	-3.6%
5.D.1	Domestic Wastewater	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5.D.1	Domestic Wastewater	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5.D.2	Industrial Wastewater	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total Waste	**kt CO_2e**	**0.0%**	**-**	**-0.0%**	**0.8%**	**4.4%**	**1.2%**	**-0.4%**	**-2.1%**	**-3.5%**	**-4.7%**	**-6.2%**	**-8.0%**	**-9.8%**	**-12.7%**

Chapter 8 Other Sources

The sector *Other* in the IPCC source sector classification (Table A.2, Annex A) that is the basis for the CRF reporting tables provides for the inclusion of greenhouse gas emission sources that may be particular to individual Parties. There are no such sources to report in Ireland.

Chapter 9 Indirect CO_2 and N_2O Emissions

9.1 Description of Sources of Indirect Emissions in GHG Inventory

Parties may report indirect emissions of CO_2 from the atmospheric oxidation of CH_4, CO and NMVOCs, and indirect emissions of N_2O from sources other than agriculture and LULUCF under this cross-sectoral category. The use of solvents manufactured using fossil fuels as feedstocks can lead to evaporative emissions of various non-methane volatile organic compounds (NMVOC), which are subsequently further oxidised in the atmosphere.

The IPCC source sector 2.D.3, *Solvent and Other Produce Use*, is important in relation to the emissions of NMVOC. NMVOC are indirect greenhouse gases which result from the use of solvents and various other volatile compounds and are therefore reported as CO_2 equivalent emissions included in national totals. Ireland reports the indirect CO_2 emissions from NMVOC in the IPPU sector 2.D.3, 2.G.4 and 2.H.2 and not in CRF Table 6.

The levels of solvent use and the emissions from solvents have changed substantially in response to product replacement and reformulation and emission controls being implemented under Integrated Pollution Prevention Control (IPPC), the Solvents Directive (CEC, 1999) and the Industrial Emissions Directive (CEP, 2010).

Indirect CO_2 emissions from NMVOC accounted for 0.13 per cent (74.5 kt of CO_2 equivalent) and 0.17 per cent (105.8 kt of CO_2 equivalent) of total national emissions in 1990 and 2022, respectively. See Figure 9.1 below. The national total for Ireland includes indirect CO_2 emissions from 2.D.3, 2.G.4 and 2.H.2 categories and is fully consistent with the national total emissions reported previously under the Kyoto Protocol.

There are no key categories in these sectors. Categories present in 2.D.3 include:

- *2.D.3.a Domestic solvent use including fungicides,*
- *2.D.3.b Road Paving with Asphalt,*
- *2.D.3.d Coating Applications,*
- *2.D.3.e Degreasing and surface cleaning,*
- *2.D.3.f Dry Cleaning,*
- *2.D.3.g Chemical Products, Manufacture and Processing,*
- *2.D.3.h Printing*,
- *2.D3.i Other solvent use* including glass wool enduction, fat, edible and non-edible oil extraction, application of glues and adhesives, preservation of wood, underseal treatment and conservation of vehicles and vehicles dewaxing

Also included are emissions from sector 2.G and 2.H including;

- *2.G.4 Other product use*; Use of tobacco
- *2.H.2 Food and beverages industry,* including bread, beer, spirits, meat, fish etc. frying/curing, coffee roasting and feedstock.

The emission estimates have negligible effect on national total emissions.

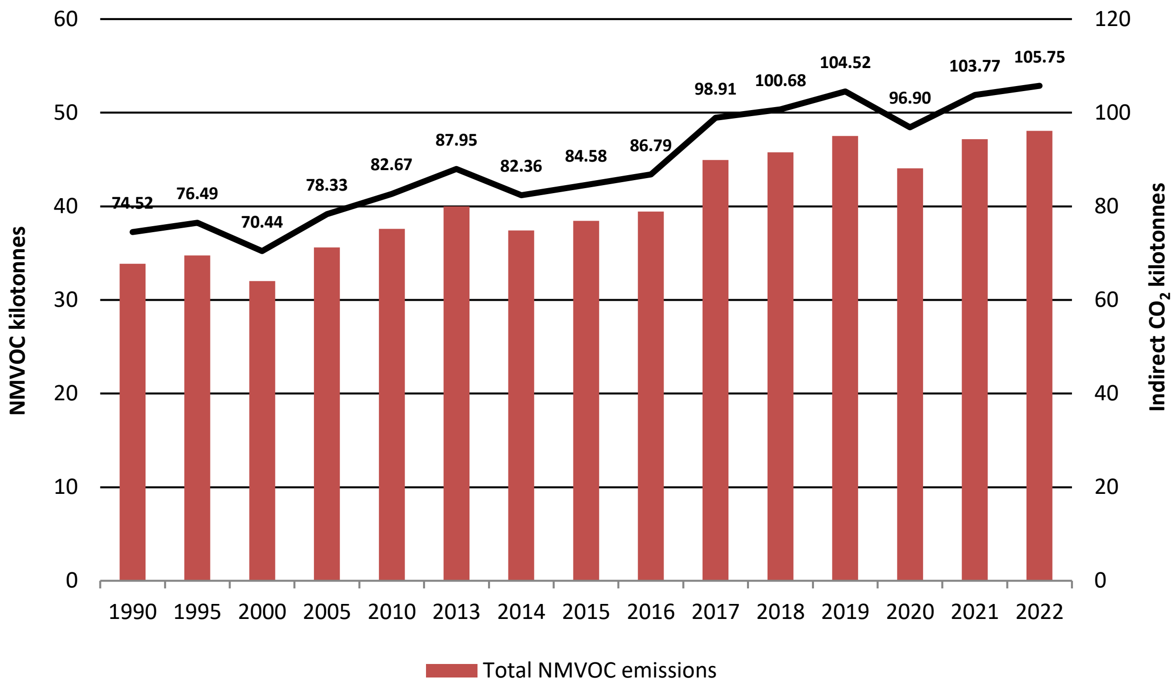


Figure 9.1 Total Indirect CO_2 emissions 1990-2022

9.2 Methodological Issues

Methodologies for estimating these NMVOC emissions can be found in the EEA/EMEP Emission Inventory Guidebook (EEA, 2023). The UNFCCC reporting format explicitly provides for the inclusion of CO_2 emissions that result from the oxidation of the carbon in NMVOC emissions. This approach is consistent with the overall sectoral approach adopted for estimating CO_2 from the combustion of fuels (Section 3.2), where the CO_2 emissions are based on the full carbon content of the fuel even though some of the carbon is usually emitted as NMVOC or CO. CO_2 emission estimates are derived from NMVOCs by assuming that 60 per cent of the mass of NMVOCs is converted to CO_2.

The activity data used for computing estimates of CO_2 emissions in *Solvent and Other Product Use* are the mass emissions of NMVOC determined for the relevant source categories. The Irish data used for this purpose are the NMVOC emissions compiled according to the EEA/EMEP Guidebook 2023 used for reporting to the UNECE under the Convention on Long Range Transboundary Air Pollution (CLRTAP) (UNECE, 1999) and the National Emission reduction Commitments Directive (EP and CEU, 2016).

Emissions from domestic solvent use (2.D.3.a), food and beverage industry (2.H.2) and Other solvent use (2.D.3.i) have steadily increased across the time series, while those from the majority of other sub-categories have decreased. The main drivers for the increasing emissions from domestic solvent use are considered to be the increased per capita consumption of cosmetics, toiletries and household products. The increase in food and beverage industry is due to an increased spirit production in Ireland. The drivers for the decrease in other sub-categories include improved management practices and abatement technologies, legislation such as the Deco Paints Directive (EP and CEU, 2004b; DEHLG, 2007) and the Solvents Directive (CEC 1999). A detailed description of the methodology behind the

NMVOC emissions from this sector can be found in Ireland's Informative Inventory Report 2024 (Hyde et al, 2024).

9.3 Uncertainties and Time-series Consistency

The uncertainties applicable to this category can be found in Annex 2.

The uncertainty of the activity data is 30 per cent.

The uncertainty of the emission factor is 5 per cent.

There are a large number of NMVOC sources within this sector, and hence a wide range of methodologies and input datasets. For many of the methodologies, it is not possible to obtain a full time series of the input data. As a result, extrapolation, interpolation and surrogate data is used to complete the time series of emissions.

All calculations requiring extrapolation, interpolation and the use of surrogate data are clearly presented in the data processing sheets and are accompanied by comments and explanatory text from the inventory compilers to ensure transparency. In particular the use of colour coding to indicate where extrapolation and interpolation is used allows a high degree of transparency.

Some methodologies draw on point source data. This is always checked for consistency with historic data and for consistency across the different point sources within the same source sector.

9.4 Category-specific QA/QC and Verification

Quality control checks have been installed to ensure that the emission estimates calculated in the data processing sheets are the same as those in the inventory dataset that is used for reporting purposes.

9.5 Category-specific Recalculations

Recalculations occurred in 2D3d Coating applications NMVOC emissions for 1990-2021 due to the correction of transcription errors in the activity data file. A decrease occurred of 3.1 per cent on average across the time series. Emissions in 2D3e degreasing for 1990-2021 decreased 14.8 per cent across the time series due to the correction of calculation methodology in this submission.

Recalculations also occurred in subcategories 2D3g Chemical products manufacturing or processing and 2D3h Printing causing a decrease of 16.6 percent and 10.7 per cent on average across the time series due to the correction of transcription errors in the activity data file. Further QAQC checks have been included in solvents files to avoid further transcription errors in emissions calculations. These recalculations are outlined in Table 4.52 in Ireland's Informative Inventory Report 2024 (Hyde et al, 2024).

9.6 Category-specific Planned Improvements

There are no planned improvements for this category.

Chapter 10 Recalculations and Improvements

10.1 Introduction

On-going demands for more complete and more accurate estimates of greenhouse gas emissions means that the methodologies being used are subject to regular revision and refinement as inventory capacity is increased and better data become available. The general improvement in inventories over time may therefore introduce inconsistencies between the emissions estimates for recent years and those for years much earlier in the time-series. Recalculated estimates are often needed to eliminate these inconsistencies and to ensure that the inventories for all years in a time-series are directly comparable with respect to the sources and gases covered and that the methods, activity data and emission factors are applied in a transparent and consistent manner. In this way, the results can be used with greater confidence in identifying trends and in monitoring progress towards the commitments that have been defined with reference to emissions in the base year. The UNFCCC reporting guidelines provide for the reporting of recalculations as part of the annual submissions from Annex 1 Parties. Justification for the recalculations should be provided, as well as explanations of the changes that have been made and the numerical values of the original and revised estimates must be compared to show the impact of the changes.

10.2 Explanation and Justification for Recalculations

This chapter describes recalculations and improvements for inventory undertaken for the 2024 submission and presents the corresponding quantitative changes in emissions and removals within the individual sectors. The recalculations are either due to the national circumstances, revised activity data and or changes in country specific emission factors. Table 10.1 records a summary of the major changes and reasons for recalculations. This section summarises the recalculations and assesses their effect in relation to total national emissions, to record the updates and the most recent emissions estimates as they appear in the 2024 submission CRF tables. The original and revised numerical values of the emissions estimates for the years 1990-2021, along with the changes related to methods, activity data and emission factors are detailed in the respective CRF Tables 8s1 to 8s4. The principal changes that give rise to recalculated estimates for the years 1990-2021 included in the 2024 submission are outlined below (Figures 10.1 to 10.6).

10.2.1 Recalculations in Energy

The overall effect of recalculations on the Energy sector emissions was negligible, with a cumulative increase of 35.2 kt CO_2 eq in the 1990-2021 trend with the largest recalculations occurring in 2021, with a decrease of 12.9 kt CO_2eq or -0.04 per cent. The main reasons for the recalculations were the redistribution of fuels (oil and natural gas) within the sectors 1.A.2, 1.A.4.a and 1.A.4.b based on new survey data (CSO ASI and BEUS) and are described in detail in Chapter 3. A summary of the changes are as follows;

1.A.2 Manufacturing Industries and Construction: There was a significant redistribution of fuel within this sector.

- An average of 726 TJ per annum of natural gas was reallocated from 1.A.2 Manufacturing Industries and Construction to 1.A.4.a Commercial/Institutional from 2001 to 2021, except for 2020, where 1742 TJ of natural gas was added to Industry from the Commercial sector.

- Approximately 171 TJ per annum of Oil was moved to 1.A.2 Manufacturing Industries and Construction from 1.A.4 Other Sectors across the time series. From 1990 to 2009 and 2019 to 2022, oil is reallocated from both 1.A.4a Commercial/Institutional and 1.A.4.b Residential into 1.A.2, while from 2010 to 2018 oil is solely moved from 1.A.4.a into 1.A.2.
- As a result of such fuel reallocations, there was an average annual decrease of 0.25 per cent in greenhouse gas emissions from 1990 to 2021, with the largest per centage change occurring between the period of 2006 and 2021 with an average of 0.65 per centage decrease. Due to the 1742 TJ addition of natural gas, 2020 saw the largest recalculation in the timeseries with a 3.1 per cent increase in emissions.

1.A.3 Transport: There were minor recalculations in the transport sector in this submission.

- Eurocontrol (model) data was revised for the years 2015 to 2021, with changes in emissions ranging from 0.1 per cent in 2019 to 1.9 per cent in 2020 for Domestic Aviation (1A3a), with an average of 0.9 per cent for this period.
- Across the time series from 1990-2021, emissions from 1.A.3b Road Transport increased by on average 0.2 per cent. The largest recalculations occurred between 2017 to 2021, where a total of 7,600 TJ of road diesel was added to the sector, resulting in an average annual increase in emissions of 1.1% for that period. This additional diesel was reallocated from industry, services, residential and agriculture.

  CO_2 emissions are responsible for 99 per cent of all road transport emissions, however, we do encounter some variation within CH_4 and N_2O throughout the timeseries. The recalculation differences for CH_4 and N_2O have been relatively small in absolute terms i.e. (0.03 kt CH_4 and 0.3 kt N_2O per annum). There was a bug in the cold emissions parameter for both NO_x (and therefore N_2O was affected) and CH_4 for cars and LCVs in 5.6.1 (model version used within 2023 submission for CH_4 / N_2O emission factors). This has now been corrected in the 5.7.1 version (model version used within 2024 submission). Some of the Euro VI vehicles were overestimated while some of the older classes of from Euro II to Euro 5 N1-1 for petrol.

  Overall, there is less than 0.1 per cent difference each year between 1990-2016. From 2017-2021, there is a recalculation difference of approx. 1 per cent per more annum which is predominantly due to an increase of diesel fuel which was redistributed following further QAQC checks across other energy sub-subsectors by the compilers of the national energy balance i.e. SEAI.
- Emissions from 1.A.3.d National Navigation were revised for 2021, with emissions increasing by 3.3 per cent or 11.6 kt CO_2 eq.

1.A.4 Other sectors. There was a significant redistribution of fuel within this sector.

- In 1.A.4.a Commercial/Institutional, these revisions included the reallocation of oil to 1.A.2 Manufacturing Industries and Construction from 118 TJ of oil per annum from 1990 to 2019, increasing to 1450 TJ per annum in 2020 and 2021. From 2001 to 2021, an average of 726 TJ of natural gas was added annually to 1.A.4.a Commercial/Institutional from 1.A.2 Manufacturing Industries and Construction, except for 2020, where 1742 TJ of natural gas was added to Industry from the Commercial sector. These revisions result in average recalculations of -0.4 per cent from 1990 to 2001, +2.2 per cent from 2002 to 2019, and -8.7 per cent in 2020 and 2021.

- In 1.A.4.b Residential, the historical revisions included an average annual reallocation of 40 TJ of oil to 1.A.2 Manufacturing Industries and Construction from 1990 to 2016, increasing to 1,116 TJ of oil per annum from 2017 to 2021. Additionally, average annual revisions of 18 TJ of coal was reallocated between 1.A.4.a Commercial/Institutional and 1.A.4.b Residential from 2009 to 2021, with 90 and 97 TJ added to 1.A.4.b in 2010 and 2011 respectively. In terms of emissions, these revisions caused average recalculations of -0.03 per cent from 1990 to 2016, and -1.2 per cent from 2017 to 2021.
- In 1.A.4.c Agriculture/Forestry/Fishing, there were recalculations from 2019 to 2021 due to minor changes in oil quantities for these years resulting in an average increase of 0.5 per cent for these years.

1.B.2 Oil and Natural Gas. There was a recalculation for venting and flaring in 2021 in this submission.

- In 1.B.2.c Venting and Flaring there is a significant recalculation in 2021 due to a correction in quantities of reported CH_4 venting. In the 2023 submission, a 5-year average from 2016 to 2020 was used to estimate 2021 values as activity data was not received in time for submission. However, the 5-year average values overestimated venting due to no production-related atmospheric emissions at the Kinsale fields in 2021 following a cessation of production. As a result, a recalculation of -10.7 kt CO_2eq or -13.1 per cent of 1.B.2 Oil and Natural Gas occurred for 2021.

The national energy balance was previously based on a top-down approach whereas the Business Energy use survey compiles aggregated data based on a bottom-up approach with individual businesses grossed to national level. The revised bottom-up approach now draws on a cross-sourcing of data using the emissions trading scheme, large industry energy network, public sector energy programme, census of industrial production and others. The revised approach (BEUS) has focused on data from 2009 to 2021 with the 2022 splits based on the latest 2021 splits.

The detailed results of the recalculations are given in CRF Tables 8s1 for the relevant years and chapter 3. The impact of the recalculations in the Energy sector between annual submissions in the 1990-2021 time series is outlined below in Figure 10.1.

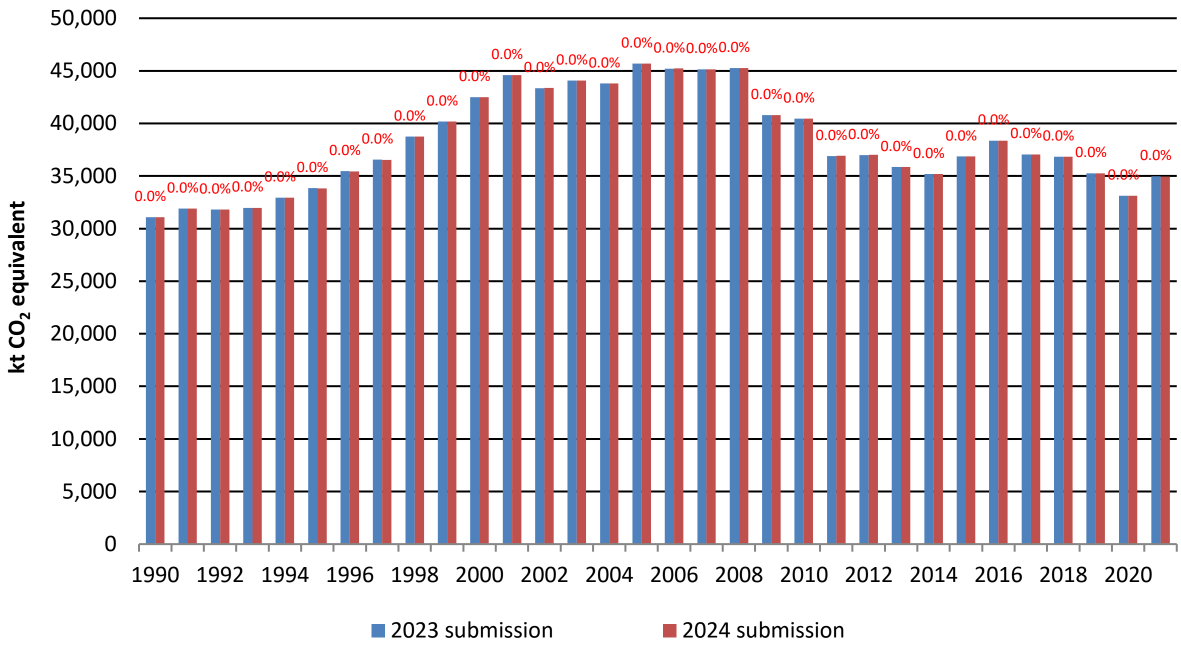


Figure 10.1 Impact of Recalculations in Energy between annual Submissions 1990-2021

10.2.2 Recalculations in Industrial Processes and Product Use

The overall impact of recalculations in the IPPU sector resulted in a decrease of 90.69 kt CO_2 eq. in total in the 1990-2021 trend. The largest recalculations occurred in the period 2005 to 2021. The results of the recalculations are given in CRF Tables 8s1 and 8s4 for the relevant years.

The reasons for the recalculation between the two submissions were;

- A recalculation occurred for the entire time series in ***Solvent use (2D3)*** due to a revision of activity data The most significant changes occurred in the years 2005 to 2021. This resulted in an average recalculation of -2.5 per cent on average per annum for the time series.
- A recalculation of CO_2 in ***Urea used as a catalyst (2D3)***, for the years 2006 to 2021 due to minor changes in activity data and a revision to the road transport model. The average change was -1.5 per cent.
- A revision to HFC emissions from ***Aerosols (2F4)***, for the years 2020 to 2021 to reflect the change in the UK inventory to take into the account of the ban on HFC with a GWP >150 and a change to the species split across the time series. The average change was a decrease in HFC emissions from this sub-category of 0.9 per cent. The only change of any significance was for 2021 with a decrease of 18.6 per cent in emissions.
- There were revised emissions from the ***Electronics industry (2E)*** with new data for the years 2020 to 2021 in this submission.

The total impact of recalculations in IPPU ranged from a decrease of -26.3 kt CO_2 eq in 2021 (-0.8 per cent) to an increase of 12.0 kt CO_2 eq in 2009 (0.4 per cent). See Figure 10.2.

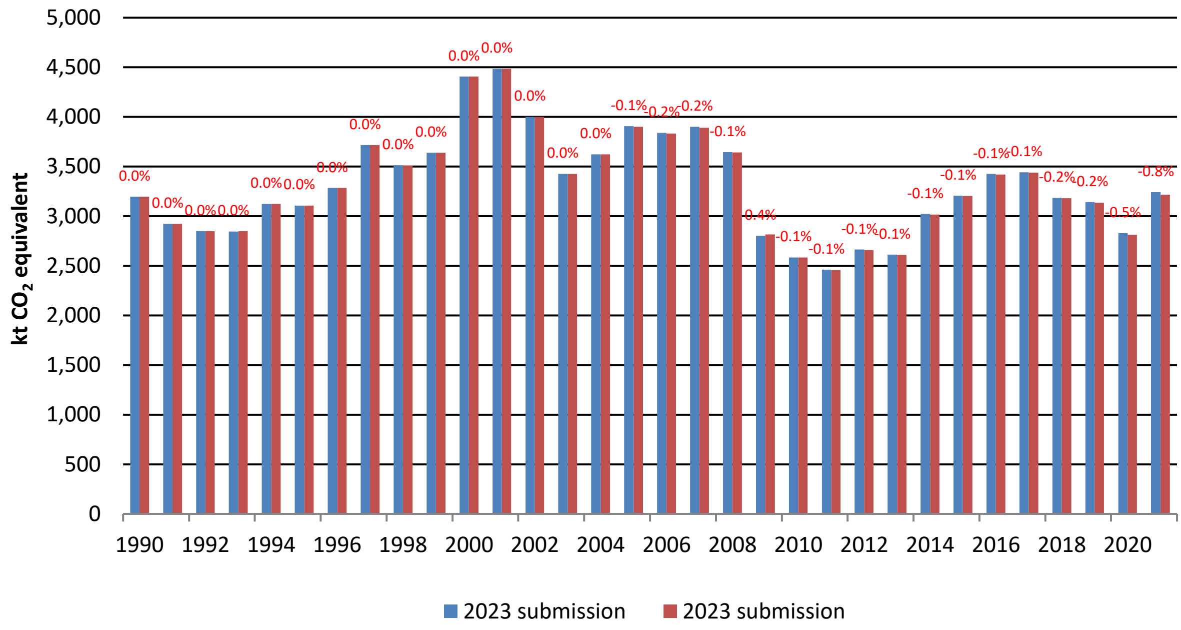


Figure 10.2 Impact of Recalculations in IPPU between annual Submissions 1990-2021

10.2.3 Recalculations in Agriculture

The overall impact of recalculations in the Agriculture sector resulted in an decrease of 314.1 kt CO_2 eq or 1.5 per cent on average and 10,050.7 kt CO_2 eq. in total in the 1990-2021 trend. The main recalculations are as follows;

3.B Manure Management for years 1990-2021 resulted in an increase of 2.6 per cent on average across the timeseries.

3.B CH_4 recalculations

An increase of 74.9 kt CO_2 eq on average across the timeseries in subcategory 3.B.1.2 Sheep and an average decrease of 7.1 kt of CO_2 eq for 3.B.1.4 Other livestock was due to the correction of the pasture manure management methane conversion factor for sheep, horses and goats following a transcription error in the previous submission.

3.B N_2O recalculations

A correction to a transcription error for sheep manure management N excretion rates resulted in a decrease of 4.3 kt CO_2 eq emissions on average across the timeseries for 3.B.2.2 Sheep and also an average decrease of 1.5 kt CO_2 eq emissions on average across the timeseries for 3.B.2.5 Indirect N_2O emissions.

3.D Agricultural Soils recalculations resulted in a 7.8 per cent decrease in emissions on average across the timeseries 1990-2021.

3.D.1 Direct N_2O Emissions from Managed soils

3.D.1.2.a Animal manures applied to soils had a recalculation decrease of 1.8 kt CO_2 eq on average across the time series and 3.D.1.3 Urine and dung deposited by grazing animals decreased on average 14.9 kt CO_2 eq, due to the correction to a transcription error for sheep manure management N excretion rates.

3.D.1.5 Mineralisation/Immobilisation Associated with loss/gain of Soil Organic matter increased on average 0.5 per cent or 0.1 kt CO_2 eq across the time series due to revisions of cropland carbon stocks.

3.D.1.6 Cultivation of organic soils decreased 379.9 kt CO_2 eq on average across the time series This was a result of recently published activity data relating to the area of grasslands on organic soils drained and the assignment of nutrient status (nutrient rich and nutrient poor status) of these soils in Ireland. Previous submission estimates for this category utilised the default approach which assumed that all grasslands on organic soil were drained and nutrient poor status was assigned.

3.D.2 Indirect Emissions from Managed Soils.

3.D.2.1 Atmospheric deposition emissions increased 26.4 kt CO_2 eq on average across the time series due to updates to synthetic fertiliser ammonia emission factors in the EEA/EMEP guidebook 2023 and the correction of a transcription error for sheep manure management N excretion rates.

3.D.2.2 Nitrogen Leaching and Runoff emissions decreased 5.8 kt CO_2 eq on average across the time series due to the correction of a transcription error for sheep manure management N excretion rates, revisions of cropland carbon stocks and the correction of a transcription error associated with the quantity of nitrogen contained in crop residues.

The impact of the recalculations in the Agriculture sector between annual submissions in the 1990-2021 time series is outlined below. The largest decrease occurred in 1990, -412.2 kt CO_2 eq (-2.1 per cent). See Figure 10.3.

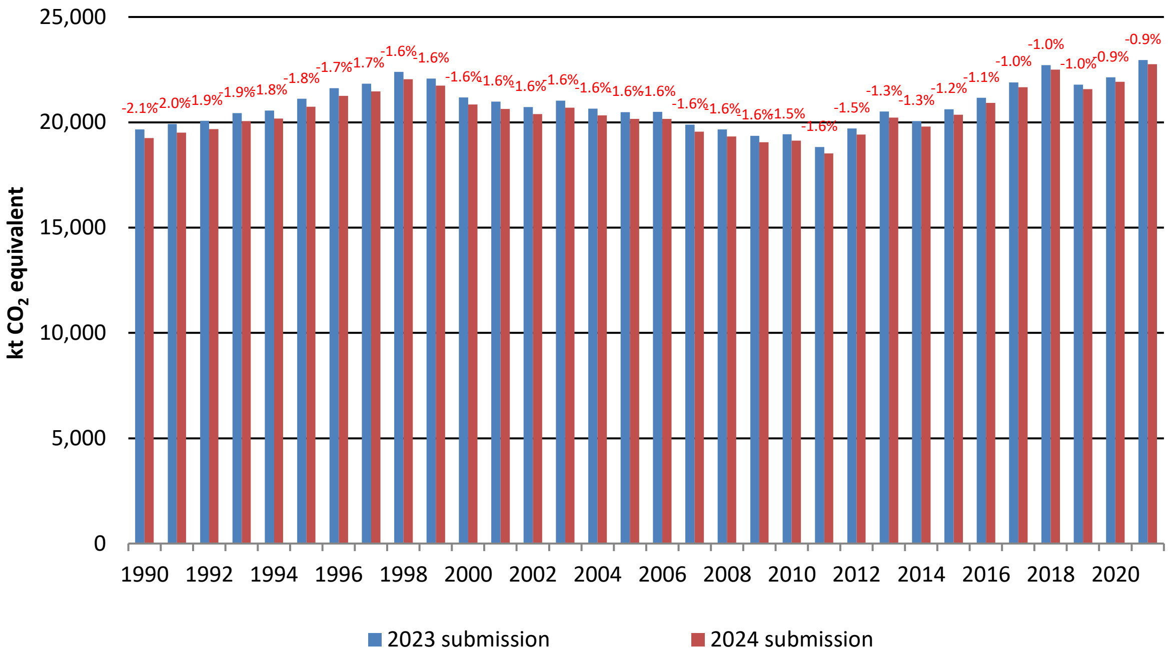


Figure 10.3 Impact of Recalculations in Agriculture between annual Submissions 1990-2021

10.2.4 Recalculations in LULUCF

The overall impact of recalculations in the LULUCF sector resulted in an average decrease of 22.3 per cent or 1,440.5 kt CO_2 eq on average across the timeseries 1990-2021. The cumulative level of the recalculation for the years 1990-2021 is -46,095.3 kt CO_2 eq. The main recalculations are as follows;

- A misallocation of aboveground biomass for 4.A.2 Land converted to forest land to ***4.A.1 Forest land remaining forest land*** to ***4.A.2 land converted to forest land*** is corrected in this submission. For the timeseries 1991-2014, there is a reduction of 2,262.8 kt CO_2 on average in the estimated removal from ***4.A.1 Forest land remaining forest land*** with an equal increase in the removal estimates for ***4.A.2 land converted to forest land***. For the years 2015-2021, in addition to the above misallocation, revised estimates for deforestation and the area of organic soil are also a contributor resulting in a -332.8 kt CO_2 eq revision for the period 2015-2021.

- Similar to previous submissions, revised analysis of the LPIS spatial dataset and its effect on rotational cropping patterns revised the carbon stock estimates in ***4.B Croplands***. Additionally revised default biomass carbon values for both annual and perennial woody crops as presented in the 2019 Refinement to the 2006 IPCC guidelines contribute to the recalculation. Combined this leads to a 115.1 kt CO_2 increase on average in emissions and removals on average across the timeseries 1990-2021.

- Significant recalculations were undertaken in ***4.C Grasslands*** with a 3,641.9 kt CO_2 eq reduction in emissions on average across the timeseries. The majority of this revision occurred in ***4.C.1 Grasslands remaining grasslands*** on foot of the adoption of country specific analysis of the extent of drainage on organic soils, the utilisation of soils data with respect to the nutrient status of these soils (nutrient rich versus nutrient poor) and the utilisation of country specific emission factors for onsite emissions and offsite emissions. Revised land use and land management factors as presented in the 2019 Refinement to the 2006 guidelines also contribute to the recalculations, but the effects are minor in comparison. This resulted in an average annual decrease of 4,860.3 kt CO_2 across the timeseries 1990-2021, 43.4 kt CH_4 and an increase of 0.03 kt N_2O. Revisions to deforestation estimates for the period 2016 to 2021 led to an increase of 103.5 kt CO_2 eq. on average for those years for ***4.C.2 land converted to grassland***..

- Significant recalculations were also undertaken for ***4.D Wetlands*** with an annual average increase in emission of 2,108.3 kt CO_2 eq across the timeseries 1990-2021. Revised categorisation of the status of wetlands present in Ireland and the adoption of country specific research results are the main contributors. On average, across the timeseries 1990-2021 there is a 390.9 kt CO_2 decrease for ***4.A.1 Wetlands remaining wetlands***, and an increase in CO_2 emissions for ***4.A Wetlands*** of 17.5 kt CO_2 when offsite emission are taken into account. In addition, there is 74.3 kt CH_4 increase on average and 0.04 kt N_2O reduction on average across the timeseries as a result of the revised categorisation of the status of wetlands present in Ireland and the adoption of country specific research results.

- For ***4.E Settlements***, there is on average 11.7 kt CO_2 eq reduction in emissions across the timeseries 1990-2021 as a result of the utilisation of revised carbon fraction in biomass removed in ***4.E.2 land converted to settlements***.

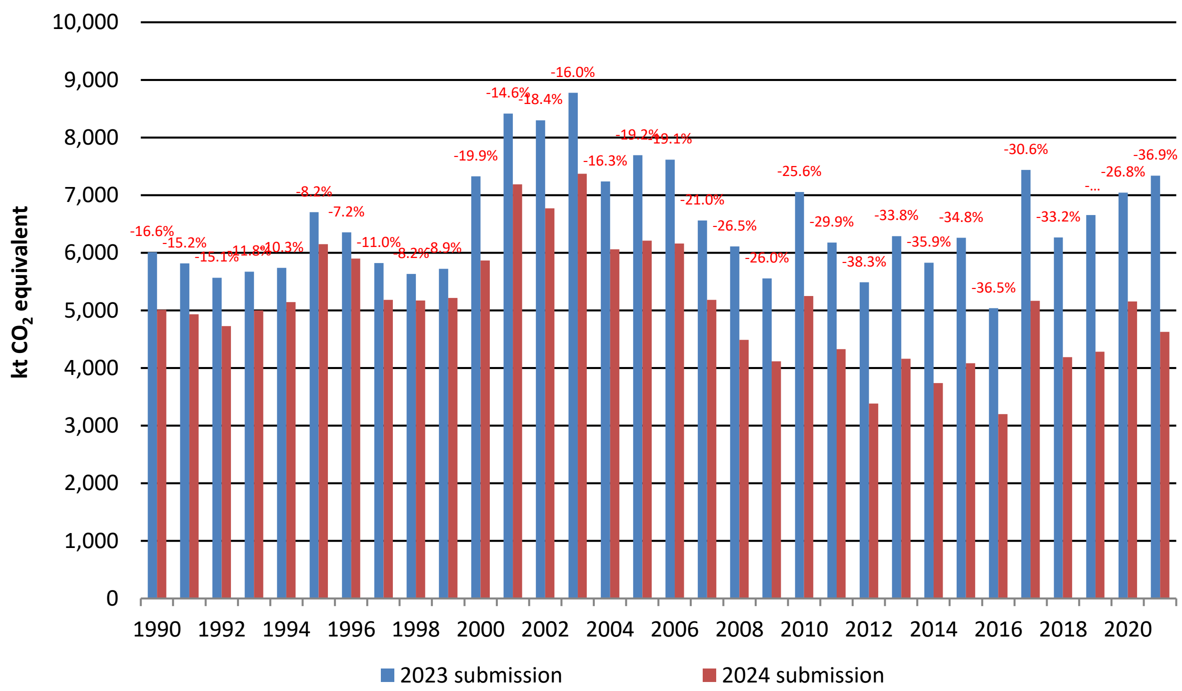


Figure 10.4 Impact of Recalculations in LULUCF between annual Submissions 1990-2021

10.2.5 Recalculations in Waste

The overall impact of recalculations in the Waste sector resulted in a 0.7 per cent decrease on average and -291.2 kt CO_2 eq. in total in the 1990-2021 trend. Emissions in 2021 decreased by 12.7 per cent. Additional information on recalculations is presented in CRF Table 8s3 for the relevant years.

The main recalculations between the two submissions are;

- In category ***Solid Waste Disposal (5A)***, there were significant recalculations for the years 2004 to 2021 due to a revision of activity data. The composition of MSW going to Solid Waste Disposal Sites was revised as increasingly significant amounts of MSW were allocated to inert/bio-stabilised instead of biodegradable wastes. This change revised the inert composition share in recent years from < 30 per cent bio-stabilised to over 60 per cent bio-stabilised and consequently resulted in less methane generation. Emissions decreased significantly from 2016 onwards, from -4.3 per cent to -16.2 per cent in 2021.
- In category ***Biological Treatment of Solid Waste (5B)***, there was a recalculation for the year 2021 with new data provided by the EPA's Waste Statistics team. Emissions decreased by 12.5 per cent.

The impact of the recalculations in the Waste sector between annual submissions in the 1990-2021 time series is outlined below in Figure 10.5. The total impact of the recalculation of the sector for the timeseries was -291.1 kt CO_2 eq.

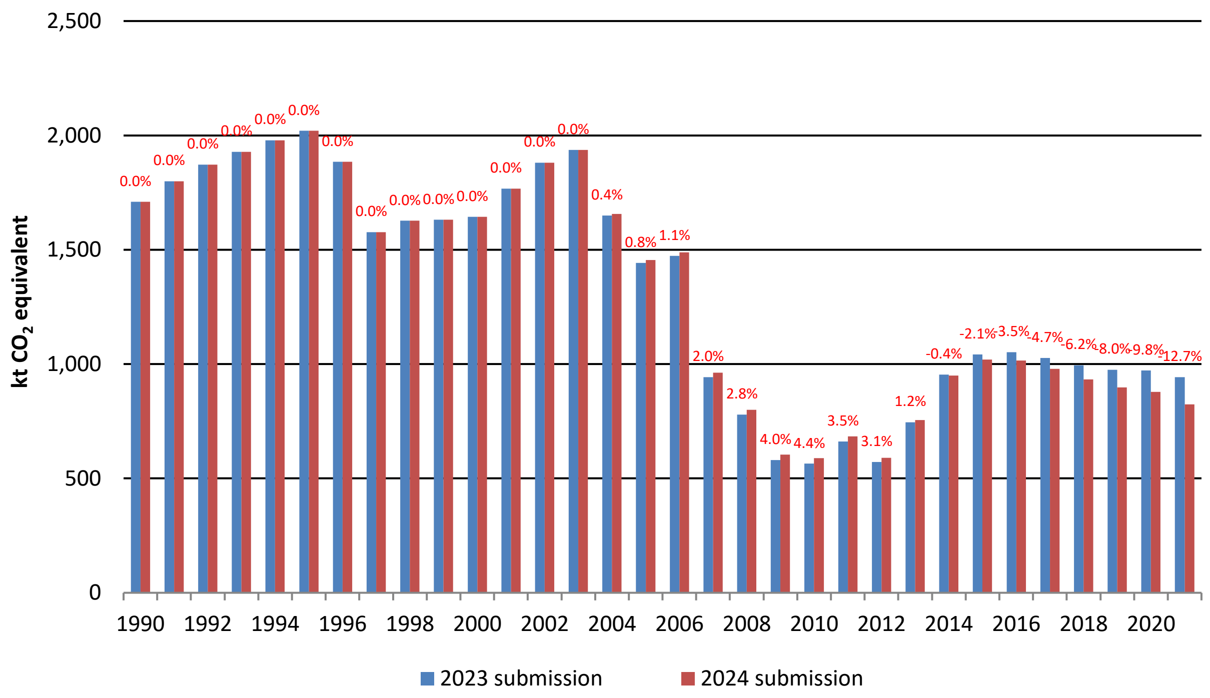


Figure 10.5 Impact of Recalculations in Waste between annual Submissions 1990-2021

10.3 Effects on Emission Levels, Trends and Time-Series Consistency

Tables 10.2 and 10.3 outline the effect of the recalculations for the years 1990-2021 according to greenhouse gas and the IPCC sectors, respectively. The overall effect on the total emissions (including indirect CO_2, excluding LULUCF) shows decreases in estimates by 0.7 per cent (-411.4 kt CO_2 eq.) in 1990 and 0.6 per cent (-354.7 kt CO_2 eq.) in 2021. The overall effect on the total emissions (including LULUCF) shows decreases in estimates by 2.3 per cent (-1,410.0 kt CO_2 eq.) in 1990 and 4.4 per cent (-3,065.2 kt CO_2 eq.) in 2021.There is no significant impact on the trend in total emissions (Chapter Two).

Cumulative emissions (excluding LULUCF) decreased over the time series 1990-2021 by 10,394.1 kt CO_2 eq. and including LULUCF by 56,489.5 kt CO_2 eq.

The largest changes coincided with the changes in the Agriculture and LULUCF sectors as shown above. The recalculations improve time-series consistency and comparability, and they take account of the inventory review process by implementing the major outstanding inventory-specific recommendations of the latest annual review reports. It may be said that fully consistent greenhouse gas inventories are available for the years 1990-2021 and that these annual inventories are complete with respect to the coverage of the seven greenhouse gases and all IPCC source categories. The range of important greenhouse gas emission sources in Ireland is quite small and the important elements of good practice are taken into account in the current approaches to estimating their emissions. The principal changes that that give rise to recalculated estimates for the years 1990-2021 included in the 2024 submission are outlined below (Tables 10.1 to 10.3 and Figure 10.6).

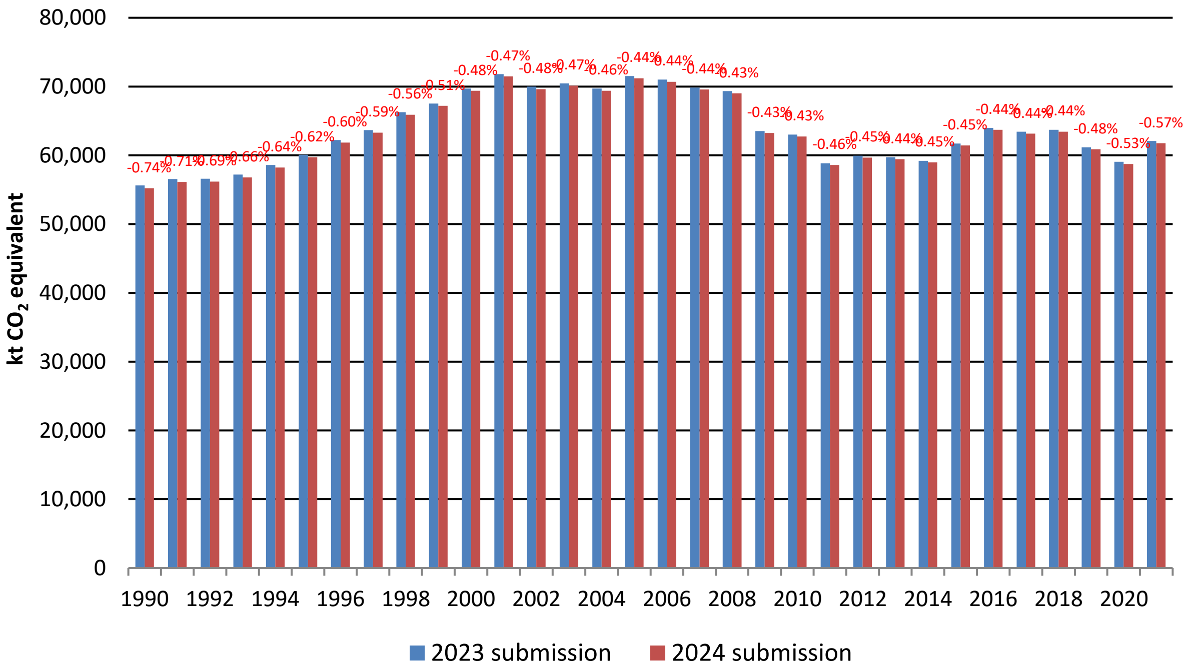


Figure 10.6 Total Impact of Recalculations between annual Submissions 1990-2021

Table 10.1 Changes in Methodological Descriptions compared to 2023 NIR

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	DESCRIPTION OF METHODS	RECALCULATIONS	REFERENCE
	Categories where the 2024 NIR includes major changes in methodological descriptions compared to the 2023 NIR	Sub-categories where changes are reflected in recalculations of previous year estimates	Reference to sub-category, gas, pages in the NIR, Annex
Total (Net Emissions)	√	√	
1. Energy	√	√	
A. Fuel Combustion (Sectoral Approach)		√	
1. Energy Industries		√	2020 and 2021 only. See section 3.2.4.1.5.
2. Manufacturing Ind and Construction		√	Revised energy data. Redistribution of fuel between “4. Other Sectors” and “Manufacturing Ind and Construction”. See chapter 3, Section 3.2.5.5
3. Transport	√	√	New COPERT model and revised Eurocontrol data. See section 3.2.6.1.5.
4. Other Sectors		√	Revised energy data. Redistribution of fuel between “4. Other Sectors” and “Manufacturing Ind and Construction”. See chapter 3 section 3.2.7.5.
5. Other			
B. Fugitive Emissions from Fuels		√	
1. Solid Fuels			
2. Oil and Natural Gas		√	
C. CO_2 Transport and Storage			
2. Industrial Processes and Product Use		√	
A. Mineral Industry			
B. Chemical Industry			
C. Metal Industry			
D. Non-Energy Products from Fuels and Solvent Use		√	Minor recalculations due to revised activity data in 2.D.3 solvent use
E. Electronics Industry		√	See section 4.6.1.5.
F. Product Uses as Substitutes for Ozone Depleting Substances		√	A revision to HFC emissions from 2.F.4 Aerosols. A revision to HFC in 2.F.1 Refrigeration and air conditioning, due revised activity data Chapter 4 Section 4.7.1.5 and 4.7.4.5.
G. Other Product Manufacture and Use		√	Minor recalculations.
H. Other			
3. Agriculture	√	√	
A. Enteric Fermentation			
B. Manure Management		√	Correction of methane correction factor for pasture for sheep, horses and goats. Correction of N excretion transcription error for sheep
C. Rice Cultivation			
D. Agricultural Soils		√	Correction of transcription error for sheep nitrogen excretion. Revisions to mineralisation/immobilisation associated with loss gain of soil organic matter. Updated indirect NH3 as a result of revised NH3 emission factors for synthetic fertilisers in 2023 EMEP/EEA guidebook. Revised methodology and use of country specific emission factors and soils data for cultivation of histosols.
E. Prescribed Burning of Savannas			
F. Field Burning of Agricultural Residues			
G. Liming			

H. Urea Application			
I. Other			
4. Land Use, Land-Use Change and Forestry	**√**	**√**	
A. Forest Land		√	Correction of transcription error in previous submission for aboveground biomass. Revised organic soils area and revised deforestation estimates for recent years (2015-2021)
B. Cropland		√	Updated analysis of cropland rotation patterns. Updated default biomass carbon values from 2019 Refinement to the 2006 guidelines.
C. Grassland	√	√	Updated analysis of drainage status, nutrient status of grasslands on organic soils. Country specific emission factors for onsite and offsite emissions from organic soils utilised. Updated land use and land management factors from the 2019 Refinement to the 2006 IPCC guidelines also adopted.
D. Wetlands	√	√	Revised categorisation of wetland status and adoption of country specific emissions factors.
E. Settlements		√	Revised carbon fraction in biomass removed utilised.
F. Other Land		√	Revisions due to residual area approach for 4.F.
G. Harvested Wood Products			
H. Other			
5. Waste		√	
A. Solid Waste Disposal		√	Revision of MSW composition going to SWDS to correct the levels of inert/bio stabilised wastes amounts from 2011 to 2021.
B. Biological Treatment of Solid Waste		√	Revised AD for composting and Anaerobic digestion for 2021
C. Incineration and Open Burning of Waste			
D. Wastewater Treatment and Discharge			
E. Other			
6. Other			
Memo Items:			
International Bunkers			
Aviation			
Marine			
Multilateral Operations			
CO_2 Emissions from Biomass			
CO_2 captured			
Long-term storage of C in waste disposal sites			
N_2O Indirect Emissions			
CO_2 Indirect Emissions			

Table 10.2 Recalculations by Gas 1990-2021

(a) Emissions by Gas 1990 –2021 reported in 2023 Submission (kt CO_2 eq)

GAS	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021
CO_2 emissions without net CO_2 from LULUCF	32,944.4	35,853.0	45,249.1	48,156.2	41,793.2	37,281.9	36,853.2	38,718.5	40,369.7	39,078.3	39,012.6	37,325.8	35,123.8	37,547.3
CO_2 emissions with net CO_2 from LULUCF	38,255.6	41,810.6	51,833.6	54,981.1	47,523.7	42,523.2	41,606.9	43,976.5	44,445.9	45,215.7	44,237.3	42,964.6	41,129.9	43,826.3
CH_4 emissions without CH_4 from LULUCF	16,138.0	17,100.7	16,885.6	16,331.5	14,535.1	15,545.3	15,642.8	16,233.4	16,685.9	17,177.2	17,543.3	17,043.1	17,286.8	17,649.7
CH_4 emissions with CH_4 from LULUCF	16,644.8	17,608.0	17,378.5	16,874.6	15,380.4	16,155.0	16,277.2	16,807.4	17,233.3	18,012.9	18,163.4	17,648.4	17,919.2	18,276.0
N_2O emissions without N_2O from LULUCF	6,524.9	6,921.2	6,871.2	5,900.3	5,582.7	5,749.6	5,524.8	5,574.8	5,675.6	5,965.4	6,289.0	5,921.8	5,926.1	6,146.6
N_2O emissions with N_2O from LULUCF	6,716.4	7,158.5	7,119.5	6,223.3	6,062.7	6,188.3	5,963.6	6,002.3	6,088.5	6,431.1	6,708.1	6,334.6	6,330.0	6,579.6
HFCs	0.5	31.4	245.7	820.4	1,016.9	1,061.1	1,139.4	1,116.6	1,184.3	1,094.3	783.9	772.0	624.1	673.0
PFCs	0.1	88.6	361.3	196.5	42.3	7.6	3.2	18.5	33.5	42.4	44.8	56.6	64.0	65.0
SF_6	34.9	81.5	53.4	100.1	34.1	44.9	38.6	45.9	40.5	40.4	42.2	34.6	19.0	16.2
NF_3	NO	4.1	46.0	26.6	27.8	21.3	18.8	16.4	15.8	26.5	18.4	11.2	12.6	12.1
Total (without LULUCF, with indirect)	**55,642.8**	**60,080.7**	**69,712.4**	**71,531.5**	**63,032.2**	**59,711.6**	**59,220.7**	**61,724.0**	**64,005.4**	**63,424.5**	**63,734.1**	**61,165.0**	**59,056.3**	**62,109.9**
Total (with LULUCF, with indirect)	61,652.3	66,782.8	77,038.0	79,222.5	70,088.0	66,001.3	65,047.7	67,983.4	69,041.8	70,863.4	69,998.1	67,822.1	66,098.8	69,448.1

(b) Recalculated Emissions by Gas 1990 –2021 reported in 2024 Submission (kt CO_2 eq)

GAS	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021
CO_2 emissions without net CO_2 from LULUCF	32,945.3	35,853.4	45,249.5	48,152.7	41,791.6	37,278.9	36,850.2	38,716.0	40,366.9	39,075.6	39,009.4	37,323.4	35,124.5	37,544.3
CO_2 emissions with net CO_2 from LULUCF	33,661.3	37,777.1	47,010.0	50,172.8	42,501.4	37,261.1	36,385.1	38,714.7	39,545.9	39,865.3	39,024.2	37,434.9	36,123.2	37,936.1
CH_4 emissions without CH_4 from LULUCF	16,225.2	17,192.2	16,973.0	16,413.8	14,603.9	15,604.4	15,690.1	16,261.4	16,698.8	17,182.9	17,533.9	17,016.6	17,246.0	17,572.6
CH_4 emissions with CH_4 from LULUCF	20,325.3	21,184.4	20,826.4	20,281.8	18,659.6	19,348.6	19,454.2	19,922.0	20,303.0	21,088.9	21,259.1	20,750.7	20,976.6	21,403.0
N_2O emissions without N_2O from LULUCF	6,025.5	6,454.7	6,446.2	5,506.0	5,243.2	5,428.7	5,212.8	5,274.0	5,386.4	5,687.1	6,021.1	5,658.2	5,669.8	5,893.5
N_2O emissions with N_2O from LULUCF	6,220.2	6,690.2	6,700.4	5,829.9	5,725.9	5,864.3	5,651.7	5,697.2	5,801.5	6,156.8	6,467.6	6,094.6	6,093.0	6,299.0
HFCs	0.5	31.4	245.7	818.2	1,016.7	1,060.9	1,139.0	1,116.0	1,183.6	1,093.5	782.9	770.6	621.4	661.1
PFCs	0.1	88.6	361.3	196.5	42.3	7.6	3.2	18.5	33.5	42.4	44.8	56.6	57.7	59.7
SF_6	34.9	81.5	53.4	100.1	34.1	44.5	38.2	45.5	40.1	40.0	41.8	34.2	17.0	15.3
NF_3	NO	4.1	46.0	26.6	27.8	21.3	18.8	16.4	15.8	26.5	18.4	11.2	9.5	8.7
Total (without LULUCF, with indirect)	**55,231.5**	**59,706.0**	**69,375.2**	**71,213.8**	**62,759.7**	**59,446.2**	**58,952.4**	**61,447.7**	**63,725.1**	**63,148.0**	**63,452.2**	**60,870.9**	**58,746.0**	**61,755.1**
Total (with LULUCF, with indirect)	60,242.3	65,857.4	75,243.3	77,425.8	68,007.9	63,608.2	62,690.3	65,530.1	66,923.4	68,313.4	67,638.7	65,152.9	63,898.5	66,382.9

(c) Per centage Change in Emissions by Gas 1990-2021

GAS	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021
CO_2 emissions without net CO_2 from LULUCF	0.00%	0.00%	0.00%	-0.01%	0.00%	-0.01%	-0.01%	-0.01%	-0.01%	-0.01%	-0.01%	-0.01%	0.00%	-0.01%
CO_2 emissions with net CO_2 from LULUCF	-12.01%	-9.65%	-9.31%	-8.75%	-10.57%	-12.37%	-12.55%	-11.97%	-11.02%	-11.83%	-11.78%	-12.87%	-12.17%	-13.44%
CH_4 emissions without CH_4 from LULUCF	0.54%	0.53%	0.52%	0.50%	0.47%	0.38%	0.30%	0.17%	0.08%	0.03%	-0.05%	-0.16%	-0.24%	-0.44%
CH_4 emissions with CH_4 from LULUCF	22.11%	20.31%	19.84%	20.19%	21.32%	19.77%	19.52%	18.53%	17.81%	17.08%	17.04%	17.58%	17.06%	17.11%
N_2O emissions without N_2O from LULUCF	-7.65%	-6.74%	-6.19%	-6.68%	-6.08%	-5.58%	-5.65%	-5.40%	-5.10%	-4.67%	-4.26%	-4.45%	-4.32%	-4.12%
N_2O emissions with N_2O from LULUCF	-7.39%	-6.54%	-5.89%	-6.32%	-5.56%	-5.24%	-5.23%	-5.08%	-4.71%	-4.27%	-3.59%	-3.79%	-3.74%	-4.26%
HFCs	0.00%	0.00%	0.00%	-0.26%	-0.02%	-0.02%	-0.03%	-0.05%	-0.06%	-0.08%	-0.13%	-0.18%	-0.43%	-1.77%
PFCs	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	-9.75%	-8.13%
SF_6	0.00%	0.00%	0.00%	0.00%	0.00%	-0.93%	-1.08%	-0.91%	-1.03%	-1.04%	-1.00%	-1.23%	-10.08%	-5.99%
NF_3	NO	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	-24%	-28%
Total (without LULUCF, with indirect)	**-0.74%**	**-0.62%**	**-0.48%**	**-0.44%**	**-0.43%**	**-0.44%**	**-0.45%**	**-0.45%**	**-0.44%**	**-0.44%**	**-0.44%**	**-0.48%**	**-0.53%**	**-0.57%**
Total (with LULUCF, with indirect)	-2.29%	-1.39%	-2.33%	-2.27%	-2.97%	-3.63%	-3.62%	-3.61%	-3.07%	-3.60%	-3.37%	-3.94%	-3.33%	-4.41%

(d) Actual Change in Emissions by Gas 1990-2021 (kt CO_2 eq)

GAS	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021
CO_2 emissions without net CO_2 from LULUCF	0.88	0.37	0.41	-3.50	-1.63	-2.95	-3.04	-2.56	-2.80	-2.63	-3.19	-2.36	0.70	-3.01
CO_2 emissions with net CO_2 from LULUCF	-4594.32	-4033.51	-4823.60	-4808.31	-5022.23	-5262.04	-5221.80	-5261.87	-4899.96	-5350.44	-5213.13	-5529.77	-5006.73	-5890.16
CH_4 emissions without CH_4 from LULUCF	87.14	91.45	87.39	82.28	68.86	59.07	47.38	28.04	12.85	5.73	-9.35	-26.45	-40.81	-77.08
CH_4 emissions with CH_4 from LULUCF	3680.50	3576.43	3447.93	3407.17	3279.24	3193.58	3176.99	3114.61	3069.67	3076.07	3095.68	3102.32	3057.39	3127.01
N_2O emissions without N_2O from LULUCF	-499.37	-466.51	-425.02	-394.32	-339.49	-320.95	-311.96	-300.89	-289.20	-278.34	-267.92	-263.54	-256.28	-253.18
N_2O emissions with N_2O from LULUCF	-496.15	-468.34	-419.09	-393.37	-336.85	-323.96	-311.86	-305.10	-287.00	-274.33	-240.51	-239.99	-237.05	-280.58
HFCs	0.00	0.00	-0.01	-2.14	-0.22	-0.21	-0.34	-0.56	-0.70	-0.84	-0.98	-1.39	-2.67	-11.88
PFCs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-6.24	-5.28
SF_6	0.00	0.00	0.00	0.00	0.00	-0.42	-0.42	-0.42	-0.42	-0.42	-0.42	-0.43	-1.91	-0.97
NF_3	NO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-3.08	-3.35
Total (without LULUCF, with indirect)	**-411.36**	**-374.68**	**-337.23**	**-317.69**	**-272.48**	**-265.45**	**-268.38**	**-276.38**	**-280.26**	**-276.49**	**-281.87**	**-294.17**	**-310.29**	**-354.75**
Total (with LULUCF, with indirect)	-1409.97	-925.42	-1794.77	-1796.66	-2080.06	-2393.05	-2357.43	-2453.35	-2118.41	-2549.96	-2359.36	-2669.25	-2200.29	-3065.21

Table 10.3 Recalculations by IPCC Sector 1990-2021

(a) Emissions by IPCC Sector 1990 –2021 reported in 2023 Submission (kt CO_2 eq)

SOURCE AND SINK CATEGORIES	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021
1. Energy	31,067.6	33,840.4	42,479.4	45,695.9	40,455.4	35,849.9	35,189.7	36,856.0	38,366.9	37,057.3	36,834.9	35,257.9	33,122.2	34,970.2
2. Industrial Processes and Product Use	3,197.4	3,107.7	4,406.8	3,905.8	2,584.6	2,611.7	3,021.4	3,205.7	3,424.7	3,442.6	3,184.9	3,141.7	2,828.0	3,242.8
3. Agriculture	19,668.6	21,112.8	21,182.8	20,487.5	19,428.0	20,504.1	20,056.2	20,620.3	21,161.5	21,897.7	22,719.2	21,789.8	22,133.3	22,953.5
5. LULUCF	6,009.4	6,702.2	7,325.6	7,691.0	7,055.8	6,289.7	5,826.9	6,259.4	5,036.5	7,438.9	6,264.0	6,657.1	7,042.5	7,338.3
5. Waste	1,709.2	2,019.8	1,643.4	1,442.3	564.2	745.9	953.4	1,042.1	1,052.2	1,027.0	995.1	975.7	972.8	943.4
6. Other	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Total (excl. LULUCF, with indirect)	**55,642.8**	**60,080.7**	**69,712.4**	**71,531.5**	**63,032.2**	**59,711.6**	**59,220.7**	**61,724.0**	**64,005.4**	**63,424.5**	**63,734.1**	**61,165.0**	**59,056.3**	**62,109.9**

(b) Recalculated Emissions by IPCC Sector 1990 –2021 reported in 2024 Submission (kt CO_2 eq)

SOURCE AND SINK CATEGORIES	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021
1. Energy	31,067.5	33,835.4	42,483.6	45,702.3	40,460.3	35,853.9	35,193.7	36,859.5	38,369.9	37,060.0	36,837.2	35,260.1	33,125.6	34,961.1
2. Industrial Processes and Product Use	3,198.3	3,108.1	4,407.2	3,900.1	2,582.8	2,608.1	3,017.5	3,202.0	3,420.7	3,438.5	3,180.1	3,136.5	2,812.7	3,216.6
3. Agriculture	19,256.5	20,742.7	20,841.0	20,157.0	19,127.8	20,229.1	19,791.9	20,365.7	20,918.6	21,670.5	22,501.7	21,576.4	21,929.8	22,754.0
4. LULUCF	5,010.8	6,151.4	5,868.1	6,212.0	5,248.2	4,162.1	3,737.9	4,082.4	3,198.3	5,165.4	4,186.5	4,282.0	5,152.4	4,627.8
5. Waste	1,709.2	2,019.8	1,643.4	1,454.4	588.9	755.1	949.2	1,020.4	1,015.9	979.0	933.3	897.9	877.8	823.4
6. Other	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Total (excl. LULUCF, with indirect)	**55,231.5**	**59,706.0**	**69,375.2**	**71,213.8**	**62,759.7**	**59,446.2**	**58,952.4**	**61,447.7**	**63,725.1**	**63,148.0**	**63,452.2**	**60,870.9**	**58,746.0**	**61,755.1**

(c) Per centage Change in Emissions by Sector 1990-2021

SOURCE AND SINK CATEGORIES	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021
1. Energy	0.00%	-0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	-0.03%
2. Industrial Processes and Product Use	0.03%	0.01%	0.01%	-0.14%	-0.07%	-0.14%	-0.13%	-0.11%	-0.12%	-0.12%	-0.15%	-0.16%	-0.54%	-0.81%
3. Agriculture	-2.10%	-1.75%	-1.61%	-1.61%	-1.55%	-1.34%	-1.32%	-1.23%	-1.15%	-1.04%	-0.96%	-0.98%	-0.92%	-0.87%
4. Land use, land-use change and forestry	-16.62%	-8.22%	-19.90%	-19.23%	-25.62%	-33.83%	-35.85%	-34.78%	-36.50%	-30.56%	-33.17%	-35.68%	-26.84%	-36.94%
5. Waste	0.00%	0.00%	0.00%	0.84%	4.37%	1.23%	-0.44%	-2.07%	-3.45%	-4.68%	-6.22%	-7.97%	-9.76%	-12.71%
6. Other	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Total (excl. LULUCF, with indirect)	**-0.74%**	**-0.62%**	**-0.48%**	**-0.44%**	**-0.43%**	**-0.44%**	**-0.45%**	**-0.45%**	**-0.44%**	**-0.44%**	**-0.44%**	**-0.48%**	**-0.53%**	**-0.57%**

(d) Actual Change in Emissions by Sector 1990-2021

SOURCE AND SINK CATEGORIES	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021
1. Energy	-0.1	-4.9	4.1	6.5	4.9	4.0	4.0	3.5	3.0	2.8	2.3	2.1	3.4	-9.1
2. Industrial Processes and Product Use	0.9	0.4	0.4	-5.6	-1.9	-3.6	-3.9	-3.7	-4.0	-4.1	-4.8	-5.2	-15.3	-26.2
3. Agriculture	-412.2	-370.1	-341.8	-330.6	-300.2	-275.1	-264.3	-254.6	-242.9	-227.2	-217.5	-213.4	-203.4	-199.5
4. Land use, land-use change and forestry	-998.6	-550.7	-1457.5	-1479.0	-1807.6	-2127.6	-2089.0	-2177.0	-1838.2	-2273.5	-2077.5	-2375.1	-1890.0	-2710.5
5. Waste	0.0	0.0	0.0	12.1	24.6	9.2	-4.2	-21.6	-36.3	-48.0	-61.9	-77.7	-95.0	-119.9
6. Other	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Total (excl. LULUCF, with indirect)	**-411.4**	**-374.7**	**-337.2**	**-317.7**	**-272.5**	**-265.5**	**-268.4**	**-276.4**	**-280.3**	**-276.5**	**-281.9**	**-294.2**	**-310.3**	**-354.7**

10.4 Response to the Review Process and Planned Improvements

Ireland recognises the need to deliver annual submissions in close conformity with the UNFCCC reporting guidelines on annual inventories to facilitate the work of expert review teams in conducting productive and efficient technical reviews of greenhouse gas inventories. Every attempt is made to participate in the UNFCCC review process and to facilitate the work of the UNFCCC secretariat, especially insofar as it impacts on the quality and transparency of the Irish estimates of emissions. The in-country review of Ireland's 2006 and 2013 submissions (UNFCCC, 2007, 2013) were an important development in this regard. The majority of the recommendations in the 2013 in-country review were implemented in the 2014 submission while further recommendations from the 2008 to 2018 centralised reviews of Ireland's inventory have also been addressed where feasible in the present submission.

This submission is the seventh submission under the new UNFCCC Reporting guidelines and is prepared using the methodological guidance provided in the 2006 IPCC guidelines regarding revised nomenclature, new GWPs and sectoral disaggregation as well as the inclusion of new categories and gases. Annex 5.1 summarises the main findings in the 2023 annual inventory review report and Ireland's response to those findings. It may be stated therefore that the inventory material being submitted in 2024 broadly meets the principles of transparency, completeness, consistency, comparability and accuracy laid down in the UNFCCC reporting guidelines.

Further general improvements to greenhouse gas inventories are taking place through consolidation and implementation of the national system, which has been fully operational since 2007, and through application of formal QA/QC procedures that have been put into effect as an integral part of the national system. Memoranda of Understanding (MOU) which define the data inputs between the inventory agency and all key data providers and which outline the responsibilities that are conferred to the data providers under the national system (Table 1.1) underpin the national system in Ireland and have improved the quality and timely delivery of the activity data. Their application has identified where additional MOUs may be useful, including some secondary MOUs incorporated in 2009.

The implementation of comprehensive QA/QC procedures in this reporting cycle according to the plan supporting the national inventory system maintains and enhances the general improvement in quality of Irish greenhouse gas inventories. The QA/QC elements include a plan and procedures for QA/QC in data selection and acquisition, data processing and reporting to comply with international requirements under Regulation No. 2018/1999 of the European Parliament and of the Council and the Paris Agreement. The plan provides guidance on and templates for appropriate quality checking, documentation and traceability, the selection of appropriate source data and calculation methodologies. It extends to peer review and expert review of inventory data and outlines the annual requirements of a continuous improvement programme for the inventory. Participation in the internal review mechanisms within the EU as part of the QA/QC plan developed for the EU inventory under Regulation No. 2018/1999 and its Implementing Regulation No. 2020/1208 provides an opportunity to engage with other Member States in the examination and assessment of individual IPCC sectors and particular issues relating to methodologies and country-specific approaches that could bring mutual benefits to their greenhouse gas inventories.

Glossary

Annex 1 Parties	Countries listed in Annex I to the United Nations Framework Convention on Climate Change
Base year	The year or period under the Kyoto Protocol on which quantified emission limitation or reduction commitments in the commitment period are based.
BOD	Biochemical Oxygen Demand
CARBWARE	A forest model to calculate carbon stock change and growth increment for Irish forests
CFCs	Chlorofluorocarbons
CH_4	Methane
CHP	Combined Heat and Power.
CMMS	Cattle Movement and Monitoring System
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CO_2 equivalent	The equivalent mass as CO_2 of other greenhouse gases converted on the basis of their global warming potential (GWP)
COFORD	National Council for Forest Research and Development
Commitment Period	The years 2008 to 2012 (first CP) or 2013 to 2020 (second CP) inclusive for which quantified emission limitation or reduction commitments are established under the Kyoto Protocol
COP	Conference of the Parties
CORINAIR	Co-ordinated Information on the environment in the European Community-AIR. CORINAIR was one of several collaborative exercises initiated under the CORINE programme to harmonise the collection and dissemination of information on the environment in the EU.
CRF	Common Reporting Format
DAF	Department of Agriculture and Food
DAFM	Department of Agriculture, Food and the Marine
DCCAE	Department of Communications, Climate Action and Environment
DCENR	Department of Communications, Energy and Natural Resources
DEHLG	Department of Environment Heritage and Local Government
DNDC	DeNitrification-DeComposition, is a computer simulation model of carbon and nitrogen biogeochemistry in agri-ecosystems
EMEP	European Monitoring and Evaluation Programme, a co-operative programme for monitoring and evaluation of the long-range transmissions of air pollutants in Europe
Emission	(of a greenhouse gas). The release of greenhouse gases into the atmosphere.
Enteric Fermentation	The digestive process in ruminant animals (e.g cattle and sheep) where bacteria convert the feed to a usable form of energy for the animal, producing CH_4 as a by product
EUROSTAT	Statistical Agency of the European Union
FAO	Food and Agriculture Organisation of the United Nations
FFS	Farm Facilities Survey
FIPS	Forest Inventory and Planning System
Fluorinated Gases	HFCs, PFCs, SF_6 and NF_3

Fossil Fuel	Peat, coal, oil and natural gas and associated derivatives
FTA	Fraction of BOD in sludge that degrades anaerobically
GDP	Gross Domestic Product
Gg	Gigagram (10^9 g) = kilo tonne = 1,000 tonnes
Greenhouse Gas	A gas in the atmosphere that allows solar radiation through to the earth's surface, but traps some of the heat radiated back from the earth's surface
GWP	The cumulative warming over a specified time period, e.g. 100 years, resulting from a unit mass of a greenhouse gas emitted at the beginning of that time period, expressed relative to an absolute GWP of 1 for CO_2
HCFCs	Hydrochlorofluorocarbon
HFCs	Hydrofluorocarbons
HGV	Heavy Goods Vehicle
IEA	International Energy Agency
IEF	Implied Emission Factor
IPC	Integrated Pollution Control
IPCC	Intergovernmental Panel on Climate Change
IUCC	Information Unit on Climate Change
kt	kilo tonne (1,000 tonnes)
Kyoto Protocol	The Protocol to the UNFCCC adopted by Decision 1/CP.3 under which industrialised countries agreed to reduce their combined greenhouse gas emissions in 1990 by at least 5 per cent by the period 2008-2012
LTO	Landing and Take-off cycle
MMS	Manure Management System
Montreal Protocol	Protocol on substances that deplete the ozone layer
Mt	million tonnes or mega tonnes
N_2O	Nitrous Oxide
NBP	Net Biome Productivity
NEE	Net Ecosystem Exchange
NF_3	Nitrogen trifluoride
NIR	National Inventory Report
NMVOC	Non Methane Volatile Organic Compounds
NO_x	Nitrogen Oxides
NRA	National Roads Authority
OSPAR	Oslo and Paris Convention for the Protection of the Marine Environment
PFCs	Perfluorocarbons
SBSTA	Subsidiary Body for Scientific and Technological Advice
SEAI	Sustainable Energy Authority of Ireland
SF_6	Sulphur Hexafluoride
Sink	The reservoir or pool in which sequestered carbon is stored; the process of sequestration
SO_2	Sulphur Dioxide
Teagasc	Irish Agriculture and Food Development Authority
TPER	Total Primary Energy Requirement
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change
VOC	Volatile Organic Compounds

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3.1.14 Historic vehicle mileage and speed

The mileage data for the above vehicle categories in Table 3.1.12 of Annex 3.1.B were not available from 1990 to 2000. The 2006 IPCC Guidelines suggests using trend extrapolation or surrogate techniques in this case. However, trend extrapolation has limited use as the change in trend of the mileage data may not be constant over time and the latter technique is not applicable for a long period of extrapolation. Thus, for the purpose of extrapolation of the mileage data, available vehicle mileage until 2013 was regressed against 34 relevant variables which were selected from World Development Indicators (WB 2013). Although back extrapolation was attempted according to the least aggregated categories (i.e. LDV and HDV), no appropriate predictors were found to be correlated with the mileage data at the level of least aggregation. Thus, the aggregated vehicle mileage (e.g. for Diesel passenger cars) was extrapolated. The historical ratios between the average mileage (e.g. Diesel passenger cars) and different sub technologies (e.g. different Euro technologies, according to engine size of Diesel passenger cars) were applied on the extrapolated average mileage data to calculate mileage data according to technological level. This approach is similar to the surrogate technique suggested in 2006 IPCC Guidelines (Volume 1 Chapter 5: Time Series Consistency). The detailed methodology is available in Alam et al. 2017.

Mileage data against variables such as GDP growth (annual %) and Long-term unemployment (% of total unemployment) were found to be highly correlated for passenger cars. The variable influential factor (VIF) was acceptable (VIF<4) and can be included into regression models for each category of vehicle (Figure 3.1.3). The model fitting R^2 and validation R^2 were acceptable (see legend in Figure 3.1.3). For goods vehicle, a model was generated with average mileage data from all LDV and HDV where GDP (annual %) was included as an explanatory variable. The model explains somewhat variation around the historic mean average mileage (R^2= 0.38, Validation R^2= 0.38). For mileage extrapolation for national bus and coach, the best fitted models were found as:

- Coach Model: variables: GDP (current US$) and Population (Total); Adjusted R^2: 0.89; VIF<5; Validation R^2:0.95,
- Bus Model: variables: Road sector energy consumption (% of total) and Urban population (% of total); Adjusted R^2: 0.95; VIF<2; Validation R^2:0.94).

However, Bus and coach mileage data for some years were required initially to develop the Bus and Coach models. Thus, the mileage for buses and coaches were developed first since 1999 from total mileage, fleet and passenger numbers. Information regarding annual total mileage, fleet size and passenger number for buses were obtained from annual reports since 1999 for two national bus operators (one nationwide coach operator and the other Dublin city based) and their average mileage data were estimated. The average mileage data for these two categories are available since 2006, and total fleet mileage and passenger trips are available since 1999. Passenger trips were regressed against the fleet data and average mileage data were derived since 1999. The adjusted R^2 of the trip-fleet regression models for each of the national bus operators were 0.52 and 0.64, respectively. The mileage of Dublin city based national operator was considered as being representative of the bus industry in Ireland as found from different statistics, however, the mileage of the national coach operator was not representative of the coach industry in Ireland. Thus, the following equation was applied to calculate coach mileage. The equation provides an acceptable level of coach mileage, which is consistent with different reports.

*Coach mileage= (MB*BF+ MB*0.7*PF)/(BF+PF)*

Where, MB = Coach mileage by national operator, BF = fleet size of the national coach operator and PF = Fleet size of the private coaches.

The average mileage values for mopeds and motorcycles were obtained from CSO, and back extrapolated where the predictor variables used were: length of the total road network (in km) and Long-term unemployment (% of total unemployment). The Model fitting R^2 was 0.59 and validation R^2 was 0.58 (Max. VIF<8).

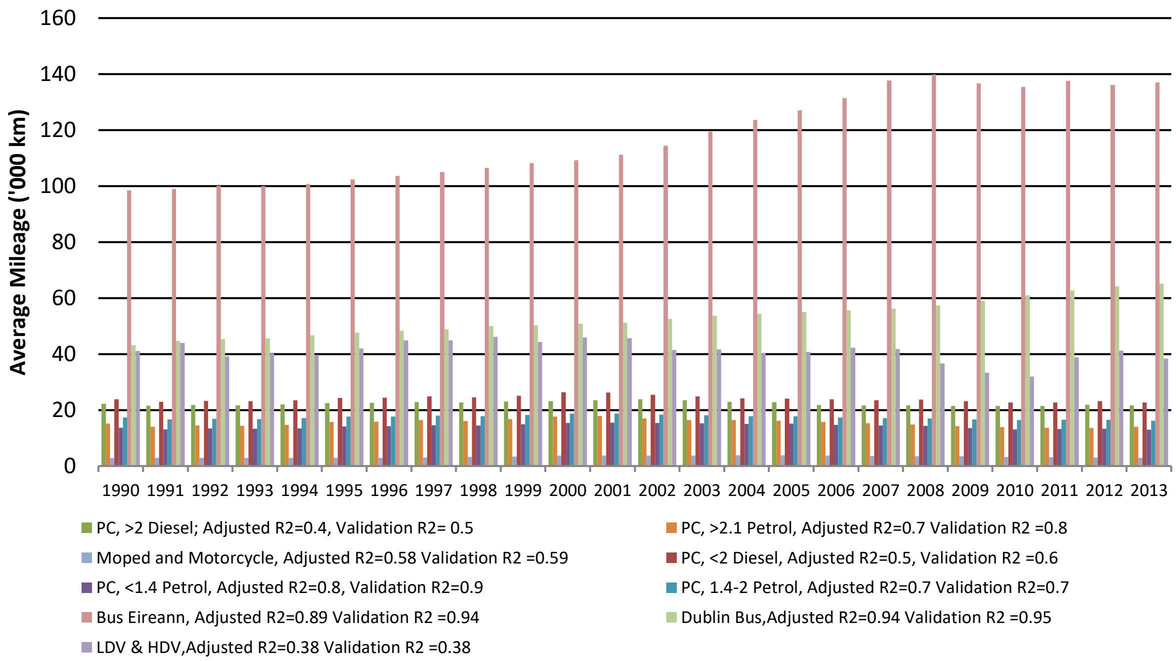


Figure 3.1.3 Average vehicle mileage by vehicle type (1990-2013)

Vehicle speeds in different roads were adopted from the reports published by Road Safety Authority in Figure 3.1.4 below. The detailed methodology is available in Alam et al. 2017.

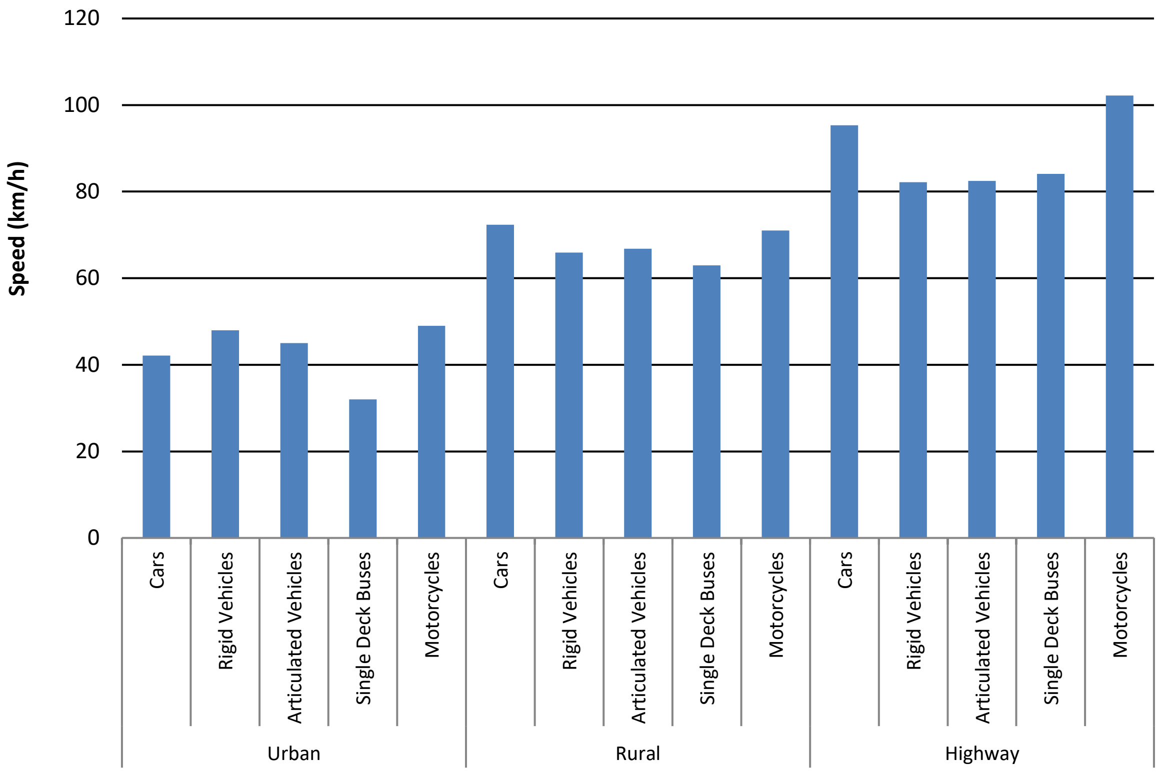


Figure 3.1.4 Vehicle speeds by vehicle type and road type

Annex 3.3.E. Nitrogen excretion values for livestock

Nitrogen excretion rates for all livestock categories included in the national inventory are presented in Table 3.3.E of Annex 3.3. Specific information in relation to the estimation of N excretion from cattle and the partitioning of nitrogen excretion into the proportion contained in urine and dung is discussed as follows.

Nitrogen excretion rates for cattle

Annual nitrogen excretion rates are determined for each cattle category defined in Table 5.3 Chapter 5. Country-specific nitrogen excretion rates are estimated using the Tier 2 approach outlined in section 10.5.2 Chapter 10, Volume 4 of the 2006 IPCC guidelines as follows:

$$N_{ex(T)} = N_{\text{intake}(T)} \bullet (1 - N_{retention(T)}) \qquad \text{Eq 10.31 (2006 IPCC Guidelines)}$$

Where

$N_{ex(T)}$ = annual N excretion rate, kg N animal^{-1} year^{-1}

$N_{\text{intake}(T)}$= annual N intake per head, kg N animal^{-1} year^{-1}

$N_{retention(T)}$= fraction of annual N intake that is retained by the animal per head

The annual N intake by the animal $N_{\text{intake}(T)}$ is calculated based on the dietary assumptions used in the development of Tier 2 emission factors for CH_4 from enteric fermentation and manure management (O'Mara, 2006) as discussed in sections 5.2.1.1 and 5.2.2 utilising equation 10.32, section 10.5.2 Chapter 10, Volume 4 of the 2006 IPCC guidelines. The amount of nitrogen excreted can then be estimated as the difference between the $N_{\text{intake}(T)}$ and $N_{retention(T)}$ (equation 10.33, section 10.5.2 Chapter 10, Volume 4 of the 2006 IPCC guidelines) as follows:

$$Nintake\ (T) = \frac{GE}{18.8} x \frac{CP\%/100}{6.25} \qquad \text{Eq 10.32 (2006 IPCC Guidelines)}$$

Where:

$N_{\text{intake}(T)}$= annual N intake per head, kg N animal^{-1} year^{-1}

GE = gross energy intake of the animal (MJ animal^{-1} day^{-1}) sourced from the Tier 2 model for the estimation of CH_4 emissions from enteric fermentation and manure management (O'Mara, 2006).

18.8 = conversion factor for dietary GE per kg of dry matter, MJ kg^{-1} (O'Mara, 2006)

CP% = percent crude protein in the diet

6.25 = conversion factor from kg dietary protein to kg of dietary N, kg feed protein (kg N)$^{-1}$

The annual N retention by the animal $N_{retention(T)}$ is calculated based on the dietary assumptions used in the development of the Tier 2 emission factors for CH_4 from enteric fermentation and manure management (O'Mara, 2006) as discussed in in sections 5.2.1.1 and 5.2.2. utilising equation 10.33, section 10.5.2 Chapter 10, Volume 4 of the 2006 IPCC guidelines.

$$N_{retention(T)} = \left[\frac{Milk \bullet \left(\frac{Milk\ PR\%}{100} \right)}{6.38} \right] + \left[\frac{WG \bullet \left[268 - \left(\frac{7.03 \bullet NE_g}{WG} \right) \right]}{6.25} \right]$$

Eq 10.33 (2006 IPCC Guidelines)

Where:

$N_{retention(T)}$= fraction of annual N intake that is retained by the animal per head

Milk = milk production, kg animal^{-1} day^{-1} (CSO)

Milk PR % = percent of protein in milk (CSO)

6.38 = conversion from milk protein to milk N, kg Protein (kg N)$^{-1}$

WG = weight gain, kg day^{-1} (O'Mara, 2006)

268 and 7.03 = constants from Equation 3-8 in NRC (1996)

NE_g = net energy for growth, MJ day^{-1} (O'Mara, 2006)

Partitioning of nitrogen excretion from cattle into nitrogen excreted in dung and nitrogen excreted in urine

Once the nitrogen excreted (N_{ex}) is calculated as described in the previous section the proportion of N in both urine (N_{urine}) and dung (N_{dung}) can be determined with the following equation:

$N_{ex(T)} = N_{urine} + N_{dung}$

Where:

$N_{ex(T)}$ = annual N excretion rate, kg N animal^{-1} year^{-1}

N_{urine} = N excreted in urine, kg N animal^{-1} year^{-1}

N_{dung} = N excreted in dung kg N animal^{-1} year^{-1}

For dairy cattle (dairy cows), N_{dung} is estimated based on the proportion of dry matter intake (0.008 kg N per kg dry matter intake) which is excreted as nitrogen in dung (Burke et al., 2008). Dry matter intake values are those used in the development of the Tier 2 emission factors for CH_4 emissions from enteric fermentation and manure management (O'Mara, 2006) as discussed in sections 5.2.1.1 and 5.2.2. N_{urine} is then estimated as the difference between $N_{ex(T)}$ and N_{dung}.

For all other cattle categories, N_{urine} is estimated based on the regression of De Prado et al (2006):

N_{urine} = ((0.1369 x % Nitrogen in diet)+0.262)

The nitrogen content of the diet is estimated based on the dietary assumptions used in the development of the Tier 2 emission factors for CH_4 emissions from enteric fermentation and manure management (O'Mara, 2006) as discussed in sections 5.2.1.1 and 5.2.2. N_{dung} is then estimated as the difference between $N_{ex(T)}$ and N_{urine}.

Relationship between the nitrogen excretion values presented in SI 605 of 2017 and the values used for livestock (excluding cattle) in national inventory estimates

Annex 3.3.F. Input Parameters for the calculation of N_2O Emissions from Agricultural Soils

The input parameters for the calculation of N_2O emissions from agricultural soils are presented in Table 3.3.F.2. Specific information in relation to EF_1 for synthetic nitrogen fertiliser application and EF_3 for urine and dung deposited on grazed pasture by cattle is discussed as follows.

Country-specific emission factors from synthetic nitrogen fertiliser application (EF_1)

The default value for EF_1, (0.006 kg N_2O-N/kg N) the emission factor associated with the application of synthetic nitrogen fertiliser application to agricultural soils does not differentiate between nitrogen fertiliser formulation or rates of application. However numerous scientific studies have found that N_2O emissions from nitrate containing fertilisers tend to be higher than those from urea based fertilisers, particularly in regions which have mild, wet climates and soils with a high organic matter content (Harty et al., 2016).

In Ireland, there are two main types of synthetic fertilisers used, calcium ammonium nitrate (CAN) and urea, with in recent years small quantities of inhibited urea being placed on the market. In 2022, CAN accounted for 75 per cent of total N fertiliser sales with urea and inhibited urea accounting for 15 per cent and 9 per cent of total sales, respectively. As part of the Agricultural Greenhouse Gas Initiative for Ireland (AGRI-I, http://www.agri-i.ie/) funded by the Department of Agriculture, Food and the Marine, two projects were undertaken to develop country-specific N_2O emission factors from synthetic fertiliser nitrogen application disaggregated by fertiliser type and application to grassland and cropland to assess potential mitigation strategies to reduce N_2O emissions from fertiliser nitrogen application (Harty et al., 2016; Roche et al., 2016).

Harty et al (2016) investigated the effect of fertiliser type over a two-year period at three grassland locations covering a range of soil and climatic conditions. The treatments investigated were: CAN, Urea, Urea+NBPT (n-butyl thiophosphoric triamide), Urea+DCD (Dicyandiamide), Urea+NBPT+DCD and a control (zero N). The nitrification inhibitor DCD is a compound that delays the bacterial oxidation of NH_4^+ by impeding the activities of soil-nitrifying bacteria. Thus, by retaining nitrogen in the form of NH_4^+ for longer, the inhibitor reduces losses through denitrification and leaching of nitrate and potentially increase the efficiency of the nitrogen applied. N-butyl thiophosphoric triamide on the other hand is a urease inhibitor and works by inhibiting the hydrolytic action of soil urease, which catalyses the hydrolysis of urea to ammonium carbonate.

Roche et al. (2016) investigated the effect of the same fertiliser types described above, but on arable land. Based on the results of Harty et al (2016) and Roche et al (2016), country-specific emission factors for CAN, Urea and inhibited urea (+NBPT) have been estimated. A weighted emission factor for CAN based on the relative proportion of grassland and arable land (92:8) was then calculated. Table 3.3.F.1 presents the emission factors derived for each product. On the basis of the emission factors presented and weighted according to fertiliser type, the value for EF_1 now used in the national inventory is on average 24 per cent higher (0.0124 kg N_2O-N/kg N) than the default value present for EF_1 in the 2006 IPCC guidelines.

Table 3.3.F.1 Fertiliser type specific emission factors

Fertiliser type	Grassland emission factor	Arable emission factor	Combined Emission factor
		EF_1 kg N_2O-N/ kg N	
CAN	0.0149	0.0035	0.0140
Urea	0.0025	0.0027	0.0025
Urea + NBPT	0.0040	0.0020	0.0040

Country-specific emission factors for urine and dung deposited by grazing cattle ($EF_{3, PRP}$)

The largest inputs of nitrogen to agricultural soils are manure from grazing livestock and synthetic nitrogen fertilisers. Nearly two thirds of cattle manure is excreted directly onto pasture. The form in which nitrogen is excreted influences the extent of the emissions caused. In particular, as the concentration of the nitrogen in an animal's diet increases, the amount of nitrogen excreted in urine increases. In addition, it has also been shown that urine patches are important sources of nitrogen loss in the form of ammonia, N_2O and nitrate leaching. The default emissions factor, EF_3 applies one single value (0.02 kg N_2O-N/kg N) to the total N excreted in urine and dung that may not necessarily reflect country-specific conditions. Additionally, the default emission factor does not take into account soil type, climatic conditions, timing of deposition or excreta form, all of which can influence the magnitude and duration of N_2O emissions (Krol et al 2016).

As part of the Agricultural Greenhouse Gas Initiative for Ireland (AGRI-I, http://www.agri-i.ie/) funded by the Department of Agriculture, Food and the Marine, a project was undertaken to develop country-specific N_2O emission factors from urine and dung and to assess the effect of soil type and season of application on the magnitude of N_2O losses (Krol et al., 2016). Cattle, dung and artificial urine treatments were applied in spring, summer and autumn to three temperate grassland sites with varying soil and weather conditions. Nitrous oxide emissions were measured over a period of 12 months to generate annual N_2O emission factors. Further details of the research are available in Krol et (2016). The results of this study indicate that the mean emission factor for dung is 0.0031 kg N_2O-N/kg N and 0.012 kg N_2O-N/kg N for urine.

The above emission factors are then combined with the values of $N_{ex(T)}$ partitioned into N_{urine} and N_{dung} described in the annex 3.3.E to derive country-specific assessments of N_2O emissions from urine and dung deposition on pasture. The resultant combined implied emission factor of 0.0086 kg N_2O-N/kg N from this analysis is 56 per cent lower than the default emission factor for EF_3.

Annex 3.4

Methodology development and activity Data for LULUCF (IPCC Sector 4)

3.4.A Derivation of Historic Deforestation Areas for LULUCF

There is currently no method to record historic land use change and this is a significant gap in the LULUCF inventory. Ireland has attempted to improve the methodology to track deforestation, in particular, but this has only been implemented for the years 2006 onwards.

There are currently two data sources available to transparently report historic deforestation. However, both methods are limited and are not fully in accordance with IPCC good practice guidance for LULUCF because they do not accurately represent forest area changes, which are consistent with the forest definition (minimum area of 0.1 ha).

3.4.A.1 Tracking Deforestation using CORINE Land Cover Datasets (Approach 3)

Deforestation areas since 1990 have been estimated using Coordination of Information on the Environment, (CORINE) Change in Land Cover (CLC) 1990-2000 and CLC 2000-2006.

3.4.A.1.a Background Information

CORINE, is an EU initiative established in 1985. The CORINE methodology for indicating *Change in Land Cover* (CLC) between 1990 and 2006 is complex (CEC 1993). Computer aided visual interpretation of satellite images (Büttner et al. 2004) was applied in the process of updating the 1990 European Land Cover to 2000 (±1 year) and the Land Cover change detection for the interval of 1990–2000, and 2000-2006 using Landsat MSS and TM satellite images. The smallest unit identified in CLC 2000 is 25 ha, and the minimum width of a linear feature is 100 m. Changes detected in the CORINE CLC were incorporated in CORINE 2000/6 only if the final CORINE polygon met the minimum mapping unit criterion of 25 ha. This means that a newly afforested area can only be detected by CORINE if it is larger than 25 ha. Clearly this is unlikely to accurately represent afforestation or deforestation since 1990, because the average size of newly established private forest parcels is 8 ha, and they are highly disperse and fragmented (Black et al, 2009).

The forest definition used by CORINE Land over (Bossard et al. 2000) is: “Areas occupied by forest and woodlands with a vegetation pattern composed of native or exotic coniferous and/or deciduous trees and which can be used for the production of timber or other forest products. The forest trees are under normal climatic conditions higher than 5 m with a canopy closure of 30 per cent at least”. Codes 311 representing deciduous forests, 312 for coniferous forests and 313 for mixed forests were used to interpret the change in forest area. The class, CLC 324, was excluded from the analysis, based on the assumption that this would represent recently felled/replanted and afforested areas, which are less than 10 years old. CLC 324 areas also include some semi-natural woodlands and scrub colonisation (not defined as forest land in the NFI), including: a) birch scrub on cutaway peatland; b) hazel encroachment in the Burren landscape and gorse colonisation on rough grazing land. This reclassification of land areas without ground truthing is one of our main concerns with the CLC 1990 to 2006 analysis.

Comparison of more recent high resolution datasets and CORINE clearly show that there is a mismatch in land cover classification in Ireland (Black et al., 2009). Therefore, we suggest that the misrepresentation of the CORINE afforested and deforestation area between 1990 and 2006 in Ireland may be associated with:

a) statistical misrepresentation of Irish forest land parcels in CORINE (i.e. low resolution of CORINE – 25 ha);
b) aggregation of classified categories, which may not reflect forest area change. This may be particularly relevant for CLC 324 (transitional woodland and scrub land, which may also include areas subjected to encroachment by hazel on the Burren, birch colonisation of cutaway midland peat and gorse on grazed upland, all of which may not be defined as forest land according the national forest definition.

CORINE classification and resolution problems have been highlighted in other comparative studies across northern Europe (Hazeu and de Wit 2004, Cruickshank and Tomlinson 1996).

3.4.A.1.b Methodology

Despite the above mentioned inappropriateness of CLC for reporting areas under LULUCF in a consistent, representative and accurate manner, this methodology uses the only data currently available to track historic land use change in Ireland.

For this exercise, the following codes were extracted; CLC 311, 312 and 313 to represent forest land area that were present in 1990, but were converted to land cover other that forest in the 2000 and 2006 time series. The resulting polygons were then intersected with a national soils map using ARC GIS to derive a land use change and soil type matrix to the periods 1990 to 2000 and 2000-2006. The resulting forest and soils GIS layers were then sampled using the NFI sample grid as discussed in the following sections below.

3.4.A.2 Sampling approach: NFI grid points and aerial photography (modified IPCC guidelines approach 3)

This sampling approach is a modification of approach 3, where the grids or centroids are sampled using a systematic sampling procedure adopted in the NFI. Note:

- The NFI was not designed to track land use change because the systematic grid (2 x 2 km) sample weighting factor is used to derive total areas statistics in 400 ha of land (i.e. 1 sample point represents 400 ha). For small changes in forest areas, such as deforestation the sampling error is very large. For example if 10 Permanent sample plot (PSP) grid points are identified to be deforested than the total area represented in 4,000 ha with a lower and upper confidence limit of 945 and 7,055 ha, respectively. This represents a sampling error of 76 per cent;
- Another problem with this method is that it does not represent forest area change in a manner that is consistent with the forest area definition (0.1 ha), therefore it conflicts with IPCC guidelines. This is why the NFI afforested areas are statistically adjusted using the IFORIS spatial data to consistently represent afforestation areas (see Chapter 11). However, there is at present no data available to adjust the NFI estimates of deforested land.

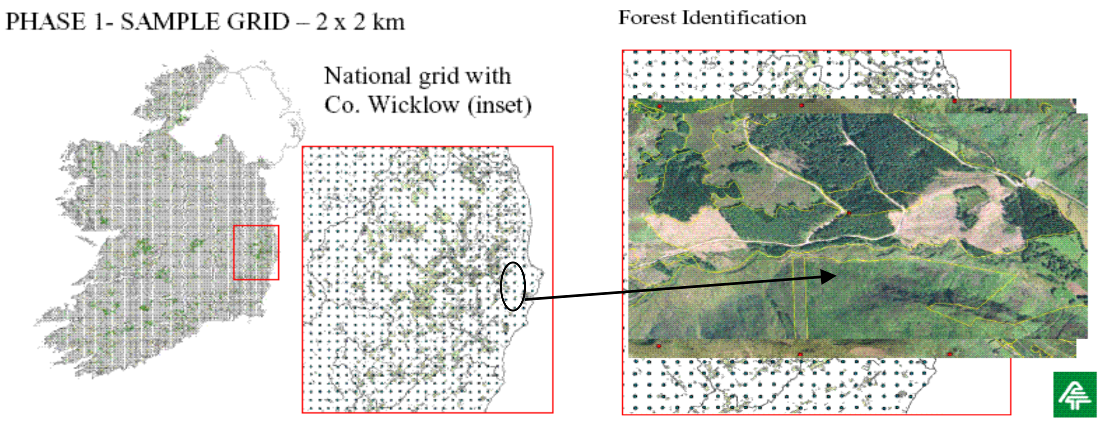


Figure 3.4.A2-1: The NFI systematic sample approach used to classify land use for each permanent sample plot (PSP)

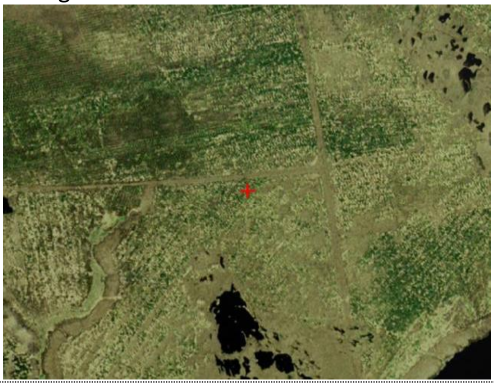
The use of the NFI stratified sample 2x2 km grid of PSP is described in chapters 6. Assessment of ca.18,000 point intersects with aerial photographs from 2000 and 2006 provides the opportunity to assess deforestation for this period. This method identified 15 NFI PSP grid samples which were deemed to be deforested between 2000 and 2006. The current land uses of these previously deforested lands were determined from photo interpretation using the 2006 images. Figure 3.4.A2-1 shows 2 examples of the GIS analysis and photo interpretation.

Assessments of deforestation from 1995 to 2000 were based on a GIS intersection of the 18,000 NFI plots with the FIP95 forest parcel polygon layer. This exercise produced 105 forest parcels which were classified as forest in the FIPS 95 dataset but where classified as non-forest land in the NFI aerial photography interpretation. These 105 polygons were cross-checked with 1995 black and white aerial photographs to verify that they were forests in 1995. However, most of the sampled forest polygons were deemed to not be deforested or were originally other land uses in 1995. This was due to interpretation inconsistencies of photographs and mapping errors in the FIPS95 layer. Only 5 NFI sample points were identified to be deforested between 1995 and 2000.

The final deforestation-land use change-soils matrices for 1995-2000 and 2000-2006 were obtained by intersecting identified deforested PSP points with the national soils map database (Table 2, Figure 3.4.A2-3).

Conversion to Wetlands

Young forest in 2000



EU peat restoration in 2006

Conversion to Grassland

Mature forest in 2000

Grassland in 2006

Conversion to Development

Young forest in 2000

Mushroom factory in 2006

Figure 3.4.A2-2: Examples of NFI PSP (as indicated by the red cross) which were classified forests in 2000 but have since been converted to other land uses in 2006

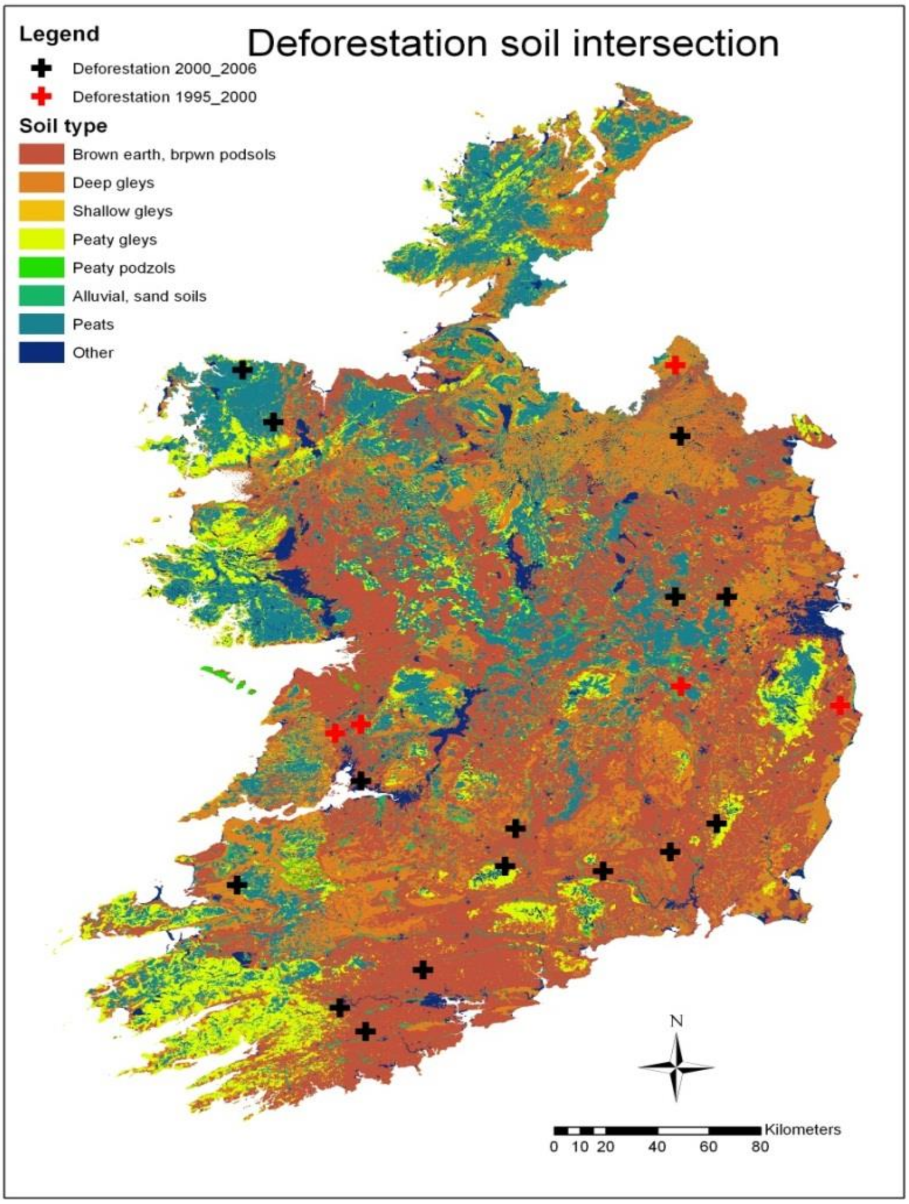


Figure 3.4.A2-3 The Irish soils map showing intersection with NFI PSP plots determined to be deforested between 1995 and 2006

Table 3.4.A3 The new deforestation, land use change and soil type matrix

Period	Source	Land use	Soil category	Area (ha) per year	% for period
1990-1994	**CLC1990-2000**			**20.6**[13]	**100**
		Grassland	Mineral	2.5	12.2
		Grassland	Peat		
		Grassland	Peaty mineral	5.7	27.9
		Settlement	Mineral	10.2	49.4
		Settlement	Peat		
		Settlement	Peaty mineral		
		Wetland	Mineral		
		Wetland	Peat		
		Wetland	Peaty mineral		
		Other	Mineral	2.2	10.5
		Other	Peat		
		Other	Peaty mineral		
1995-1999	**NFI-FIPs 95**			**333.3**[14]	**100**
		Grassland	Mineral	266.7	80
		Grassland	Peat		
		Grassland	Peaty mineral		
		Settlement	Mineral		
		Settlement	Peat		
		Settlement	Peaty mineral		
		Wetland	Mineral		
		Wetland	Peat		
		Wetland	Peaty mineral		
		Other	Mineral	66.6	20
2000-2005	**NFI-2000-2006**			**857.1**[15]	**100**
		Grassland	Mineral	342.8	40
		Grassland	Peat		0
		Grassland	Peaty mineral	57.4	6.7
		Settlement	Mineral	171.4	20
		Settlement	Peat		0
		Settlement	Peaty mineral		0
		Wetland	Mineral	56.6	6.6
		Wetland	Peat	114.0	13.3
		Wetland	Peaty mineral		0
		Other	Mineral	57.4	6.7
		Other	Peat	57.4	6.7
		Other	Peaty mineral		0

[13] The CLC 1990-1994 area was calculated using the values show in table 1a to be, where annual deforestation area 1990-1994 = $\frac{area\_1990 \rightarrow 2000}{10 \times 5} \times 5$

[14] NFI 1995-1999 area was calculated using the values show in table 2a to be, where the annual deforested area 1995-1999 = $\frac{area\_1995 \rightarrow 2000}{6 \times 5} \times 5$

[15] NFI 2000-2005 area was calculated using the values show in table 2b to be, where the annual deforested area 2000-2005 = $\frac{area\_2000 \rightarrow 2006}{7 \times 6} \times 6$

Period	Source	Land use	Soil category	Area (ha) per year	% for period
2006	**Felling licence and land taken out**			**376.44**	**100**
	242.34+134.1	Grassland	Mineral	5.3	1.4
	(LFL+LTO)[16]	Grassland	Peat		0
		Grassland	Peaty mineral	19.7	5.2
		Settlement	Mineral	17.1	4.5
		Settlement	Peat		0
		Settlement	Peaty mineral	0.6	0.2
		Wetland	Mineral		0
		Wetland	Peat	299.9	79.7
		Wetland	Peaty mineral	30.8	8.2
		Other	Mineral	3.1	0.8
		Other	Peat		0
		Other	Peaty mineral		0
2007	**Felling licence and land taken out**			**338.7**	**100**
	174.83+163.9	Grassland	Mineral	0.6	0.2
	(LFL+LTO)[4]	Grassland	Peat	14.5	4.3
		Grassland	Peaty mineral		0
		Settlement	Mineral	4.7	1.4
		Settlement	Peat	0.8	0.3
		Settlement	Peaty mineral		0
		Wetland	Mineral		0
		Wetland	Peat	297.2	87.7
		Wetland	Peaty mineral		0
		Other	Mineral	8.6	2.5
		Other	Peat	12.4	3.6
		Other	Peaty mineral		
2008	**Felling licence and land taken out**			**294.5**	**100**
	26.42+268	Grassland	Mineral	80.2	27.2
	(LFL+LTO)[4]	Grassland	Peat	0.04	0.01
		Grassland	Peaty mineral		0
		Settlement	Mineral	66.4	22.6
		Settlement	Peat		0
		Settlement	Peaty mineral		0
		Wetland	Mineral		0
		Wetland	Peat	24.5	8.3
		Wetland	Peaty mineral	21.2	7.2
		Other	Mineral	100.9	34.3
		Other	Peat		0
		Other	Peaty mineral	1.1	0.4
2009	**Felling licence and land taken out**			**196.9**	**100**
	49.9+147	Grassland	Mineral	5.1	2.6
	(LFL+LTO)[4]	Grassland	Peat		
		Grassland	Peaty mineral		
		Settlement	Mineral	15.4	7.8
		Settlement	Peat	1.5	0.7
		Settlement	Peaty mineral	1.5	0.8
		Wetland	Mineral		0
		Wetland	Peat		0
		Wetland	Peaty mineral		0
		Other	Mineral	121.1	61.5
		Other	Peat	19.9	10.1
		Other	Peaty mineral	32.4	16.4
2010	**Felling licence and land taken out**			**124**	**100**
	26+98	Grassland	Mineral	39.7	39.1
	(LFL+LTO)[4]	Grassland	Peat		
		Grassland	Peaty mineral		

[16] LFL is areas from limited felling licence records and LTO is the areas from lands taken out

Period	Source	Land use	Soil category	Area (ha) per year	% for period
		Settlement	Mineral	7.9	6.3
		Settlement	Peat		0.7
		Settlement	Peaty mineral	47.2	37.9
		Wetland	Mineral		0
		Wetland	Peat	0.5	0.4
		Wetland	Peaty mineral		0
		Other	Mineral	18.5	14.8
		Other	Peat	4.5	3.6
		Other	Peaty mineral	6.1	6.9

3.4.B Calibration of CBM-CFS3

3.4.B.1 Definition of species, productivity index and area matrices

CBM-CFS3 requires aggregated inventory data for pre and post 1990 forest areas based on species cohorts and productivity classes to reflect the different forest management practices in Ireland (see Table 3.4.B.1-1 and 3.4.B.1-2). These are used to define the age class structure and 'state of the forest' for each species and management group in the "Inventory table" in the Simulation database (see section 6.3.3.1.1) when running CBM-CFS3 (Kull et al., 2016). Consideration of the modelling requirements and data sources influences the stratification of areas. It was necessary to group some species into groups (cohorts) and productivity index ranges to ensure that sufficient data was available to construct biomass volume curves and volume increment curves based on data from the NFI (see methodology below). The NFI provided information on forest stands at a plot sample grid resolution of 2 km^2, so this equated to ca 1700-1900 stands over the period 2006-2017. The number of NFI plots imposes a limitation on the number of strata that could be derived for projection, so stratification was limited to species/productivity strata. As a relatively small island with a temperate oceanic climate, Ireland does not have multiple distinct climatic zones making these two variables the most meaningful for stratifying the estate of the forest (i.e. there are no administrative or climatic regions defined in the AIDB (Kull et al., 2016, Grassi et al., 2018). The species cohort strata were also defined to ensure that no new strata can be created in the future (i.e. the strata structure should not change over time).

The final stratification includes:

i. Species cohorts by area including open areas and temporally unstocked lands as separate strata (Table 3.4.B.1-2)
ii. The abundant conifer species cohorts Spruce and Pine were further stratified into productivity classes to reflect different growth rates, thinning interventions and rotation ages.
iii. Species cohorts and productivity classes were then grouped in to 5-year age-class bins, which was used for the initialisation state for all modelling exercises.
iv. For afforestation areas, additional soil type strata were used because soil type effects the changes in SOC following afforestation (Table 3.4.B.1-1). The final inventory tables of species/soil type matrix for FL_FL in 2019 is shown in Table 3.4.B.1-2. The species soil type for afforestation strata since 1960 has over 4800 records, but the species soil strata for afforestation in 2021 is shown in Table 3.4.B.1-3

    The total afforestation area is derived from NFI and the IFORIS (afforestation grant GIS database) and the proportion of species/soil strata are derived from NFI plot data (Table 6.3). The stratification of soil types was based on available SOC data in the national soil database (Black et al., 2014 and SOLUM project). Generalised soil types were grouped in to WRB groups, which have similar SOC values. For example, all brown earths were grouped into the Cambisol group. CBM-CFS3 uses a non-forest SOC value for initialising the slow C pool value in the DOM model. However, the peat (organic soil emissions) component is not currently modelled in CBM-CFS3 so these emissions are applied after the CBM-CFS3 simulations, using tier 2 emission factors. The non-forest mineral SOC value is a function of the mean soil value for a soil stratum on the previous land use. For Ireland, all afforestation of mineral soils occurs on managed or semi natural grasslands. The applied SOC values for grasslands cambisol, gleysol, luvisols and podzols are 92, 87, 76 and 77 t C ha^{-1}, respectively. Peat soils SOC values are set to zero because peat emissions are determined using Tier 2 emission factors.

Table 3.4.B.1-1: A summary of species/soil matrix area showing the percentage of areas for each species soil strata based on the NFI 2022.

	Soil strata (% of total area 2022)					
Species strata	**Peat**	**Cambisols**	**Gleysols**	**Luvisols**	**Podzolic**	**Grand Total**
CB mix	1.5	1.0	2.2	0.0	0.0	4.8
Cmix	7.1	0.6	3.4	0.0	0.3	11.3
FGB	2.2	0.4	2.9	0.2	0.2	5.9
OC	0.9	0.3	1.1	0.0	0.5	2.8
Pine12-20	4.8	0.4	0.0	0.6	0.0	5.9
Pine4-12	2.2	0.0	0.0	0.0	0.0	2.2
SGB	0.0	0.1	1.1	0.0	0.0	1.2
Spruce 13-16	4.4	0.0	0.2	0.2	0.2	5.0
Spruce 17-20	9.7	0.8	1.9	0.4	0.3	13.0
Spruce 24-30	7.5	1.6	9.3	0.0	2.0	20.3
Spruce 4-12	4.9	0.1	0.2	0.0	0.2	5.4
Spruce20-24	12.3	0.7	7.4	0.7	0.9	22.1
Grand Total	57.6	6.2	29.6	2.1	4.5	100.0

Table 3.4.B.1-2: A stratification summary of species cohorts and productivity index classes of FL-FL areas in 2019

Description of strata	Code	Area (ha)	Mean volume ha^{-1}
Conifer mixtures (more than 25% of conifer or broadleaf)	CBmix	21345	271
Conifer broadleaf mixtures (less than 75% of dominant conifer spp)	Cmix	23754	206
Fast growing broadleaves (birch, ash, alder, sycamore etc)	FGB	104050	171
Slow growing broadleaves (oak, beech etc)	SGB	22550	197
Open areas within forest boundaries e.g. roads	forest open area	32265	
Other conifers (except Pine or Spruce)	OC	16527	299
Pine (Lodgepole, Scots pine and others) with a site index of 4-12m*	Pine4-12	16126	159
Pine (Lodgepole, Scots pine and others) based on a site index of 12-20m*	Pine12-20	30981	331
Spruce (Sitka spruce or Norway spruce) based on a site index of 4-12m**	Spruce4-12	41017	251
Spruce (Sitka spruce or Norway spruce) based on a site index of 13-16m**	Spruce13-16	40215	366
Spruce (Sitka spruce or Norway spruce) based on a site index of 17-20m**	Spruce17-20	49382	393
Spruce (Sitka spruce or Norway spruce) based on a site index of 20-24m**	Spruce20-24	70325	471
Spruce (Sitka spruce or Norway spruce) based on a site index of 24-30m**	Spruce24-30	15725	446
Clearfelled areas yet to be replanted	temporarily unstocked	11208	

*Site index (top height at 30 years) based on Lodgepole pine; ** site index (top height at 30 years) based on Sitka spruce (Broad and Lynch, 2006)

Table 3.4.B.1-3: A stratification summary of species cohorts and productivity index classes of afforestation areas in 2022

Year AR	Species/soil	Total area
2022	NF_Cbmix_brw	6.5
2022	NF_Cbmix_brw	6.5
2022	NF_Cbmix_brw	6.5
2022	NF_Cbmix_brw	6.5
2022	NF_Cbmix_gly	13.2
2022	NF_Cbmix_gly	13.2
2022	NF_Cbmix_gly	13.2
2022	NF_Cbmix_gly	13.2
2022	NF_Cbmix_peat	7.9
2022	NF_Cbmix_peat	7.9
2022	NF_Cbmix_peat	7.9
2022	NF_Cbmix_peat	7.9
2022	NF_Cmix_brw	4
2022	NF_Cmix_brw	4
2022	NF_Cmix_brw	4
2022	NF_Cmix_brw	4
2022	NF_Cmix_gly	19.6
2022	NF_Cmix_gly	19.6
2022	NF_Cmix_gly	19.6
2022	NF_Cmix_gly	19.6
2022	NF_Cmix_pdz	1.2
2022	NF_Cmix_pdz	1.2
2022	NF_Cmix_pdz	1.2
2022	NF_Cmix_pdz	1.2
2022	NF_Cmix_peat	35.3
2022	NF_Cmix_peat	35.3
2022	NF_Cmix_peat	35.3
2022	NF_Cmix_peat	35.3
2022	NF_FGB_brw	2
2022	NF_FGB_brw	2
2022	NF_FGB_brw	2
2022	NF_FGB_brw	2
2022	NF_FGB_gly	15
2022	NF_FGB_gly	15
2022	NF_FGB_gly	15
2022	NF_FGB_gly	15
2022	NF_FGB_lvs	0.7
2022	NF_FGB_lvs	0.7
2022	NF_FGB_lvs	0.7
2022	NF_FGB_lvs	0.7
2022	NF_FGB_pdz	0.9
2022	NF_FGB_pdz	0.9
2022	NF_FGB_pdz	0.9
2022	NF_FGB_pdz	0.9
2022	NF_FGB_peat	11.3
2022	NF_FGB_peat	11.3
2022	NF_FGB_peat	11.3
2022	NF_FGB_peat	11.3
2022	NF_OC_brw	1.4
2022	NF_OC_brw	1.4
2022	NF_OC_brw	1.4

2022	NF_OC_brw	1.4
2022	NF_OC_gly	5.5
2022	NF_OC_gly	5.5
2022	NF_OC_gly	5.5
2022	NF_OC_gly	5.5
2022	NF_OC_pdz	2.3
2022	NF_OC_pdz	2.3
2022	NF_OC_pdz	2.3
2022	NF_OC_pdz	2.3
2022	NF_OC_peat	4.4
2022	NF_OC_peat	4.4
2022	NF_OC_peat	4.4
2022	NF_OC_peat	4.4
2022	NF_Pine12-20_brw	3
2022	NF_Pine12-20_brw	3
2022	NF_Pine12-20_brw	3
2022	NF_Pine12-20_brw	3
2022	NF_Pine12-20_lvs	3.8
2022	NF_Pine12-20_lvs	3.8
2022	NF_Pine12-20_lvs	3.8
2022	NF_Pine12-20_lvs	3.8
2022	NF_Pine12-20_peat	23
2022	NF_Pine12-20_peat	23
2022	NF_Pine12-20_peat	23
2022	NF_Pine12-20_peat	23
2022	NF_Pine4-12_peat	9.7
2022	NF_Pine4-12_peat	9.7

Year AR	Species/soil	Total area
2022	NF_Pine4-12_peat	9.7
2022	NF_Pine4-12_peat	9.7
2022	NF_SGB_brw	0.5
2022	NF_SGB_brw	0.5
2022	NF_SGB_brw	0.5
2022	NF_SGB_brw	0.5
2022	NF_SGB_gly	6.2
2022	NF_SGB_gly	6.2
2022	NF_SGB_gly	6.2
2022	NF_SGB_gly	6.2
2022	NF_Spruce13-16_gly	0.9
2022	NF_Spruce13-16_gly	0.9
2022	NF_Spruce13-16_gly	0.9
2022	NF_Spruce13-16_gly	0.9
2022	NF_Spruce13-16_lvs	0.9
2022	NF_Spruce13-16_lvs	0.9
2022	NF_Spruce13-16_lvs	0.9
2022	NF_Spruce13-16_lvs	0.9
2022	NF_Spruce13-16_pdz	0.7
2022	NF_Spruce13-16_pdz	0.7
2022	NF_Spruce13-16_pdz	0.7
2022	NF_Spruce13-16_pdz	0.7
2022	NF_Spruce13-16_peat	19.9
2022	NF_Spruce13-16_peat	19.9
2022	NF_Spruce13-16_peat	19.9
2022	NF_Spruce13-16_peat	19.9
2022	NF_Spruce17-20_brw	4.3
2022	NF_Spruce17-20_brw	4.3
2022	NF_Spruce17-20_brw	4.3

2022	NF_Spruce17-20_brw	4.3
2022	NF_Spruce17-20_gly	8.2
2022	NF_Spruce17-20_gly	8.2
2022	NF_Spruce17-20_gly	8.2
2022	NF_Spruce17-20_gly	8.2
2022	NF_Spruce17-20_lvs	1.6
2022	NF_Spruce17-20_lvs	1.6
2022	NF_Spruce17-20_lvs	1.6
2022	NF_Spruce17-20_lvs	1.6
2022	NF_Spruce17-20_pdz	1.1

Year AR	Species/soil	Total area
2022	NF_Spruce17-20_pdz	1.1
2022	NF_Spruce17-20_pdz	1.1
2022	NF_Spruce17-20_pdz	1.1
2022	NF_Spruce17-20_peat	43.5
2022	NF_Spruce17-20_peat	43.5
2022	NF_Spruce17-20_peat	43.5
2022	NF_Spruce17-20_peat	43.5
2022	NF_Spruce20-24_brw	2.6
2022	NF_Spruce20-24_brw	2.6
2022	NF_Spruce20-24_brw	2.6
2022	NF_Spruce20-24_brw	2.6
2022	NF_Spruce20-24_gly	34.3
2022	NF_Spruce20-24_gly	34.3
2022	NF_Spruce20-24_gly	34.3
2022	NF_Spruce20-24_gly	34.3
2022	NF_Spruce20-24_lvs	4.3
2022	NF_Spruce20-24_lvs	4.3
2022	NF_Spruce20-24_lvs	4.3
2022	NF_Spruce20-24_lvs	4.3
2022	NF_Spruce20-24_pdz	3.7
2022	NF_Spruce20-24_pdz	3.7
2022	NF_Spruce20-24_pdz	3.7
2022	NF_Spruce20-24_pdz	3.7
2022	NF_Spruce20-24_peat	58.4
2022	NF_Spruce20-24_peat	58.4
2022	NF_Spruce20-24_peat	58.4
2022	NF_Spruce20-24_peat	58.4
2022	NF_Spruce24-30_brw	8.4
2022	NF_Spruce24-30_brw	8.4
2022	NF_Spruce24-30_brw	8.4
2022	NF_Spruce24-30_brw	8.4
2022	NF_Spruce24-30_gly	44.6
2022	NF_Spruce24-30_gly	44.6
2022	NF_Spruce24-30_gly	44.6
2022	NF_Spruce24-30_gly	44.6
2022	NF_Spruce24-30_pdz	9.9
2022	NF_Spruce24-30_pdz	9.9
2022	NF_Spruce24-30_pdz	9.9
2022	NF_Spruce24-30_pdz	9.9
2022	NF_Spruce24-30_peat	35.4

Year AR	Species/soil	Total area
2022	NF_Spruce24-30_peat	35.4
2022	NF_Spruce24-30_peat	35.4
2022	NF_Spruce24-30_peat	35.4
2022	NF_Spruce4-12_brw	0.5
2022	NF_Spruce4-12_brw	0.5
2022	NF_Spruce4-12_brw	0.5
2022	NF_Spruce4-12_brw	0.5
2022	NF_Spruce4-12_gly	0.7
2022	NF_Spruce4-12_gly	0.7
2022	NF_Spruce4-12_gly	0.7
2022	NF_Spruce4-12_gly	0.7
2022	NF_Spruce4-12_pdz	0.8
2022	NF_Spruce4-12_pdz	0.8
2022	NF_Spruce4-12_pdz	0.8
2022	NF_Spruce4-12_pdz	0.8
2022	NF_Spruce4-12_peat	21
2022	NF_Spruce4-12_peat	21
2022	NF_Spruce4-12_peat	21
2022	NF_Spruce4-12_peat	21
	Open area	340.6
	Total area	2273

3.4.B.2 Defining silvicultural rules for simulation of management events

CBM-CFS3 requires a set of silvicultural rules to control when thinning and clear fell events can take place based on rotation and the minimum age thinning can take place. This is defined in the disturbance event table in the Simulation database (Kull et al., 2016). Silvicultural rules shown in Table 3.4.B.2-1 were derived from the NFI 2006-2021. The thinning practices are also reflected in the Irish Thinning Protocol published during as part of the National Development Plan 2000-2006 (FDA, 2007).

Table 3.4.B.2-1: Yield class values, minimum clearfell (CF) and thinning (TH) age for corresponding site index categories.

Species	Site index category	YC Range	Min CF age	Thin min age
Spruce	4-12	6-13	50	NA
	12-16	14-18	39	22
	17-20	19-21	34	20
	20-24	22-25	31	18
	24-30	26-30	27	15
Pine	4-12	4-10	46	NA
	12-20	11-14	30	15
SGB			65	25
FGB			38	15
Cmix			40	15
CBmix			40	15
OC			40	15

The maximum forest age suitable for thinning is 5 years lower than the clearfell age

3.4.B.3 Deriving stand level biomass and merchantable volume estimates from NFI data

Single tree biomass values for different components (merchantable, non-merchantable, sapling, foliage, branches, stemwood, bark etc.) were derived based on NFI DBH and H country specific equations for different species (Table 3.4.B.3-1). The carbon fraction of biomass was assumed to be 0.5. Merchantable volume for individual trees was derived using equations used on the NFI (NFI, 2021) and those published by Black (2016)

Scaling from individual trees to stand based estimates required the use of proportional area expansion factors (NFI, 2021). Tree measurements within NFI plots were systematically sampled (see Figure 6.6), so all trees were not measured in a plot. The sampling method, in conjunction with an assumption of homogeneous spatial distribution of diameters within a stand, informs the calculation of a sampling weight or *expansion factor* (EF) which is used to allow for the possibility that some trees on a given plot were not sampled. The expansion factor is inversely proportional to the prior probability that a given tree is included in the sample, based on the diameter class of the tree (Figure 6.6). Each tree in the sample is thus replicated a number of times equal to its expansion factor. For example, the estimated number of trees on a plot with a single sampled tree of greater than 70 mm is $(12.62/3)^2$. Figure 6.6 shows that trees of three diameter classes are only recorded if they are observed within a certain distance from the plot centre. The expansion factor used by the NFI assumes a random distribution for tree diameter in the plot. Because of that assumption, the weight assigned to a tree in the *i*th diameter class is:

$$\frac{R_3^2}{R_i^2} \quad \text{..} \quad (3.4.1)$$

where R_i denotes the radius of the concentric circle associated with the *i* th diameter class.

In practice, the expansion factor, or weight, is used to estimate plot-level features, e.g. basal area. In such calculations, the number of trees of the *i* th diameter class that were not included in the sample is estimated by $\frac{R_3^2}{R_i^2}$ x n_i, where n_i is the number of trees of the *i* th class that are included in the sample. The expansion factor therefore defines the relationship between each included tree and the estimated number of trees of the same class that were not included (Equation 3.4.1).

$$n_{ij} \times EXF_{ij} = \hat{N}_{ij} \text{...} (3.4.2)$$

where n_{ij} _ EXF_{ij} is the product of the expansion factor for the *j* th tree in the *i* th class, and $\check{N}_{ij}$ is the corresponding estimate. In the terminology of the NFI, the RHS of Equation 3.4.2 is the representative tree number. Individual-tree estimates can be aggregated for the entire plot to give stand-level estimates. For example the aboveground biomass carbon of a plot (t C/ha) $GTOTAL_{(AB)}$ of a plot is calculated as:

$$GTOTAL_{(AB)} = \frac{\sum[ABij \times EXFij] \times 20}{1000} \text{...} (3.4.3)$$

where, 20 is the factor used to scale up to 1 ha and 1000 is used to convert kilogrammes of biomass carbon to tonnes.

Table 3.4.B.3-1: Allometric equations used to calculate biomass component for individual trees (kg d.wt tree^{-1})

Similar species are grouped into 6 different cohorts based on available research information (Spruces, Pines, Larches, Other conifers, fast growing broadleaves and slow growing broadleaves). Abbreviations: AB-above ground, TB-total biomass, BB-below ground, FB-foliage, SB-stem (i.e. timber >7cm diameter), L_{HR}= lop and top from harvest residues, DBH diameter at breast height (1.3 m) in cm, H –height in m.

Eq	Function	Range	Equation	Coefficients				r^2	RMSE	Slope	Source
				a	b	c	d				
Spruce											
1	AB	H>4m	$a \times DBH^b + c \times H^d$	0.23	2.12	5 x 10^{-6}	4.99	0.91	0.29	1.01	i, ii
2	AB	H<4m	$a \times H^b \times c$	1.32	1.7	1.38		0.86	0.2	1.1	i, ii
3	TB		$\exp[Ln(a) + b \times Ln(AG)]$	1.02	1.033	0.006		0.91	0.08	1.03	ii, iii
4	BB		TB-AB								
5	FB		$AB \times a + b \times \exp[-c \times AB]$	0.025	0.089	0.0003		0.68	3.4	0.98	i, ii
6	SB		$\exp[Ln(a) + b \times Ln(AG)]$	0.405	1.09			0.99	2.99	1.03	ii, iii
7	L_{HR}		AB-SB								
Pines											
8	AB	H>3.8m	$a \times DBH^b + c \times H^d$	0.07	2.42	0.039	2.51	0.93	0.13	0.94	ii, iii
9	AB	H<3.8m	$a \times H^b$	0.12	3.91			0.95	0.74	0.95	i, ii
10	TB		$\exp[Ln(a) + b \times Ln(AG)]$	1.15	1.01	0.0003		0.96	0.4	1.01	ii, iii
4	BB		TB-AB								
5	FB		$AB \times a + b \times \exp[-c \times AB]$	0.025	0.089	0.003		0.68	3.4	0.98	i, ii
11	SB		$\exp[Ln(a) + b \times Ln(AG)]$	0.71	1.005			0.97	0.27	0.96	ii, iii
7	L_{HR}		AB-SB								
Larch											
12	AB	H>2m	$a \times DBH^b + c \times H^d$	0.11	2.31	0.001	3.29	0.94	0.27	0.94	ii, iii
13	AB	H<2m	$a \times H^b$	0.03	1.91			0.67	0.44	1.2	i, ii
14	TB		$\exp[Ln(a) + b \times Ln(AG)]$	1.43	0.98	0.0003		0.99	0.25	0.99	ii, iii
4	BB		TB-AB								

Eq	Function	Range	Equation	Coefficients				r^2	RMSE	Slope	Source
				a	b	c	d				
5	FB		$AB\times a+b\times\exp[-c\times AB]$	0.025	0.089	0.003		0.68	3.4	0.98	i, ii
15	SB		$\exp[Ln(a)+b\times Ln(AG)]$	0.903	0.972			0.98	0.28	0.96	ii, iii
7	L_{HR}		AB-SB								
Other conifers											
16	AB	H>3.8m	$a\times DBH^{b}+c\times H^{d}$	0.022	2.73	0.19	2.06	0.96	0.46	1.008	ii, iii
17	AB	H<3.8m	$a\times H^{b}\times c$	0.005	1.58	1.12		0.86	0.28	1.02	i, ii
18	TB		$\exp[Ln(a)+b\times Ln(AG)]$	1.59	0.96	0.0006		0.99	0.28	1.005	ii, iii
4	BB		TB-AB								
5	FB		$AB\times a+b\times\exp[-c\times AB]$	0.025	0.089	0.003		0.68	3.4	0.98	i, ii
19	SB		$\exp[Ln(a)+b\times Ln(AG)]$	0.89	0.96			0.98	0.57	1.055	ii, iii
7	L_{HR}		AB-SB								
Fast growing broadleaves											
20	AB	H>3.0m	$a+\left[\frac{b\times DBH^{c}}{DBH^{c}+246872}\right]$	0.08	25000	2.5	246872				iv
21	AB	H<3.0m	$a\times H^{b}$	0.031	1.72			0.84	0.88	0.91	i, ii
22	BB		$\exp(-a+Ln(DBH)+b)$	1.509	0.284						iv
23	FB	DBH>10cm	$a\times(DBH\times10)^{b}$	0.009	1.47			0.96			v
24	FB	DBH<10cm	$AB\times0.3$					0.78	1.2	0.79	i, ii
25	SB	DBH>19cm	$a\times(DBH\times10)^{b}$	0.0002	2.5			0.97			v
26	SB	DBH<9cm	$\frac{AB+BB}{1.4}$								BEF
7	L_{HR}		AB-SB								
Slow growing broadleaves											
20	AB	H>3.0m	$a+\left[\frac{b\times DBH^{c}}{DBH^{c}+246872}\right]$	0.06	25000	2.5	246872				iv

Eq	Function	Range	Equation	Coefficients				r^2	RMSE	Slope	Source
				a	b	c	d				
21	AB	H<3.0m	$a \times H^b$	0.031	1.72			0.84	0.88	0.91	i, ii
22	BB		$\exp(-a + Ln(DBH) + b)$	1.509	0.284						iv
27	FB	DBH>3cm	$a + b \times DBH^c$	0.375	0.0024	2.517		0.90			vi
28	FB	DBH<3cm	$AB \times 0.3$					0.78	1.2	0.79	i, ii
29	SB	DBH>35cm	$a \times DBH^b$	0.0001	2.535			0.97			v
30	SB	DBH<9cm	$\frac{AB + BB}{1.4}$								BEF, vii
7	L_{HR}		AB-SB								

i National research harvested tree database (COFORD funded project CARBiFOR)
ii Black et al., Biomass equations for modelling C dynamics in Irish forests (in prep)
iii Forest Research pulled tree database (Brice Nicholl, NRS, Forest Research, UK)
iv Brown S (2002) . Measuring carbon in forests: current status and future challenges. Environmental Pollution 116: 363-372.
v Johansson, T. Dry matter amounts and increment in 21-to 91-year-old common alder and grey alder some practical implicatons. Canadian Journal of Forest Research 29 1679-1690.
vi Bartelink, H.H., Allometric relationship for biomass and leaf area of beech (Fagus sylvatica L). Annals of Forest Science, 1997. 54: p. 39-50.
vii Black K., Tobin B., Saiz G., Byrne K. & Osborne B. (2004). Improved estimates of biomass expansion factors for Sitka spruce. Irish Forestry 61:50-65.

3.4.B.4 Merchantable volume to biomass equations

CBM-CFS3 uses merchantable stem volume (stump to 7cm diameter) from the NFI plot data as primary input for the determination of biomass components (Figure 3.4.B.4-1, Boudewyn et al., 2007). To derive sufficient data to carry out model calibration, species cohorts (Table 3.4.B.1-1) were further simplified into 5 strata (Table 3.4.B.4-1). The FGB and SGB strata were also combined to solve eq 3.4.4, 3.4.5 and 3.4.6 because there was insufficient data to solve the parameters. Parameters for the FGB/SGB biomass equations were used to define biomass components for the CBmix and Cmix strata, OC model parameters were used for the Cmix stratum biomass components. The CBM-CFS3 default C fraction of 0.5 was used to convert biomass to C. These biomass equations are specified in the AIDB tables during model calibration (Kull et al., 2006, Pilli et al., 2013).

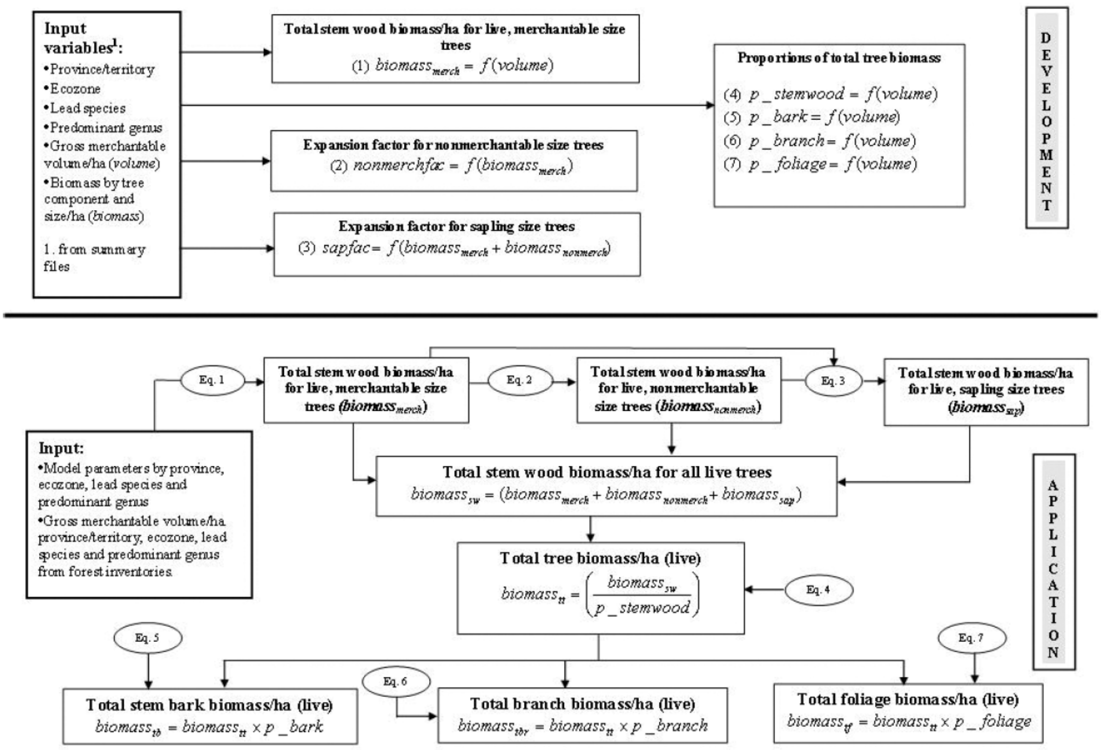


Figure 3.4.B.4-1 Summary flow chart of development and application of biomass component functions in CBM-CFS3, taken from Boudewyn et al (2007). Note that eq. references in the diagram do not match the text below, but the equation names do.

Biomass equations

Merchantable stem biomass (*bm*, t ha^{-1}), which excludes stumps, tops and non-merchantable trees, to volume (v, m^{3}ha^{-1}), equation:

$$bm = a \times v^b \quad (3.4.4)$$

Table 3.4.B.4-1: Parameters derived for conversion of merchantable volume to biomass using Eq 3.4.4.

Cohort	a	b	Vol limit (m3/ha)	Min limit (m3/ha)	RMSE
Spruce	1.583	0.764	1020	3.6	10.4
Pine	0.974	0.899	1120	2.1	17.7
Other conifers	1.406	0.799	950	5.42	11.7
***Fast growing broadleaves (FGB)**	0.384	1.150	650	4.2	42.5
***Slow growing broadleaves (SGB)**	0.384	1.150	650	4.2	42.5

* The FGB and SGB strata were combined to solve the parameters because there was insufficient data to solve the parameters for the individual stratum

A large component of young forests do not contain merchantable timber but still may have a considerable stem biomass that is nonmerchantable (*bn*). The *nonmerchfactor* corrects for this based on the following*:*

$$nonmerchfactor(f) = k + a \times bm^b \quad (3.4.5)$$

$nonmerchfactor = \frac{bnm}{bm}$, where *bnm=bn+bm*

Table 3.4.B.4-2: Parameters conversion for estimation of the non merchantable biomass fraction using Eq 3.4.5.

Cohort	k	a	b	*f* bnlimit	Min limit f	RMSE
Spruce	0.863	0.597	-0.302	3.4	1	0.08
Pine	0.723	1.728	-0.363	4.5	1	0.17
Other conifers	0.906	1.304	-0.536	2.1	1	0.06
***FGB**	0.471	49.165	-0.942	7.2	1.05	32
***SGB**	0.471	49.165	-0.942	7.2	1.05	32

*The FGB and SGB strata were combined to solve the parameters because there was insufficient data to solve the parameters for the individual stratum

Saplings also do not contain timber (DBH >0cm) but still may have a biomass value (bs). The *saplingfactor* corrects for this based on the following*:*

$$saplingfactor(f) = k + a \times bnm^b \quad (3.4.6)$$

$saplingfactor = \frac{bsnm}{bnm}$, where $bsnm = bs + bnm$

Table 3.4.B.4-3: Parameters conversion for estimation of the sapling biomass fraction using Eq 3.4.5.

Cohort	k	a	b	*f* bslimit	RMSE
Spruce	1.0091	0.4289	-0.869	1.6	0.02
Pine	0.9922	0.6071	-0.9240	1.9	0.004
Other conifers	0.9922	0.6071	-0.9240	1.8	0.004
***FGB**	0.9912	100	-1.9745	1.8	0.014
***SGB**	0.9912	100	-1.9745	1.8	0.014

*The FGB and SGB strata were combined to solve the parameters because there was insufficient data to solve the parameters for the individual stratum

Biomass proportion equations

Models to predict the proportional division of total biomass to stemwood, bark, branches and foliage are derived from NFI tree and plot information and biomass algorithms (NIR, 2017) using a multinomial modelling approach. Total aboveground biomass ($Biomass_{ag}$) can be derived from $Biomass_{swt}$ (bm + nonmerchfactor + saplingfactor), and an expansion factor p_stemwood derived from standing merchantable volume (v, m^3 ha^{-1}), based on eq 3.4.7 (Boudewyn et al 2007):

$$Biomass_{ag} = \frac{Biomass_{swt}}{p_{stemwood}} \qquad (3.4.7)$$

and

$$p_{stemwood} = \frac{1}{1+e^{a1+a2\times v+a3\times lv}+e^{b1+b2\times v+b3\times lv}+e^{c1+c2\times v+c3\times lv}} \qquad (3.4.8)$$

Where *lv* is the natural log of volume plus 5, ln(v+5)

The other above ground biomass components (foliage, branch and bark) are estimated using the same proportional equations parameters as shown above, but on a proportional basis so that the total biomass equals the sum of proportions.

Bark biomass (*Biomassbk*) is estimated as follows:

$$Biomass_{bk} = Biomass_{ag} \times p_{bark} \qquad (3.4.9)$$

$$p_{bark} = \frac{e^{a1+a2\times v+a3\times lv}}{1+e^{a1+a2\times v+a3\times lv}+e^{b1+b2\times v+b3\times lv}+e^{c1+c2\times v+c3\times lv}} \qquad (3.4.10)$$

Branch biomass (*Biomassbr*) is estimated as follows:

$$Biomass_{br} = Biomass_{ag} \times p_{branch} \qquad (3.4.11)$$

$$p_{branch} = \frac{e^{b1+b2\times v+b3\times lv}}{1+e^{a1+a2\times v+a3\times lv}+e^{b1+b2\times v+b3\times lv}+e^{c1+c2\times v+c3\times lv}} \qquad (3.4.12)$$

Foliage biomass (*Biomassfl*) is estimated as follows:

$$Biomass_{fl} = Biomass_{ag} \times p_{bark} \qquad (3.4.13)$$

$$p_{foliage} = \frac{e^{c1+c2\times v+c3\times lv}}{1+e^{a1+a2\times v+a3\times lv}+e^{b1+b2\times v+b3\times lv}+e^{c1+c2\times v+c3\times lv}} \qquad (3.4.14)$$

Table 3.4.B.4-4:: Parameters for all biomass fractions. The fractions for FGB and SGB were taken directly from Boudewyn (2007).

Cohort		1	2	3	*Vol* limit	RMSE	
Spruce	a	-1.07341	0.00011	-0.17291	771	Stemwood	0.04
	b	1.06544	0.00027	-0.43841		Bark	0.01
	c	0.65877	0.00028	-0.41110		Branch	0.03
						Foliage	0.02
Pine	a	-2.18146	-0.00004	0.00825	891	Stemwood	0.07
	b	-1.96692	-0.00003	0.01106		Bark	0.11
	c	-1.68418	0.00007	-0.10473		Branch	0.06
						Foliage	0.06
Other conifers	a	-0.94047	0.00015	-0.18072	910	Stemwood	0.08
	b	1.150062	0.00031	-0.50674		Bark	0.11
	c	0.89950	0.00037	-0.57301		Branch	0.04
						Foliage	0.09
FGB	a	-1.6458	0.00002	-0.02892	599	Stemwood	0.09
	b	-0.67447	-0.00034	-0.1204		Bark	0.01
	c	-0.83940	-0.00120	-0.25447		Branch	0.03
						Foliage	0.02
SGB	a	-2.23522	-0.00055	0.00469	1099	Stemwood	0.14
	b	-1.38733	-0.00014	0.04913		Bark	0.06
	c	-2.38719	-0.00063	-0.15867		Branch	0.07
						Foliage	0.12

Belowground biomass was calculated using equations and parameters defined by Li et al. (2003).

3.4.B.5 Standing volume and increment curves

Current annual increment (CAI) curves for the species cohort strata were parametrised using merchantable volume (under bark) data from the 2006-2017 NFI cycles (Table 3.4.B.5.1). A modified Chapman-Richards growth function was used:

$$CAI = a \times exp^{-b \times age} \times 1 - exp^{(-b \times age)^{c-1}} \qquad (3.4.15)$$

Table 3.4.B.5.1: Solved parameters for CAI of different species cohorts

		Parameter	
Cohort	**a**	**b**	**c**
CBmix	69.654	0.027	2.922
Cmix	114.533	0.032	3.670
FGB	85.532	0.071	5.001
OC	155.663	0.036	4.217
Pine4-12	149.682	0.033	6.821
Pine12-20	147.517	0.038	4.525
SGB	47.157	0.022	3.057
Spruce4-12	142.815	0.034	6.509
Spruce13-16	330.124	0.038	5.604
Spruce17-20	292.059	0.057	5.783
Spruce20-24	393.734	0.075	6.525
Spruce24-30	628.315	0.111	9.029

CBM-CFS3 also uses standing volume curves during the model initialisation of DOM pools under forest management. Standing volume curves were derived for the same cohorts using a standing volume Chapman-Richards function based on the NFI data (Table 3.4.B.5.2):

$$CAI = a \times 1 - exp^{(-b \times age)^{c}} \quad (3.4.16)$$

Table 3.4.B.5.2: Solved parameters for standing volume of different species cohorts

		Parameter	
Cohort	**a**	**b**	**c**
CBmix	367.393	0.037	1.784
Cmix	330.955	0.053	2.488
FGB	631.321	0.003	0.814
OC	890.057	0.004	0.790
Pine4-12	215.211	0.078	5.214
Pine12-20	384.23	0.081	5.784
SGB	324.666	0.046	3.532
Spruce4-12	270.545	0.094	21.86
Spruce13-16	555.356	0.053	5.247
Spruce17-20	763.412	0.063	5.439
Spruce20-24	536.339	0.156	15.956
Spruce24-30	560.118	0.174	13.467

3.4.B.6 Turnover and transfers rates of C pools

Table 3.4.B.6.1 Biomass turnover and litterfall transfer rates. AG=aboveground, BG=belowground, SW=softwood, HW=hardwood.

CBM-CFS3 pool	Turnover rates (%C yr^{-1})	DOM pool receiving turnover	Litterfall transfers (% transferred to DOM pool)
Merchantable stem (SW,HW)[a]	1	Snag stems	100
Other wood (HW, SW)[b]	4	Snag branches	25
		AG fast	75
Foliage (SW)[c]	15	AG very fast	100
Foliage (HW)[b]	95	AG very fast	100
Fine roots (HW,SW)[d]	64.1	AG very fast	50
		BG very fast	50
Coarse roots (HW,SW)[d]	2	AG fast	50
		BG fast	50

[a] Derived form NFI 2012-2017; [b]Kurz et al. (1992) [c]Tobin et al., 2007; [d] Li et al. (2003)

3.4.B.7 Disturbance matrices

Table 3.4.B.7.1: The Disturbance matrix for thinning (25%) showing C transfers and emissions

From \ to	Softwood merch	Softwood foliage	Softwood others	Softwood sub-merch	Softwood coarse roots	Softwood fine roots	Hardwood merch	Hardwood foliage	Hardwood others	Hardwood sub-merch	Hardwood coarse roots	Hardwood fine roots	Above Ground Very Fast soil C	Below Ground Very Fast soil C	Above Ground Fast soil C	Below Ground Fast soil C	Medium soil C	Above Ground Slow soil C	Below Ground Slow soil C	Softwood Stem Snag	Softwood Branch Snag	Hardwood Stem Snag	Hardwood Branch Snag	Black C	Peat	Em. CO2	Em. CH4	Em. CO	Em. N2O	Products
Softwood merchantable	0.75																			0.025										0.23
Softwood foliage		0.75											0.225													0.03				
Softwood others			0.75																	0.25										
Softwood sub-merch				0.75																	0.25									
Softwood coarse roots					0.75										0.125	0.125														
Softwood fine roots						0.75								0.125	0.125															
Hardwood merchantable							0.75													0.025										0.23
Hardwood foliage								0.75					0.25																	
Hardwood others									0.75														0.25							
Hardwood sub-merch										0.75												0.25								
Hardwood coarse roots											0.75				0.125	0.125														
Hardwood fine roots												0.75	0.125	0.125																
Above Ground Very Fast soil C													1																	
Below Ground Very Fast soil C														1																
Above Ground Fast soil C															1															
Below Ground Fast soil C																1														
Medium soil C																	1													
Above Ground Slow soil C																		1												
Below Ground Slow soil C																			1											
Softwood Stem Snag																				1										
Softwood Branch Snag																					1									
Hardwood Stem Snag																						1								
Hardwood Branch Snag																							1							
Black C																								1						
Peat																									1					

Table 3.4.B.7.2: The Disturbance matrix for clearfells showing C transfers and emissions

From \ to	Softwood merch.	Softwood foliage	Softwood others	Softwood sub-merch	Softwood coarse roots	Softwood fine roots	Hardwood merch.	Hardwood foliage	Hardwood others	Hardwood sub-merch	Hardwood coarse roots	Hardwood fine roots	Above Ground Very Fast soil C	Below Ground Very Fast soil C	Above Ground Fast soil C	Below Ground Fast soil C	Medium soil C	Above Ground Slow soil C	Below Ground Slow soil C	Softwood Stem Snag	Softwood Branch Snag	Hardwood Stem Snag	Hardwood Branch Snag	Black C	Peat	Em. CO_2	Em. CH_4	Em. CO	Em. N_2O	Products
Softwood merchantable																				0.03										0.97
Softwood foliage													0.9													0.10				
Softwood others															0.7								0.3							
Softwood sub-merch															0.7								0.3							
Softwood coarse roots															0.5	0.5														
Softwood fine roots													0.5	0.5																
Hardwood merchantable																						0.10								0.90
Hardwood foliage													0.9													0.10				
Hardwood others															0.7								0.3							
Hardwood sub-merch															0.7								0.3							
Hardwood coarse roots															0.5	0.5														
Hardwood fine roots													0.5	0.5																
Above Ground Very Fast soil C													1																	
Below Ground Very Fast soil C														1																
Above Ground Fast soil C															1															
Below Ground Fast soil C																1														
Medium soil C																	1													
Above Ground Slow soil C																		1												
Below Ground Slow soil C																			1											
Softwood Stem Snag																				1										
Softwood Branch Snag																					1									
Hardwood Stem Snag																						1								
Hardwood Branch Snag																							1							
Black C																								1						
Peat																									1					

Table 3.4.B.7.3: The Disturbance matrix for afforestation showing C transfers and emissions

From \ to	Softwood merch	Softwood foliage	Softwood others	Softwood sub-merch	Softwood coarse roots	Softwood fine roots	Hardwood merch	Hardwood foliage	Hardwood others	Hardwood sub-merch	Hardwood coarse roots	Hardwood fine roots	Above Ground Very Fast soil C	Below Ground Very Fast soil C	Above Ground Fast soil C	Below Ground Fast soil C	Medium soil C	Above Ground Slow soil C	Below Ground Slow soil C	Softwood Stem Snag	Softwood Branch Snag	Hardwood Stem Snag	Hardwood Branch Snag	Black C	Peat	Em. CO2	Em. CH4	Em.CO	Em. N2O	Products
Softwood merchantable	1																													
Softwood foliage		1																												
Softwood others			1																											
Softwood sub-merch				1																										
Softwood coarse roots					1																									
Softwood fine roots						1																								
Hardwood merchantable							1																							
Hardwood foliage								1																						
Hardwood others									1																					
Hardwood sub-merch										1																				
Hardwood coarse roots											1																			
Hardwood fine roots												1																		
Above Ground Very Fast soil C													1																	
Below Ground Very Fast soil C														1																
Above Ground Fast soil C															1															
Below Ground Fast soil C																1														
Medium soil C																	1													
Above Ground Slow soil C																		1												
Below Ground Slow soil C																			1											
Softwood Stem Snag																				1										
Softwood Branch Snag																					1									
Hardwood Stem Snag																						1								
Hardwood Branch Snag																							1							
Black C																								1						
Peat																									1					

3.4.B.8 Transitions between L-FL and FL-FL

CBM was set up to estimate CSCs for all afforestation since 1960 in order to construct an historic L_FL time series using a 30-year transition period to FL_FL. The software automatically tracks afforestation areas and associated C stocks and transfers the information to the FL-FL category. Table 3.4B8-1 shows historical afforestation and deforestation rates and the relationship between L-FL and FL-FL areas

Table 3.4.B.7.3: Afforestation and deforestation data used to derive the relationship between L-FL and FL-FL and how areas are transitioned to each category using the 30 year period

Year	Afforestion	Defor FL-FL	Defor L-L-FL	FL-FL	L-FL
	kha/yr	kha/yr		kha	kha
1960	10.359				
1961	9.644				
1962	9.389				
1963	9.611				
1964	9.196				
1965	8.763				
1966	7.209				
1967	8.483				
1968	8.151				
1969	8.164				
1970	8.086				
1971	8.386				
1972	9.381				
1973	9.697				
1974	9.328				
1975	9.178				
1976	8.559				
1977	8.334				
1978	8.253				
1979	7.722				
1980	6.190				
1981	6.374				
1982	6.514				
1983	6.025				
1984	5.665				
1985	5.389				
1986	7.248				
1987	8.610				
1988	11.707				
1989	15.126				
1990	15.817	0.021	0.000	226.331	254.743
1991	19.147	0.021	0.000	239.999	260.202
Year	Afforestion	Defor FL-FL	Defor L-L-FL	FL-FL	L-FL
	kha/yr	kha/yr		kha	kha
1992	16.699	0.021	0.000	247.175	269.704
1993	15.998	0.021	0.000	255.842	277.014
1994	19.459	0.021	0.000	268.894	283.401
1995	23.710	0.333	0.000	282.008	293.664
1996	20.981	0.333	0.000	287.709	308.610
1997	11.434	0.333	0.000	285.039	322.382
1998	12.928	0.333	0.000	294.683	325.332
1999	12.668	0.333	0.000	302.240	330.109
2000	15.695	0.857	0.000	312.575	334.613
2001	15.465	0.857	0.000	319.574	342.222
2002	15.054	0.857	0.000	326.692	349.301
2003	9.097	0.857	0.000	329.259	354.974
2004	9.739	0.857	0.000	338.741	354.374
2005	10.096	0.857	0.000	347.569	354.785
2006	8.037	2.000	0.000	352.688	355.703
2007	7.175	1.600	0.000	358.785	355.181
2008	6.249	2.000	0.000	364.193	354.022
2009	6.648	0.800	0.000	372.044	352.018
2010	8.314	0.800	0.000	378.509	353.068

2011	6.653	1.600	0.000	383.283	353.347
2012	6.652	0.000	0.800	389.797	352.685
2013	6.252	1.600	0.000	394.222	352.912
2014	6.156	0.000	0.400	399.887	353.003
2015	6.293	0.400	0.400	404.876	353.507
2016	6.500	0.400	0.400	411.724	352.359
2017	5.536	0.400	0.000	419.534	349.285
2018	4.025	1.200	0.000	430.041	341.603
2019	3.550	0.400	0.000	444.767	330.027
2020	2.434	0.800	0.000	459.784	316.644
2021	2.016	0.000	0.000	478.931	299.514
2022	2.273	0.160	0.021	495.469	285.067

3.4.C Description of the FORCARB model

The FORCARB model is used to calculate CSC for the historic time series from 1990 to 2006. This is then adjusted (Figure 3.4.C.1-1) to ensure a time series consistency. The FORCARB model uses a similar C flow modelling approach as described for CARBWARE (NIR, 2017), but the main difference is that the growth, harvest and mortality is derived from stand level British Forestry Commission (BFC) yield tables as described by Black et al. (2012). The breakdown of species distributions was derived from an intersection of NFI and Coillte sub-compartments as described by Black et al. (2012). Species were grouped into cohorts and a representative species table was selected from the BFC yield tables to derive stand variables such as DBH, stocking etc (Table 3.4.C-1).

Table 3.4.C-1 Breakdown of species used in the pre-1990 and post-1990 forest categories

Cohort	**Species table**	**Proportion**
Spruce	Sitka spruce	0.593
Pine	Lodgepole pine	0.307
Larch	Japanese Larch	0.081
FGB	Sycamore, Ash, Birch	0.004
SGB	Beech	0.016

The yield class categories, silviculture and rotation age for each species within the pre-1990 and post-1990 categories for the period 1990-1999 were derived from the FIPS 95 dataset, modified from Gallagher et al, (2004, see Table 3.4.C-2). The matrix was modified for the period 2000-2012 using NFI and Coillte sub-compartment information as described by Black et al, 2012 (Table 6.6)

The FORCARB growth model describes gains and losses in biomass pools on mean tree-level allometric functions (DBH and height, Annex 3.4.B.3) and stand attributes (stocking) for representative species, according to the BFC yield models (Edwards and Christy 1981, Black et al., 2012). Stand attributes, such as age, mean DBH, top height, stocking and timber harvested, for five species cohorts (spruce, larch, pine, slow growing and fast growing broadleaves), were used as inputs for the calculation of cumulative stand biomass using species-specific allometric relationships (as described for CARBWARE models above). Harvest, thinning's and stock changes associated with mortality are specified in the static yield class tables (Edwards and Christy 1981, Black et al., 2012).

A modified expo-linear growth function (Monteith, 2000) was used to more accurately simulate biomass during the early years of the rotation and interpolate growth over time, since static models provide data at 5 year intervals and do not consider growth of young forest (<10 years old).

Table 3.4.C-2 Yield class, silviculture and rotation criteria selected for periods 1990-1999 and 2000-2012

Species cohort	Yield class	Proportion of cohort	Silviculture	Rotation
		Period :1990-1999 (Source FIPS 95)		
Spruce	10	0.37	No thinning	MMAI
	16	0.26	No thinning	MMAI
	20	0.20	Thin	MMAI less 20%
	24	0.17	Thin	MMAI less 20%
Pines	10	1.00	Thin	MMAI
Larch	10	1.00	Thin	MMAI
FGB	6	1.00	Thin	MMAI
SBG	6	1.00	Thin	MMAI
		Period :2000-2012 (Source NFI-Coillte intersect)		
Spruce	10	0.37	No thinning	MMAI
	16	0.13	No thinning	MMAI
	20	0.20	Thin	MMAI less 20%
	24	0.17	Thin	MMAI less 20%
	16	0.13	No thinning	MMAI less 30%
Pines	10	0.30	No thinning	MMAI
	10	0.80	No thinning	30% less MMAI
Larch	10	1.00	Thin	MMAI
FGB	6	1.00	Thin	MMAI
SBG	6	1.00	Thin	MMAI

MMAI is maximum mean annual increment, which determines the age of clearfell.

Stand biomass (*St*) was expressed as:

$$St = Mt\left[\frac{1-e^{-k_s(k_t - t)}}{1-e^{-k_s k_t t}}\right] \qquad (3.4.17)$$

where:

$$Mt = \frac{Cm}{Rm}\ln\left[1+\frac{Co}{Cm}e^{Rmt}\right] \qquad (3.4.18)$$

where:

Mt is Monteith's function, *Cm* is maximum growth rate, *C*o is initial absolute growth rate and *R*m is the initial relative growth rate and *t* is time (years). Parameters *Cm, Rm, Co,* k_s and k_t were fitted using the least squares optimisation method to estimated stand biomass values.

The annual increment in above or below ground biomass for any given year was then calculated as:

$$\Delta C_b = St_{n+1} - St_n \qquad (3.4.19)$$

The same C allocation models described for the CARBWARE models were applied to simulate the biomass gains and losses and the transfer of C between pools (see NIR, 2017). The resulting static tables with carbon gains, losses for biomass, net litter, deadwood pools and harvest volume were used to derive estimates of CSC from areas and age class distributions for reporting in categories *4.A.1 Forest Land Remaining Forest Land (see* section *6.3.4, Ch 6).*

For *4.A.1* For the *Forest Land Remaining Forest Land* category, age class distributions were initially derived from afforestation data before 1990 and felled/restocked areas. The age class distributions were then adjusted using optimisation procedures using the prescribed total harvest volume for each species cohort. The age class distributions were validated against data obtained age class distributions for 1998, 2006 and 2012 (section 6.3.4). The FORCARB model was initially run to determine net emissions/removals in pools for the entire time series. Since the initial age class distribution in 1990 and changes in age class could not be determined from the FIPS 95 data, age class was modelled using a partial least squares optimisation based on total harvest volume (EUROSTAT harvest volume). This optimisation essentially adjusts the age class distribution until the least difference between EUROSTAT and modelled FORCARB harvests is obtained (i.e. the minimum RMSE is obtained after at least 100 iterations). The optimisation procedure was initially performed on the 1990 data set, followed by repeated optimisation procedures in the following years. The age class distribution for 1990 (blue histograms) was based on an incomplete Coillte inventory for 1986 (Black et al., 2012, Figure 3.4.C-1). Figure 3.4.C-1 also shows the posterior age-class distribution (red histograms) following harvest optimisation for the year 1990. To ensure that the derived FORCARB age-class distributions over the entire time series were realistic, validations were made against independent age class data for 1998, 2006 and 2012 data (Black et al, 2012, Figure 3.4.C-1).

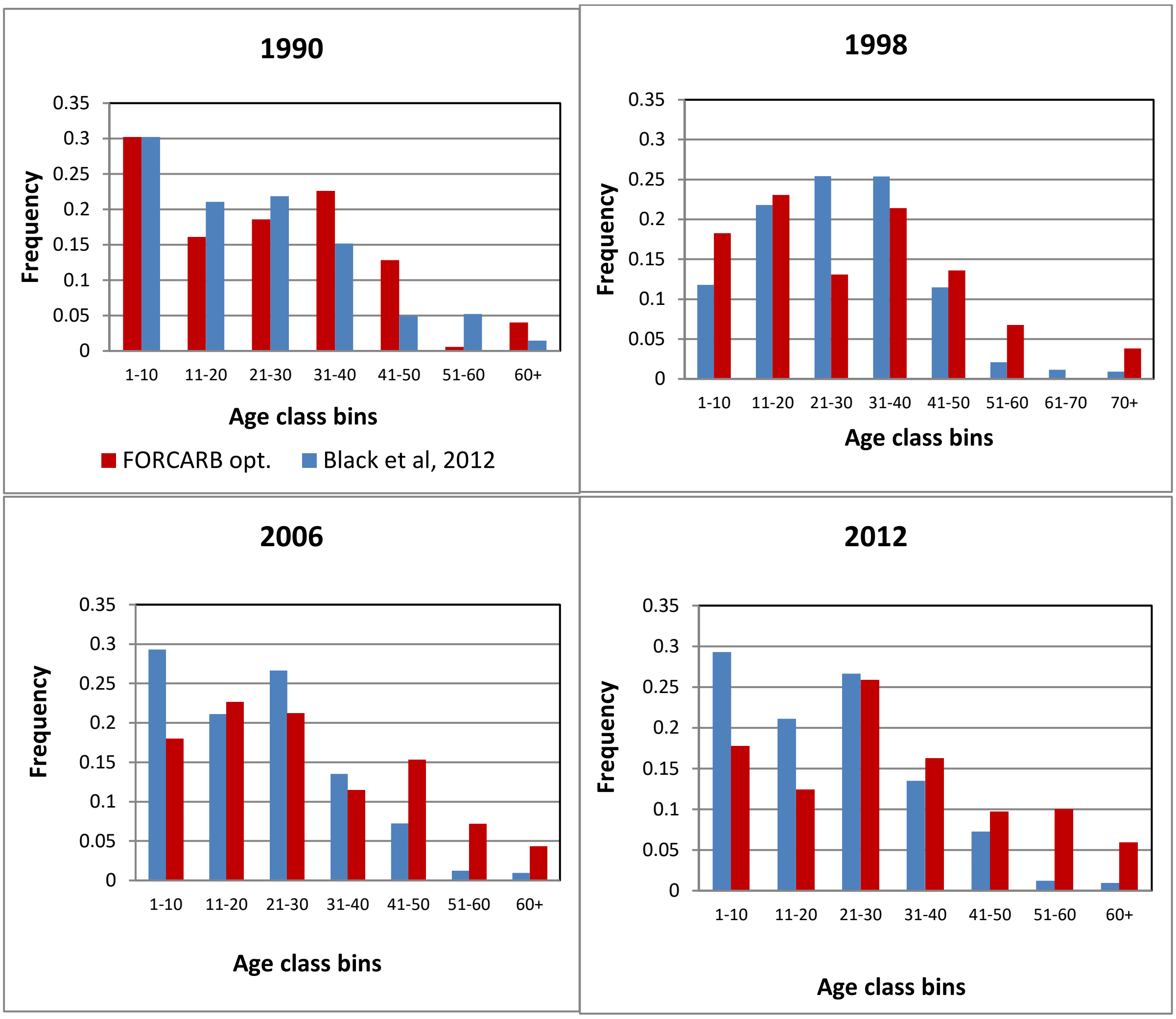


Figure 3.4.C-1 Validation of optimised age-class distributions

3.4.C.1 Time Series Adjustment of Living Biomass and DOM Pools

To ensure that there is no bias introduced in estimates over the time series due to the use of the different models, the 1990 to 2005 FORCARB series was adjusted (Figure 3.4.C.1-1) and rescaled using tier 1 2006 IPCC guidelines time series overlap approaches (Volume 1, Chapter 5):

a) Living biomass gains (*LBgian*, kt C) from the 2006 to 2012 time series for the CBM-CFS3 and FORCARB model outputs were compared. The ratio (2.19) of the total CBM-CFS3 and FORCARB LBgain values for 2006-2012 was used to adjust the time series:

$$LB\ gain_{adj} = LB\ gain_{ini.} \times 2.10 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (eq\ 3.4.20)$$

where, *LBgain*$_{adj}$ is the adjusted living biomass gain value and *LBgain*$_{ini}$ is the initial FORCARB estimate. This method is consistent with eq 5.1 Chapter 5, Volume 1 2006 IPCC guidelines.

b) The adjusted biomass losses (*LBloss*) were scaled using the ratio of living biomass gains to living biomass losses, derived for each year in the 1990-2006 time series. For example the adjustment for 1990 is:

$$LB\ loss_{adj(1990)} = LBgain_{adj(1990)} \times \frac{LB\ loss_{ini(1990)}}{LBgain_{ini(1990)}} \ldots\ldots\ldots\ldots\ldots (eq\ 3.4.21)$$

c) For dead organic matter (DOM), the ratio (1.06) of the average CBM-CFS3 to average FORCARB values for 2007-2012 was used to adjust the time series:

$$DOM_{adj} = DOM_{ini.} \times 1.06 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (eq\ 3.4.22)$$

d) There were no adjustments to the organic soil EF, since approached are identical.

e) The mineral soil CSC changes for the time series 1990-2005 was estimated using the average emission factor (-0.0108 tC/ha) for mineral soils based on CBM-CFS3 soil CSC for the period 2006-2017.

Figure 3.4.C.1-1 shows the initial FORCARB estimates (blue symbols) and the time series adjustment as (red symbols) reported in the CRF table 4.A.1 and Table 6.7. Both time series show the same trend but the adjusted values show a higher net removal of CO_2. This is due to fundamental differences in the model input variables and the spatial scale at with the FORCARB and CBM-CFS3 models operate. There are also known underestimated biases in the FORCARB model introduced when BFC yield tables are used. These are introduced by:

a) Use of prescribed thinning cycles and clearfell regimes which do not occur in practice. The CBM-CFS3 model imposes harvest when this is indicated in the NFI or felling licence records, as this gives a clear indication that the land owner intends to harvest a site. Also, rotation ages as prescribed in the BFC are generally higher that those imposed under current management practice (Black et al., 2007; 2012);

b) Predefined stocking rates in the FORCARB model, which are generally under estimated, when compared to the real situation as evident from NFI data and national research (Black et al., 2007). This would result in an underestimation of LBgains when the FORCARB model is run;

c) Differences in the current annual increment when BFC yield table (as used in FORCARB) are compared to NFI (CBM-CFS3) and national research information;

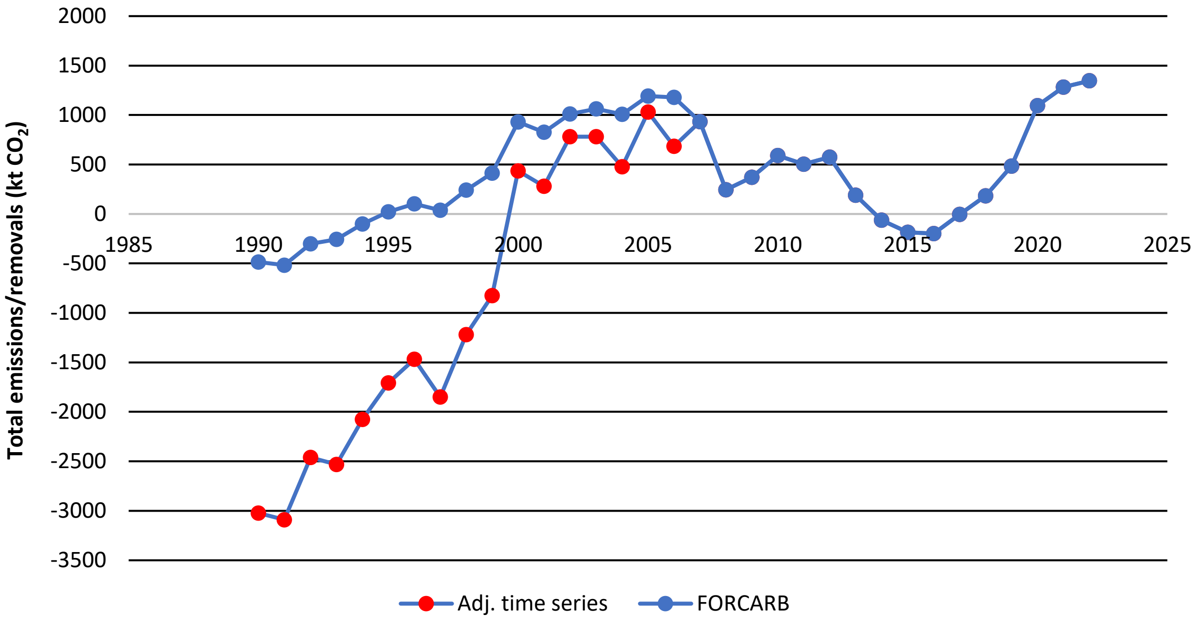


Figure 3.4.C.1-1 Adjusted time series for forest category 4.A.1

d) The CBM-CFS3 model provides a more accurate assessment of increment in younger stand than the FORCARB, BFC based model;

e) Although the average yield class of the major species, Sitka spruce is similar for both the FORCARB and CBM-CFS3 based estimates. The median is higher for the NFI based assessment, which would also result in a higher increment when compared to the FORCARB model.

3.4.D.1 Detailed Land Use Change Matrix

Table 3.4.D-1 Forest land Matrix ('000 ha)

Year	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Forest remaining Forest	465.26	481.05	500.18	516.86	532.84	551.96	575.34	595.99	607.09	619.68	631.49	646.33	660.94	675.14	683.38	692.26	700.35
Grassland to Forest	6.39	9.03	7.88	9.94	8.13	9.22	9.63	4.37	5.29	7.70	7.71	5.50	5.57	3.46	5.37	5.85	6.03
Wetland (unmanaged) to Forest	9.43	10.12	8.82	6.06	11.33	14.49	11.35	7.06	7.64	4.97	7.98	9.97	9.48	5.64	4.37	4.25	2.01
Wetland (managed) to Forest	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Converted to Grassland (managed)	0.01	0.01	0.01	0.01	0.01	0.27	0.27	0.27	0.27	0.27	0.40	0.40	0.40	0.40	0.40	0.40	NO
Converted to Wetlands (managed)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	0.17	0.17	0.17	0.17	0.17	0.17	0.00
Converted to Wetlands (unmanaged)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Converted to Settlements	0.01	0.01	0.01	0.01	0.01	NO	NO	NO	NO	NO	0.17	0.17	0.17	0.17	0.17	0.17	0.40
Converted to Other land	0.00	0.00	0.00	0.00	0.00	0.07	0.07	0.07	0.07	0.07	0.11	0.11	0.11	0.11	0.11	0.11	1.60
Initial area	465.28	481.07	500.20	516.88	532.86	552.30	575.67	596.32	607.42	620.01	632.35	647.19	661.80	675.99	684.23	693.11	702.35
Final area	481.07	500.20	516.88	532.86	552.30	575.67	596.32	607.42	620.01	632.35	647.19	661.80	675.99	684.23	693.11	702.35	708.39
Year	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	
Forest remaining Forest	706.79	711.97	717.41	723.26	729.98	735.83	740.88	746.73	752.09	757.18	763.28	767.62	771.24	773.99	776.43	778.26	
Grassland to Forest	5.49	6.25	5.06	7.52	5.70	6.14	5.84	5.47	5.39	5.57	5.11	3.16	3.19	2.14	1.86	1.77	
Wetland (unmanaged) to Forest	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	
Wetland (managed) to Forest	1.69	NO	1.58	0.79	0.95	0.51	0.42	0.68	0.90	0.93	0.43	0.86	0.35	0.30	0.16	0.50	
Converted to Grassland (managed)	NO	0.40	0.40	0.80	1.20	NO	1.20	NO	NO	0.40	0.40	0.40	0.40	0.80	NO	0.02	
Converted to Wetlands (managed)	0.40	NO	0.40	NO	0.40	NO	0.40	0.40	0.80	0.40	NO	NO	NO	NO	NO	0.00	
Converted to Wetlands (unmanaged)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	
Converted to Settlements	1.20	1.20	NO	NO	NO	0.80	NO	NO	NO	0.40	NO	0.80	NO	NO	NO	0.16	
Converted to Other land	NO	0.40	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	
Initial area	708.39	713.97	718.21	724.06	731.58	736.63	742.48	747.13	752.89	758.38	763.68	768.82	771.64	774.79	776.43	778.44	
Final area	713.97	718.21	724.06	731.58	736.63	742.48	747.13	752.89	758.38	763.68	768.82	771.64	774.79	776.43	778.44	780.54	

Table 3.4.D-2 Cropland Matrix ('000 ha)

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Cropland Remaining Cropland	749.07	749.05	749.02	749.00	748.96	748.92	748.87	748.82	748.77	748.70	748.66	748.59	748.53	748.44	748.35	748.26	748.16
Cropland to Settlement	0.03	0.02	0.03	0.02	0.04	0.04	0.05	0.05	0.06	0.06	0.05	0.07	0.06	0.08	0.09	0.10	0.10
Initial Area	749.10	749.07	749.05	749.02	749.00	748.96	748.92	748.87	748.82	748.77	748.70	748.66	748.59	748.53	748.44	748.35	748.26
Final Area	749.07	749.05	749.02	749.00	748.96	748.92	748.87	748.82	748.77	748.70	748.66	748.59	748.53	748.44	748.35	748.26	748.16
Year	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Cropland Remaining Cropland	748.12	748.11	748.04	747.96	747.94	747.93	747.91	747.89	747.87	747.85	747.82	747.79	747.75	747.71	747.68	747.63	748.12
Cropland to Settlement	0.04	0.00	0.08	0.08	0.02	0.01	0.02	0.02	0.02	0.02	0.03	0.03	0.04	0.04	0.04	0.04	0.04
Initial Area	748.16	748.12	748.11	748.04	747.96	747.94	747.93	747.91	747.89	747.87	747.85	747.82	747.79	747.75	747.71	747.68	748.16
Final Area	748.12	748.11	748.04	747.96	747.94	747.93	747.91	747.89	747.87	747.85	747.82	747.79	747.75	747.71	747.68	747.63	748.12

Table 3.4.D-3 Grassland Matrix ('000 ha)

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Grassland Remaining Grassland	4416.80	4407.51	4399.31	4389.11	4380.58	4370.92	4361.04	4356.37	4350.72	4342.60	4334.61	4328.76	4322.89	4318.92	4312.95	4306.43	4299.70
Forest to Grassland	0.01	0.01	0.01	0.01	0.01	0.27	0.27	0.27	0.27	0.27	0.40	0.40	0.40	0.40	0.40	0.40	NO
Grassland to Forest	6.39	9.03	7.88	9.94	8.13	9.22	9.63	4.37	5.29	7.70	7.71	5.50	5.57	3.46	5.37	5.85	6.03
Grassland to Settlement	0.31	0.27	0.32	0.27	0.41	0.45	0.51	0.57	0.63	0.69	0.54	0.75	0.70	0.91	1.01	1.08	1.10
Initial Area	4423.50	4416.81	4407.51	4399.32	4389.12	4380.59	4371.19	4361.31	4356.64	4350.99	4342.87	4335.01	4329.16	4323.29	4319.32	4313.35	4306.83
Final Area	4416.81	4407.51	4399.32	4389.12	4380.59	4371.19	4361.31	4356.64	4350.99	4342.87	4335.01	4329.16	4323.29	4319.32	4313.35	4306.83	4299.70
Year	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	
Grassland Remaining Grassland	4293.78	4287.48	4281.98	4273.96	4268.88	4263.79	4257.75	4253.31	4247.69	4241.89	4236.80	4233.73	4230.50	4228.34	4226.85	4224.61	
Forest to Grassland	NO	0.40	0.40	0.80	1.20	NO	1.20	NO	NO	0.40	0.40	0.40	0.40	0.80	NO	0.02	
Grassland to Forest	5.49	6.25	5.06	7.52	5.70	6.14	5.84	5.47	5.39	5.57	5.11	3.16	3.19	2.14	1.86	1.77	
Grassland to Settlement	0.43	0.05	0.84	0.89	0.18	0.16	0.20	0.17	0.22	0.24	0.38	0.31	0.43	0.43	0.43	0.47	
Initial Area	4299.70	4293.78	4287.88	4282.38	4274.76	4270.08	4263.79	4258.95	4253.31	4247.69	4242.29	4237.20	4234.13	4230.90	4229.14	4226.85	
Final Area	4293.78	4287.88	4282.38	4274.76	4270.08	4263.79	4258.95	4253.31	4247.69	4242.29	4237.20	4234.13	4230.90	4229.14	4226.85	4224.63	

Table 3.4.D-3a Managed Wetland Matrix ('000 ha)

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Managed Wetland Remaining Managed Wetland	1230.1	1220.0	1211.1	1205.1	1193.8	1179.3	1167.9	1160.9	1153.2	1148.2	1140.3	1130.5	1121.2	1115.7	1111.5	1107.4	1105.6
Unmanaged Wetlands to Managed Wetlands	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Managed Wetland to Forest	9.43	10.12	8.82	6.06	11.33	14.49	11.35	7.06	7.64	4.97	7.98	9.97	9.48	5.64	4.37	4.25	2.01
Managed Wetland to Unmanaged Wetland	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Initial Area	1239.5	1230.1	1220.0	1211.1	1205.1	1193.8	1179.3	1167.9	1160.9	1153.2	1148.2	1140.4	1130.6	1121.3	1115.9	1111.7	1107.6
Final Area	1230.1	1220.0	1211.1	1205.1	1193.8	1179.3	1167.9	1160.9	1153.2	1148.2	1140.4	1130.6	1121.3	1115.9	1111.7	1107.6	1105.6
Year	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	
Managed Wetland Remaining Managed Wetland	1103.9	1104.3	1102.7	1102.3	1101.4	1101.2	1100.8	1100.5	1100.0	1099.9	1099.9	1099.0	1098.7	1098.4	1098.2	1097.7	
Unmanaged Wetlands to Managed Wetlands	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	
Managed Wetland to Forest	1.69	-	1.58	0.79	0.95	0.51	0.42	0.68	0.90	0.93	0.43	0.86	0.35	0.30	0.16	0.50	
Managed Wetland to Unmanaged Wetland	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	
Initial Area	1105.6	1104.3	1104.3	1103.1	1102.3	1101.8	1101.2	1101.2	1100.9	1100.8	1100.3	1099.9	1099.0	1098.7	1098.4	1098.2	
Final Area	1104.3	1104.3	1103.1	1102.3	1101.8	1101.2	1101.2	1100.9	1100.8	1100.3	1099.9	1099.0	1098.7	1098.4	1098.2	1097.7	

Table 3.4.D-3b Unmanaged Wetland Matrix ('000 ha) (continued)

Year	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Unmanaged Wetland Remaining Unmanaged Wetland	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78
Forest to Unmanaged Wetland	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Managed Wetlands to Unmanaged Wetlands	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Unmanaged Wetland to Forest	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Unmanaged Wetland to Managed Wetland	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Initial Area	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78
Final Area	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78
Year	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**202**	**2021**	**2022**	
Unmanaged Wetland Remaining Unmanaged Wetland	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	
Forest to Unmanaged Wetland	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	
Managed Wetlands to Unmanaged Wetlands	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	
Unmanaged Wetland to Forest	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	
Unmanaged Wetland to Managed Wetland	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	
Initial Area	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	
Final Area	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	126.78	

Table 3.4.B-4 Settlement Matrix ('000 ha)

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Settlement Remaining Settlement	103.37	103.74	104.06	104.44	104.77	105.25	105.76	106.35	107.00	107.72	108.51	109.30	110.34	111.31	112.53	113.86	115.27
Forest to Settlement	0.01	0.01	0.01	0.01	0.01	NO	NO	NO	NO	NO	0.17	0.17	0.17	0.17	0.17	0.17	0.40
Cropland to Settlement	0.03	0.02	0.03	0.02	0.04	0.04	0.05	0.05	0.06	0.06	0.05	0.07	0.06	0.08	0.09	0.10	0.10
Grassland to Settlement	0.31	0.27	0.32	0.27	0.41	0.45	0.51	0.57	0.63	0.69	0.54	0.75	0.70	0.91	1.01	1.08	1.10
Other land to Settlement	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.04	0.04	0.03	0.04	0.04	0.05	0.06	0.06	0.07
Initial Area	103.37	103.74	104.06	104.44	104.77	105.25	105.76	106.35	107.00	107.72	108.51	109.30	110.34	111.31	112.53	113.86	115.27
Final Area	103.74	104.06	104.44	104.77	105.25	105.76	106.35	107.00	107.72	108.51	109.30	110.34	111.31	112.53	113.86	115.27	116.94
Year	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	
Settlement Remaining Settlement	116.94	118.63	119.89	120.85	121.88	122.08	123.06	123.30	123.49	123.74	124.41	124.85	126.00	126.50	126.99	127.48	
Forest to Settlement	1.20	1.20	NO	NO	NO	0.80	NO	NO	NO	0.40	NO	0.80	NO	NO	NO	0.16	
Cropland to Settlement	0.04	0.00	0.08	0.08	0.02	0.01	0.02	0.02	0.02	0.02	0.03	0.03	0.04	0.04	0.04	0.04	
Grassland to Settlement	0.43	0.05	0.84	0.89	0.18	0.16	0.20	0.17	0.22	0.24	0.38	0.31	0.43	0.43	0.43	0.47	
Other land to Settlement	0.03	0.00	0.05	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.03	0.03	0.03	0.03	
Initial Area	116.94	118.63	119.89	120.85	121.88	122.08	123.06	123.30	123.49	123.74	124.41	124.85	126.00	126.50	126.99	127.48	
Final Area	118.63	119.89	120.85	121.88	122.08	123.06	123.30	123.49	123.74	124.41	124.85	126.00	126.50	126.99	127.48	128.18	

Table 3.4.B-5 Other Land Matrix ('000 ha)

Year	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Other Land Remaining Other Land	4.22	4.21	4.19	4.18	4.16	4.13	4.17	4.20	4.23	4.26	4.29	4.36	4.44	4.50	4.55	4.60	4.65
Forest to Other Land	0.00	0.00	0.00	0.00	0.00	0.07	0.07	0.07	0.07	0.07	0.11	0.11	0.11	0.11	0.11	0.11	1.60
Other Land to Settlement	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.04	0.04	0.03	0.04	0.04	0.05	0.06	0.06	0.07
Initial Area	4.24	4.23	4.21	4.20	4.18	4.16	4.20	4.24	4.27	4.30	4.33	4.41	4.48	4.55	4.61	4.67	4.72
Final Area	4.23	4.21	4.20	4.18	4.16	4.20	4.24	4.27	4.30	4.33	4.41	4.48	4.55	4.61	4.67	4.72	6.25
Year	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	
Other Land Remaining Other Land	6.23	6.23	6.58	6.52	6.51	6.50	6.49	6.48	6.47	6.45	6.43	6.41	6.39	6.36	6.34	6.31	
Forest to Other Land	NO	0.40	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	
Other Land to Settlement	0.03	0.00	0.05	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.03	0.03	0.03	0.03	
Initial Area	6.25	6.23	6.63	6.58	6.52	6.51	6.50	6.49	6.48	6.47	6.45	6.43	6.41	6.39	6.36	6.34	
Final Area	6.23	6.63	6.58	6.52	6.51	6.50	6.49	6.48	6.47	6.45	6.43	6.41	6.39	6.36	6.34	6.31	

Annex 4.A Ireland’s Energy Balance - Stakeholders, Surveys and Sources

Sustainable Energy Authority of Ireland (SEAI)

The Sustainable Energy Authority of Ireland was established as Ireland's national energy authority under the Sustainable Energy Act 2002. SEAI's mission is to play a leading role in transforming Ireland into a society based on sustainable energy structures, technologies and practices. To fulfil this mission SEAI aims to provide well-timed and informed advice to Government, and deliver a range of programmes efficiently and effectively, while engaging and motivating a wide range of stakeholders and showing continuing flexibility and innovation in all activities.

The SEAI statistics team is part of the Data & Insights Department under the Research and Policy Insights Directorate. The statistics team inform evidence based decision making and sustainable energy solutions. We provide policy relevant research, guidance, robust evidence and statistics.

Its core functions are to:

- Collect, process and publish energy statistics to support policy analysis and development in line with national needs and international obligations;
- Conduct statistical and economic analyses of energy services sectors and sustainable energy options;
- Contribute to the development and promulgation of appropriate sustainability indicators.

National Legislation

- Sustainable Energy Act 2002.
  http://www.irishstatutebook.ie/pdf/2002/en.act.2002.0002.pdf

Further information on Ireland's Energy Statistics can be found here;

https://www.seai.ie/data-and-insights/seai-statistics/

EU Legislative Requirements

- Under the European Energy Statistics Regulation of 2008, no.1099, Ireland is legally obliged to submit energy statistics to Eurostat. The Regulation came into force on 1st January 2009 and SEAI are collecting data on behalf of Ireland from this date. The data collected to fulfil these requirements is also used to complete Ireland's Energy Balance.
  https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02008R1099-20220220
- Information regarding gas and electricity prices is sent to Eurostat twice a year under Regulation (EU) 2016/1952 European statistics on natural gas and electricity prices.

  https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32016R1952
- Annual statistics on district heating and cooling and on combined heat and power (CHP) generation are sent to Eurostat once a year under Directive 2012/27/EU on energy efficiency.

  https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02012L0027-20230504

Quality Reports

Every five years, Member States provide the Commission (Eurostat) with a report on the quality of the data transmitted as well as on methodological changes that have been made. Ireland's last quality report on energy statistics was completed on July 2022.

https://ec.europa.eu/eurostat/cache/metadata/EN/nrg_quant_simsqu_ie.htm

Quality Commitment

The SEAI is committed to quality and continuously strives to improve and ensure accurate, precise, and detailed statistics. The SEAI subscribes fully to the principles set out in the Irish Statistical System Code of Practice (ISSCOP) and has signed a statement of commitment to these principles.

https://www.seai.ie/data-and-insights/seai-statistics/production-of-statistics/Quality-Commitment-Statement.pdf

Methodology

The scope and detail of the statistics collected and processed are determined by several factors, including international reporting obligations, informing, and supporting evidence-based policy, providing data to help guide government infrastructure investment, and to educate and update the public to promote active citizenship on climate change and sustainability.

https://www.seai.ie/data-and-insights/seai-statistics/production-of-statistics/Methodology.pdf

Dissemination and Revisions

The Energy Statistics team, under the head of the Data & Insights Department in SEAI, has sole responsibility for deciding on the content and timing of statistical releases (subject to the completeness of the data and requirements associated with international reporting obligations).

https://www.seai.ie/data-and-insights/seai-statistics/production-of-statistics/Dissemination-Revisions.pdf

Confidentiality Commitment

Given Ireland's small size and limited number of actors in certain sectors, particular care is taken to obfuscate and aggregate data-entries and categories that would otherwise potentially identify or provide market-intelligence on the data provider.

https://www.seai.ie/data-and-insights/seai-statistics/production-of-statistics/Confidentiality-Commitment-Statement.pdf

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