

# Ireland's National Inventory Report 2021

Greenhouse Gas Emissions 1990-2019



## ENVIRONMENTAL PROTECTION AGENCY

The Environmental Protection Agency (EPA) is responsible for protecting and improving the environment as a valuable asset for the people of Ireland. We are committed to protecting people and the environment from the harmful effects of radiation and pollution.

### The work of the EPA can be divided into three main areas:

**Regulation:** *We implement effective regulation and environmental compliance systems to deliver good environmental outcomes and target those who don't comply.*

**Knowledge:** *We provide high quality, targeted and timely environmental data, information and assessment to inform decision making at all levels.*

**Advocacy:** *We work with others to advocate for a clean, productive and well protected environment and for sustainable environmental behaviour.*

## Our Responsibilities

### Licensing

We regulate the following activities so that they do not endanger human health or harm the environment:

- waste facilities (e.g. landfills, incinerators, waste transfer stations);
- large scale industrial activities (e.g. pharmaceutical, cement manufacturing, power plants);
- intensive agriculture (e.g. pigs, poultry);
- the contained use and controlled release of Genetically Modified Organisms (GMOs);
- sources of ionising radiation (e.g. x-ray and radiotherapy equipment, industrial sources);
- large petrol storage facilities;
- waste water discharges;
- dumping at sea activities.

### National Environmental Enforcement

- Conducting an annual programme of audits and inspections of EPA licensed facilities.
- Overseeing local authorities' environmental protection responsibilities.
- Supervising the supply of drinking water by public water suppliers.
- Working with local authorities and other agencies to tackle environmental crime by co-ordinating a national enforcement network, targeting offenders and overseeing remediation.
- Enforcing Regulations such as Waste Electrical and Electronic Equipment (WEEE), Restriction of Hazardous Substances (RoHS) and substances that deplete the ozone layer.
- Prosecuting those who flout environmental law and damage the environment.

### Water Management

- Monitoring and reporting on the quality of rivers, lakes, transitional and coastal waters of Ireland and groundwaters; measuring water levels and river flows.
- National coordination and oversight of the Water Framework Directive.
- Monitoring and reporting on Bathing Water Quality.

### Monitoring, Analysing and Reporting on the Environment

- Monitoring air quality and implementing the EU Clean Air for Europe (CAFÉ) Directive.
- Independent reporting to inform decision making by national and local government (e.g. *periodic reporting on the State of Ireland's Environment and Indicator Reports*).

### Regulating Ireland's Greenhouse Gas Emissions

- Preparing Ireland's greenhouse gas inventories and projections.
- Implementing the Emissions Trading Directive, for over 100 of the largest producers of carbon dioxide in Ireland.

### Environmental Research and Development

- Funding environmental research to identify pressures, inform policy and provide solutions in the areas of climate, water and sustainability.

### Strategic Environmental Assessment

- Assessing the impact of proposed plans and programmes on the Irish environment (e.g. *major development plans*).

### Radiological Protection

- Monitoring radiation levels, assessing exposure of people in Ireland to ionising radiation.
- Assisting in developing national plans for emergencies arising from nuclear accidents.
- Monitoring developments abroad relating to nuclear installations and radiological safety.
- Providing, or overseeing the provision of, specialist radiation protection services.

### Guidance, Accessible Information and Education

- Providing advice and guidance to industry and the public on environmental and radiological protection topics.
- Providing timely and easily accessible environmental information to encourage public participation in environmental decision-making (e.g. *My Local Environment, Radon Maps*).
- Advising Government on matters relating to radiological safety and emergency response.
- Developing a National Hazardous Waste Management Plan to prevent and manage hazardous waste.

### Awareness Raising and Behavioural Change

- Generating greater environmental awareness and influencing positive behavioural change by supporting businesses, communities and householders to become more resource efficient.
- Promoting radon testing in homes and workplaces and encouraging remediation where necessary.

### Management and structure of the EPA

The EPA is managed by a full time Board, consisting of a Director General and five Directors. The work is carried out across five Offices:

- Office of Environmental Sustainability
- Office of Environmental Enforcement
- Office of Evidence and Assessment
- Office of Radiation Protection and Environmental Monitoring
- Office of Communications and Corporate Services

The EPA is assisted by an Advisory Committee of twelve members who meet regularly to discuss issues of concern and provide advice to the Board.



## **IRELAND**

# **NATIONAL INVENTORY REPORT 2021**

### **GREENHOUSE GAS EMISSIONS 1990 - 2019 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 2020 and refers to the greenhouse gas inventory time-series for the years 1990-2019.

This is the fourth submission of the inventory under the Revision of the UNFCCC Inventory Reporting Guidelines on annual inventories for Parties included in Annex I to the Convention adopted by COP at Warsaw (Decision 24/CP.19). 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 listed in table 2.14 of the errata to the contribution of Working Group 1 to the Fourth Assessment Report of the IPCC as contained in Annex III of the decision. The Common Reporting Format (CRF) tables reported in this submission were generated by the CRF Reporter 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 2021 under the UNFCCC and the Kyoto Protocol.

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. Part II contains the supplementary information required under Article 7, paragraph 1 of the Kyoto Protocol, which refers mainly to the reporting and accounting of emissions and removals for activities under Article 3, paragraph 3 (Afforestation, Reforestation and Deforestation) and Article 3, paragraph 4 (Forest management, Cropland management and Grazing land management). 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 Environmental Sustainability (OES) 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 No.](#)

[525/2013](#) of the European Parliament and of the Council and the UNFCCC. In addition to complying with the UNFCCC reporting guidelines, the 2021 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 Act 2015](#) 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.

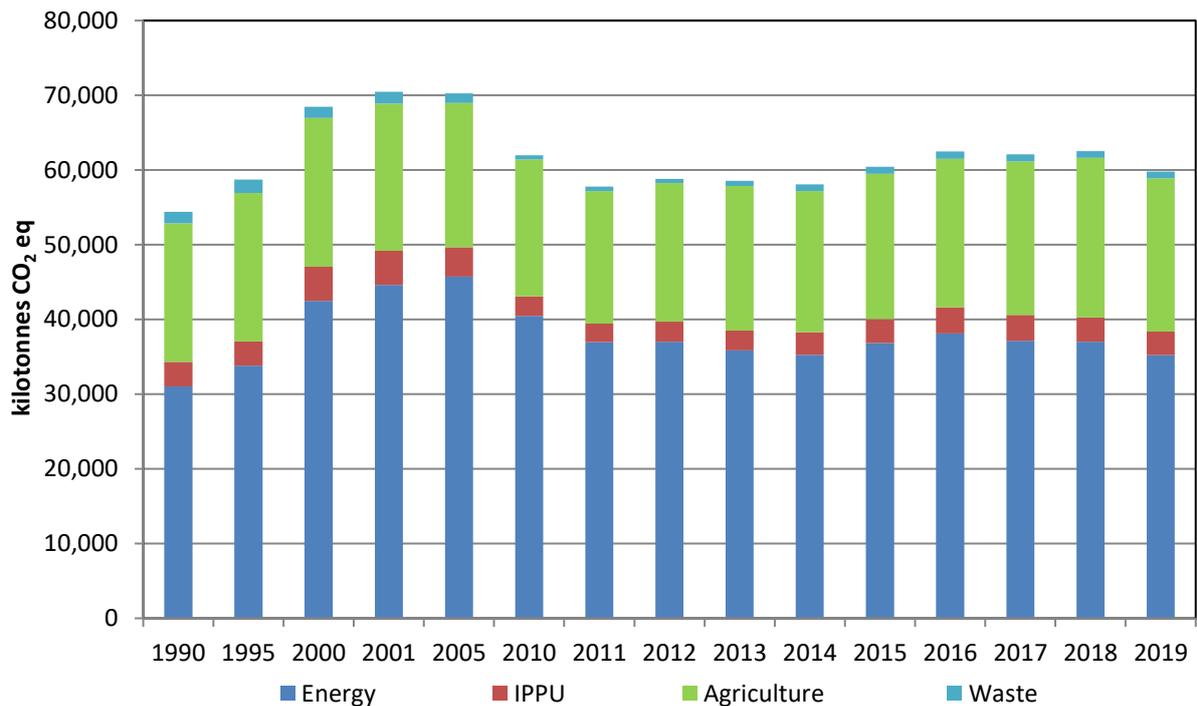
Ireland's commitment on greenhouse gases under the Kyoto Protocol pursuant to its Article 3, paragraph 9, the Doha Amendment ([1/CMP.8](#)) is set out in Annex B of the protocol. Ireland's quantified emission limitation reduction commitment (QELRCs) for the period 2013 to 2020 is 80 percent of its base year emissions. The QELRCs for the European Union and its Member States for the second commitment period under the Kyoto Protocol are based on the understanding that these will be fulfilled jointly with the European Union and its member States and Iceland, in accordance with Article 4 of the Kyoto Protocol. The legislative agreements setting out joint fulfilment under Article 4 of the Kyoto Protocol between the European Union and its Member States ([Council Decision EU 2015/1339](#)), and the European Union and its Member States and Iceland ([Council Decision EU 2015/1340](#)) were finalised in July 2015.

The European Union's Effort Sharing Decision ([No. 406/2009/EC](#)) established binding annual targets for Member States for the period 2013–2020. 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 is set out in Annex II of the decision and limits emissions to -20 per cent compared to 2005 greenhouse gas levels. Ireland's actual annual emissions allocations (AEAs) for each year of the period 2013 to 2020 are set out in Annex II to [Decision 2017/1471](#) as adjusted by the amounts in Annex II to [Decision 2013/634/EU](#).

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

In 2019, total emissions of greenhouse gases including indirect emissions from solvent use (without *LULUCF*) in Ireland were 59,777.6 kt CO<sub>2</sub> equivalent, which is 9.9 per cent higher than emissions in 1990 as presented in Figure ES.1. Total greenhouse gas emissions excluding indirect emissions from solvent use, reported in the IPPU sector, in Ireland were 59,671.7 kt CO<sub>2</sub> equivalent. Ireland's national total emissions includes indirect CO<sub>2</sub> emissions from solvent use.

The total for 2019 is 15.2 per cent lower than the peak of 70,487.2 kt CO<sub>2</sub> equivalent in 2001 when emissions reached a maximum following a period of unprecedented economic growth. The *Energy* sector accounted for 58.9 per cent of total emissions in 2019, *Agriculture* contributed 34.3 per cent while a further 5.3 per cent emanated from *Industrial Processes and Product Use* and 1.5 per cent was due to *Waste*. Emissions of CO<sub>2</sub> accounted for 62.4 per cent of the national total in 2019, with CH<sub>4</sub> and N<sub>2</sub>O contributing 24.6 per cent and 11.5 per cent, respectively. The combined emissions of HFC, PFC, SF<sub>6</sub> and NF<sub>3</sub> accounted for 1.5 per cent of total emissions in 2019.



**Figure ES.1 National total Greenhouse Gas emissions (excluding LULUCF) 1990-2019**

An approach 1 level assessment of emission source categories (ranking on the basis of their contribution to total emissions) identified 29 key categories in 2019 (excluding the *LULUCF* sector). There were 19 key categories of CO<sub>2</sub>, accounting for 60.8 per cent of total emissions. There were six key categories of CH<sub>4</sub>, three key categories of N<sub>2</sub>O and 1 key category of HFC in level assessment, which accounted for 23.2 per cent, 10.0 per cent and 1.1 per cent of total emissions, respectively. The results of the approach 1 key category analysis clearly show the impact of CO<sub>2</sub> emissions from energy consumption on total emissions in Ireland. These combustion sources of CO<sub>2</sub> emissions accounted for 17 out of 29 key categories identified by level assessment in 2019 or 57.0 per cent of total emissions. The top ten key categories contributed 75.4 per cent of total emissions in 2019 with emissions of CO<sub>2</sub> from the combustion of liquid fuels by road traffic being the single largest source, accounting for 19.2 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 3.85 per cent in the 2019 inventory (excluding the *LULUCF* sector) and a trend uncertainty of 2.33 per cent for the period 1990 to 2019. These values are determined largely by the low uncertainty in the estimates of CO<sub>2</sub> 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 62.4 per cent of emissions contributed by CO<sub>2</sub> in 2019 are estimated to have an uncertainty of 1.27 per cent. Emissions of CH<sub>4</sub> from 3.A Enteric Fermentation and N<sub>2</sub>O from 3.D.1 Direct N<sub>2</sub>O Emissions from Managed Soils sectors combined account for the majority of the level uncertainty (contributing 92.0 per cent and 94.2 per cent, respectively to each gas uncertainty) in the 2019 inventory. The impact of HFC, PFC, SF<sub>6</sub> and NF<sub>3</sub> on inventory uncertainty in the year 2019 was negligible (0.80 per cent) because they account for only 1.5 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 2019. 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 2021 submission and the latest inventories for the years 1990-2019 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 1990-2019 time-series. The largest increase took place in transport with an increase of 137.0 per cent on 1990 levels, while there were increases of 12.0 per cent from the manufacturing industry and construction sector. Emissions from energy industries, were 16.5 per cent below 1990 levels in 2019. 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 10.6 per cent above 1990 levels in 2019. As the emissions from energy increased, the contribution of agriculture to total national emissions decreased from 34.0 per cent in 1990 to 27.2 per cent in 2008. In recent years, emissions from Agriculture have been increasing and the share of the national total emissions is now 34.3 per cent in 2019. Over the period 1990-2019 total national emissions grew by 9.9 per cent with emissions increasing in sectors; Energy up 13.5 per cent, Agriculture up 10.6 per cent and decreasing in sectors; IPPU down 3.8 per cent and Waste down 41.7 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<sub>2</sub>), nitrogen oxides (NO<sub>x</sub>), carbon monoxide (CO) and non-methane volatile organic compounds (NMVOC). Emissions of SO<sub>2</sub> contribute to the formation of aerosols, which may offset the effects of greenhouse gases, while CO, NO<sub>x</sub> and NMVOC are precursors of ozone, another naturally occurring greenhouse gas. This NIR does not describe the methods used to estimate emissions of SO<sub>2</sub>, NO<sub>x</sub>, CO and NMVOC but the annual emissions estimates over the period 1990-2018 are included in the submission.

Indirect CO<sub>2</sub> 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 1990-2018 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 2019 in Ireland are of the order of 94.1 per cent in the case of SO<sub>2</sub>, 80.7 per cent for CO and 41.4 per cent for NO<sub>x</sub> and 21.2 per cent for NMVOC.



# **PART I**

## **ANNUAL INVENTORY SUBMISSION 2021**

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# Chapter 1 Introduction

## 1.1 Background and Context

This report constitutes Ireland's National Inventory Report (NIR), for the years 1990-2019, as required under the United Nations Framework Convention on Climate Change. Ireland's submission under the UNFCCC in 2019 is also to be considered its official submission under the Kyoto Protocol.

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.

- 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) is provided.
- Part II contains the supplementary information required under Article 7, paragraph 1 of the Kyoto Protocol, which refers mainly to the reporting and accounting of emissions and removals for activities under Article 3, paragraph 3 (Afforestation, Reforestation and Deforestation) and Article 3, paragraph 4 (Forest management, Cropland management and Grazing land management), i.e. emissions by sources and removals by sinks of GHGs resulting from LULUCF activities.

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 Decision ([No. 406/2009/EC](#)) and the Kyoto Protocol. 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 and the Kyoto Protocol. 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 [<http://www.epa.ie/ghg/documents/>]. 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 5.4.1 of Annex 5.3. It includes carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O), the most widely known and most ubiquitous of the anthropogenic greenhouse gases, along with 19 hydrofluorocarbons (HFC), 9 perfluorocarbons (PFC), sulphur hexafluoride (SF<sub>6</sub>) and nitrogen trifluoride (NF<sub>3</sub>). The global warming potentials (GWPs) of the various greenhouse gases vary greatly, and are as listed in table 2.14 of the errata to the contribution of Working Group 1 to the Fourth Assessment Report of the IPCC as contained in Annex III of the decision 24/CP.19. 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<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O are important because they are normally emitted in large amounts, HFCs, PFCs, SF<sub>6</sub> and NF<sub>3</sub> 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<sub>2</sub>), nitrogen oxides (NO<sub>x</sub>), carbon monoxide (CO) and non-methane volatile organic compounds (NMVOC). Emissions of SO<sub>2</sub> contribute to the formation of aerosols, which may offset the effects of greenhouse gases, while CO, NO<sub>x</sub> 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<sub>2</sub>, NO<sub>x</sub>, 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 reporting format also accommodates the reporting of emissions and removals under Article 3, paragraphs 3 and 4, of the Kyoto Protocol (i.e. emissions by sources and removals by sinks of GHGs resulting from KP LULUCF activities) for the years 2013-2020 of the second commitment period (CP2). The additional tables use a hierarchical system similar to that for reporting under the Convention, with flexibility for Parties to provide as much disaggregation as is necessary to reflect the variation in the parameters underlying the estimates of emissions and removals for the Article 3, paragraphs 3 and 4, activities applicable in their territories. The Kyoto reporting tables also include the accounting quantity for each relevant activity i.e. the quantity of units to be added or subtracted from a Party's assigned amount in accordance with the provisions of Article 7, paragraph 4, of the Protocol.

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 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, this total being consistent with that for the categories included in Annex A of the Kyoto Protocol. Ireland's national total during the second commitment period also includes indirect CO<sub>2</sub> 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 reporting under the Kyoto Protocol for the first commitment period (previous CRF sector 3, solvent and other product use).

### 1.2.1.3 Supplementary Information

For a Party to the Kyoto Protocol, the annual inventory submission under the Convention is also its annual inventory submission under the Protocol. Supplementary information required under Article 7, paragraph 1, of the Kyoto Protocol comprises the GHG emissions and removals under Article 3, paragraphs 3 and 4, of the Kyoto Protocol, details of all Kyoto units for the year subsequent to the inventory year as generated by the national registry and compiled in the Standard Electronic Format, changes in the national system and national registry and information on the minimisation of adverse impacts of climate change and response measures on developing countries in accordance with Article 3, paragraph 14. All supplementary information relating to the Kyoto Protocol is provided in Part II of this report.

## 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 Environmental Sustainability (OES) 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 OES, the Climate Change and Circular Economy Programme (CCCEP), compiles the national greenhouse gas emission inventories for submission on behalf of the DCCA under the Framework Convention on Climate Change and Regulation (EU) 525/2013, the latter being the basis for EU Member States' reporting under the Convention and the Kyoto Protocol. 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, DECLG 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), also within the EPA's 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, as well as those in respect of Article 3, paragraphs 3 and 4, activities under the Kyoto Protocol, 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 OES.

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 and Circular Economy Programme in OES. 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) 525/2013 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.

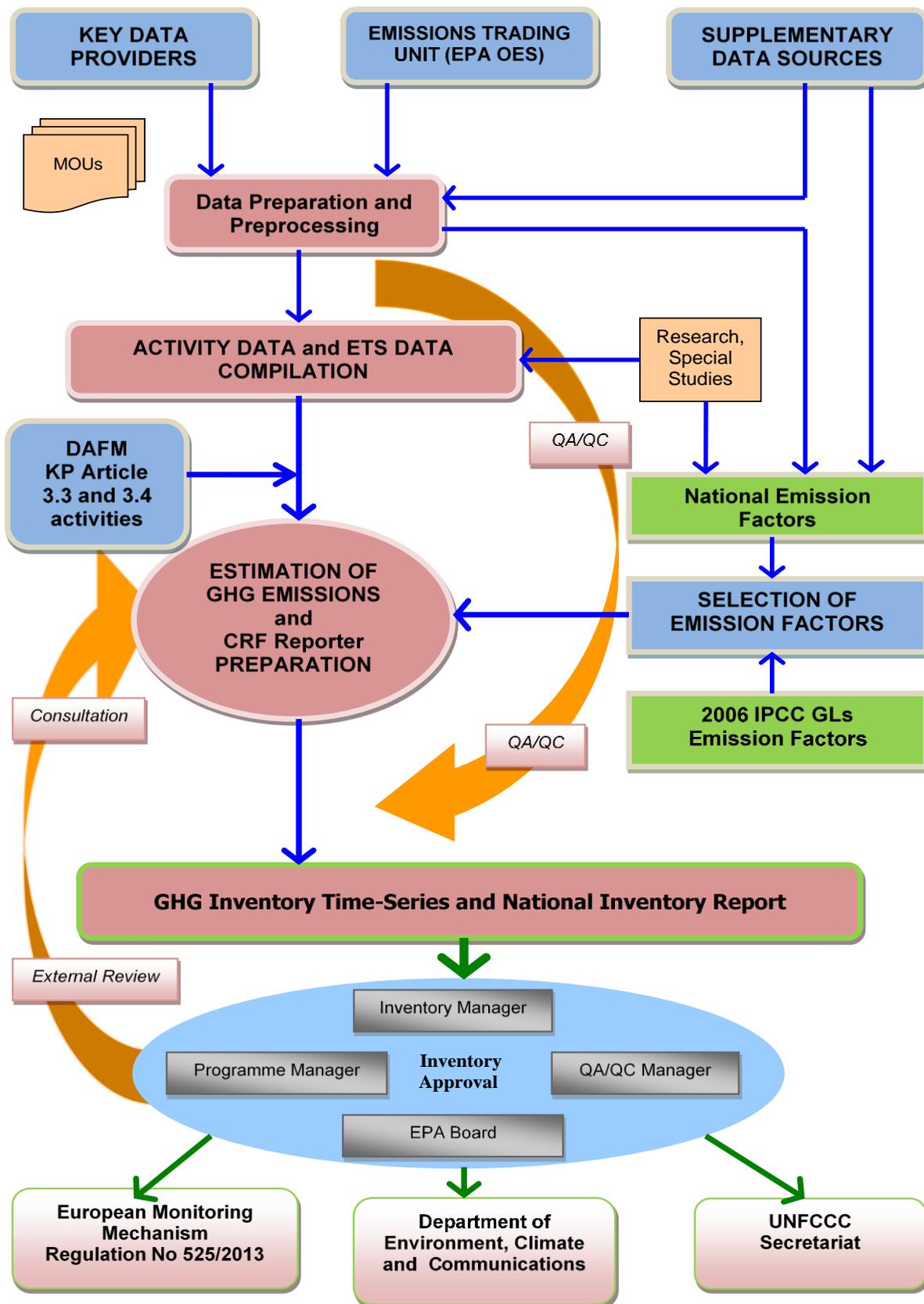


Figure 1.1 National Inventory System Overview

### 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 and for Kyoto Protocol activities under Article 3, paragraphs 3 and 4, 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) 525/2013, 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 15<sup>th</sup> January deadline prescribed by Regulation (EU) 525/2013, which governs the reporting of greenhouse gases and implementation of the Kyoto Protocol by the European Union and its EU Member States.

After the 15<sup>th</sup> 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 15<sup>th</sup> January submission by Member States to the European Commission are incorporated into the inventory between 15<sup>th</sup> January and 15<sup>th</sup> March.

The complete and final inventory submission, including the National Inventory Report, is submitted to the European Commission by 15<sup>th</sup> March as required under Regulation (EU) 525/2013. This version of the latest inventory is fixed and retained for submission to the UNFCCC secretariat by 15<sup>th</sup> 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 2020 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 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 inventory team has contracted an external service provider, Aether, to assist in aspects of inventory compilation from 2013 to 2020. The transparency, robustness and accessibility of the inventory data within the electronic filing structures were assessed by Aether, who concluded that the system is very well organised.

The ETS returns to the ETU provide for the complete coverage of CO<sub>2</sub> 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 has been no change in the national inventory arrangements since the previous annual inventory submission in April 2020.

## 1.4 Inventory Preparation, and Data Collection, Processing and Storage

### 1.4.1 GHG Inventory and KP-LULUCF 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<sub>2</sub> 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	<b>Table 1.1-1.4</b> 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)	<b>Table 2.1</b> 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	LULUCF and Article 3.3 and 3.4 of the Kyoto Protocol
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 <sub>2</sub> estimates and related fuel and production data for installations covered by the EU ETS <sup>1</sup>	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 and Article 3.3 & 3.4 activities
**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 and Article 3.3 & 3.4 activities

<sup>1</sup>ETS – Emissions Trading Scheme

\*These bodies have MOUs with SEAI rather than with OES

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

A Tier 3 model, CFS-CBM (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, The National Roads Authority (NRA) 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 OES 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<sub>4</sub> and N<sub>2</sub>O. 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<sub>2</sub> emissions, fuel use and emission factors for major combustion sources and industrial processes. The emissions trading scheme covers 104 stationary installations in Ireland with combined CO<sub>2</sub> emissions of 14,179.0 kt in 2019, accounting for 23.7 per cent of total greenhouse gas emissions (59,777.6 kt CO<sub>2</sub> 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<sub>2</sub> emissions for the purposes of reporting national GHG inventories under the Convention and the Protocol.

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 1990-2019. 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 Convention and a Tier 3 model is applied for carbon stock changes for Article 3, paragraph 3 and paragraph 4, activities under the Kyoto Protocol.

### 1.5.1 Carbon dioxide (CO<sub>2</sub>)

Tier 2 or Tier 3 methods are used for the majority of CO<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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 both Convention reporting and Article 3, paragraph 3 and paragraph 4, activities under the Kyoto Protocol is a Tier 3 methodology. The methods for CO<sub>2</sub> in other LULUCF categories and for relevant CH<sub>4</sub> and N<sub>2</sub>O emissions in this sector are invariably Tier 1.

### 1.5.2 Methane (CH<sub>4</sub>)

Ireland's national circumstances are well captured in the Tier 2 methods applied for the major sources of CH<sub>4</sub> in the inventory, which are enteric fermentation and manure management associated with cattle and the CH<sub>4</sub> emissions from solid waste disposal sites.

Tier 2 and Tier 3 methods are used for CH<sub>4</sub> 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<sub>4</sub> emissions.

### 1.5.3 Nitrous oxide (N<sub>2</sub>O)

Ireland relies on the simplified IPCC Tier 1 methodologies and country specific and default emission factors to estimate all N<sub>2</sub>O emissions in agriculture, which is the main source of N<sub>2</sub>O in the inventory.

Tier 2 and Tier 3 methods are used for N<sub>2</sub>O 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<sub>2</sub>O 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 2019 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.

The 2006 IPCC guidelines encourage inventory agencies to use approach 2 for its key category analysis, and this has also been suggested in previous annual inventory review reports. In response to this, initial work on using approach 2 was carried out, which highlighted differences between the level of disaggregation found in the approach 1 key category analysis compared to the approach 1 uncertainty assessment. Some sub-categories are reported at a more detailed level in the key category analysis compared to the Uncertainty Analysis (such as transport). Due to resource constraints, it was not possible to complete this work for this year's submission, so the finalisation of the approach 2 key category analysis and the further disaggregation of the approach 1 uncertainty assessment are planned improvements for the 2022 submission.

### 1.6.1 Key Categories at IPCC Level 2

As inventories of CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O were developed in Ireland during the 1990s, it was quickly established that CO<sub>2</sub> 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<sub>4</sub> emissions produced by Ireland's large cattle herd and the N<sub>2</sub>O 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<sub>2</sub>. 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<sub>2</sub> emissions from fuel combustion and CH<sub>4</sub> and N<sub>2</sub>O 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 2019 are shown in Table 1.2 and Table 1.3, respectively. It can be seen that there are nine highly significant key categories of emissions in Ireland in the 1990 and 2019 including; CO<sub>2</sub> 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<sub>2</sub> process emissions from *2.A.1 Cement Production* along with the CH<sub>4</sub> emissions from categories *3.A Enteric Fermentation, 3.B Manure Management* and *5.A Solid Waste Disposal* and N<sub>2</sub>O emissions from *3.D Agricultural Soils*. These nine categories accounted for 91.8 per cent and 94.7 per cent of total emissions in 1990 and 2019, respectively. In the case of 2019 emissions, one additional Level 2 source category is needed to reach the cumulative 95 per cent threshold that defines key categories: HFC emissions from *2.F.1 Refrigeration and air-conditioning*. Category *2.F.1* is key in 2019 level analysis and not in 1990, whereas categories *2.B.1* and *2.B.2* are key in 1990 level analysis and not in 2019.

The increase in the contribution of CO<sub>2</sub> emissions from category *1.A.3 Transport* from 9.2 per cent in 1990 to 20.2 per cent in 2019 is notable, along with the reduction in the contribution from *1.A.4 in Other Sectors Energy* from 18.2 per cent in 1990 to 14.6 per cent in 2019. 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<sub>2</sub> 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<sub>2</sub> emissions from *4.G Harvested Wood Products*, are also key categories in 2019.

**Table 1.2 Key Categories at IPCC Level 2 in 1990**

IPCC Category code	IPCC Category (level 2)	GHG	1990 Estimate (kt CO <sub>2</sub> eq)	Level Assessment (%)	Cumulative Total of Level (%)
1.A.1.	Energy Industries	CO2	11,145.01	20.49	20.49
3.A	Enteric Fermentation	CH4	10,466.07	19.24	39.73
1.A.4	Other Sectors (Comm/Resid/Agric)	CO2	9,895.33	18.19	57.92
3.D.	Agricultural Soils	N2O	5,820.50	10.70	68.62
1.A.3	Transport	CO2	5,029.81	9.25	77.86
1.A.2.	Manufacturing Industries and Construction	CO2	4,078.24	7.50	85.36
5.A	Solid Waste Disposal	CH4	1,318.08	2.42	87.78
3.B	Manure Management	CH4	1,288.15	2.37	90.15
2.B.2	Nitric Acid Production	N2O	995.32	1.83	91.98
2.B.1	Ammonia Production	CO2	990.23	1.82	93.80
2.A.1	Cement Production	CO2	884.00	1.62	95.42

**Table 1.3 Key Categories at IPCC Level 2 in 2019**

IPCC Category code	IPCC Category (level 2)	GHG	2019 Estimate (kt CO <sub>2</sub> eq)	Level Assessment (%)	Cumulative Total of Level (%)
3.A	Enteric Fermentation	CH4	12,151.21	20.33	20.33
1.A.3	Transport	CO2	12,045.94	20.15	40.48
1.A.1.	Energy Industries	CO2	9,217.97	15.42	55.90
1.A.4	Other Sectors (Comm/Resid/Agric)	CO2	8,751.95	14.64	70.54
3.D.	Agricultural Soils	N2O	5,723.32	9.57	80.11
1.A.2.	Manufacturing Industries and Construction	CO2	4,567.77	7.64	87.76
2.A.1	Cement Production	CO2	1,892.60	3.17	90.92
3.B	Manure Management	CH4	1,572.27	2.63	93.55
5.A	Solid Waste Disposal	CH4	676.88	1.13	94.68
2.F.1	Product Uses as Substitutes for ODS -Refrigeration and air-con	HFC	671.60	1.12	95.81

**Table 1.4 Summary of Methods**

<b>IPCC SOURCE AND SINK CATEGORIES</b>	<b>CO<sub>2</sub></b>	<b>CH<sub>4</sub></b>	<b>N<sub>2</sub>O</b>	<b>HFC</b>	<b>PFC</b>	<b>SF<sub>6</sub></b>	<b>NF<sub>3</sub></b>
<b>1. Energy</b>	<b>M T1, T2, T3</b>	<b>M, T1, T2, T3</b>	<b>M, T1, T2, T3</b>				
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	NA	T1	NA				
2. Oil and Natural Gas	CS, T3	CS, T1, T3	CS, T3				
C. Carbon Dioxide Transport and Storage	NA						
<b>2. Industrial Processes and Product Use</b>	<b>CR, T1, T2, T3</b>	<b>NA</b>	<b>T1</b>	<b>T1, T2, T3</b>	<b>T2</b>	<b>T1, T2</b>	<b>T2</b>
A. Mineral Industry	T3	NA	NA	NA	NA	NA	NA
B. Chemical Industry	T1	NA	T1				
C. Metal Production	NA	NA	NA				
D. Non-Energy Products from Fuels and Solvent Use	T1, T2	NA	NA				
E. Electronic Industry	NA	NA	NA	T2	T2	T2	T2
F. Product Uses as Substitutes for ODS	NA	NA	NA	T1, T2, T3	NA	NA	NA
G. Other Product Manufacture and Use	CR		T1			T1, T2	
H. Other							
<b>3. Agriculture</b>	<b>T1</b>	<b>CS, T1, T2</b>	<b>T1, T2</b>				
A. Enteric Fermentation		CS, T1, T2	NA				
B. Manure Management		T1, T2	T2				
C. Rice Cultivation		NA	NA				
D. Agricultural Soils		NA	T1				
E. Prescribed Burning of Savannas		NA	NA				
F. Field Burning of Agricultural Residues		NA	NA				
G. Liming	T1						
H. Urea Application	T1						
I. Other	NA						
<b>4. Land-Use, Land-Use Change and Forestry</b>	<b>CS, D, T1, T2, T3</b>	<b>D, T1, T2</b>	<b>D, T1, T2</b>				
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	D, T1				
D. Wetlands	D, T1, T2, T3	D, T2	D, T2				
E. Settlements	D, T1, T3	NA	T1				
F. Other Land	T1, T3	NA	T1				
G. Harvested wood products	T2						
H. Other	NA	NA	NA				
<b>5. Waste</b>	<b>T1</b>	<b>T1, T2</b>	<b>T1</b>				
A. Solid Waste Disposal	NA	T2	NA				
B. Biological treatment of solid waste	NA	T1	T1				
C. Incineration and open burning of waste	T1	T1	T1				
D. Wastewater treatment and discharge	NA	T1, T2	T1				
E. Other	NA	NA	NA				
<b>6. Other</b>	<b>NA</b>	<b>NA</b>	<b>NA</b>				
<b>Article 3.3 Afforestation and Deforestation</b>	<b>T3</b>	<b>M, T1, T3</b>	<b>M, T1, T3</b>				
<b>International Bunkers</b>							
Aviation	T1	M, T3	M, T3				
Navigation	T1	T1	T1				
<b>Multilateral Operations</b>	<b>NA</b>	<b>NA</b>	<b>NA</b>				
<b>CO<sub>2</sub> Emissions from Biomass</b>	<b>T1</b>	<b>T1</b>	<b>T1</b>				
<b>CO<sub>2</sub> captured</b>	<b>NA</b>	<b>NA</b>	<b>NA</b>				
<b>Long-term storage of C in waste disposal sites</b>	<b>NA</b>	<b>NA</b>	<b>NA</b>				
<b>Indirect N<sub>2</sub>O</b>	<b>NA</b>	<b>NA</b>	<b>NA</b>				
<b>Indirect CO<sub>2</sub></b>	<b>T1</b>	<b>NA</b>	<b>NA</b>				

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 <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O	HFC	PFC	SF <sub>6</sub>	NF <sub>3</sub>
<b>1. Energy</b>	<b>CS, D, M, PS</b>	<b>D, M</b>	<b>D, M</b>				
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	IE	IE	IE				
B. Fugitive Emissions from Fuels	CS, PS	CS, D, PS	CS, PS				
1. Solid Fuels	NA	D	NA				
2. Oil and Natural Gas	CS, PS	CS, D, PS	CS, PS				
C. Carbon Dioxide Transport and Storage	NA	NA	NA				
<b>2. Industrial Processes and Product Use</b>	<b>CR, D, PS</b>	<b>NA</b>	<b>D</b>	<b>CS</b>	<b>NA</b>	<b>NA</b>	<b>NA</b>
A. Mineral Industry	PS						
B. Chemical Industry	CS	NA	PS				
C. Metal Production	D	NA					
D. Non-Energy Products from Fuels and Solvent Use	D	NA	NA	NA	NA	NA	NA
E. Electronic Industry				CS	CS	CS	CS
F. Product Uses as Substitutes for ODS				CS	NA	NA	NA
G. Other Product Manufacture and Use	CR		D	NA		CS	
H. Other							
<b>3. Agriculture</b>	<b>D</b>	<b>CS, D</b>	<b>CS, D</b>				
A. Enteric Fermentation		CS, D	NA				
B. Manure Management		CS, D	CS, D				
C. Rice Cultivation		NA	NA				
D. Agricultural Soils		NA	CS, D				
E. Prescribed Burning of Savannas							
F. Field Burning of Agricultural Residues		NA	NA				
G. Liming	D						
H. Urea Application	D						
I. Other	NA						
<b>4. Land-Use, Land-Use Change and Forestry</b>	<b>CS, D, OTH</b>	<b>CS, D</b>	<b>CS, D</b>				
A. Forest Land	CS	CS, D	CS, D				
B. Cropland	D	D	D				
C. Grassland	CS, D	D	D				
D. Wetlands	CS, D	CS, D	CS, D				
E. Settlements	CS, D, OTH	NA	D				
F. Other Land	CS	NA	D				
G. Harvested wood products	D						
H. Other	NA	NA	NA				
<b>5. Waste</b>	<b>D</b>	<b>CS, D</b>	<b>D</b>				
A. Solid Waste Disposal	NA	CS, D	NA				
B. Biological treatment of solid waste	NA	D	D				
C. Incineration and open burning of waste	D	D	D				
D. Wastewater treatment and discharge	NA	CS, D	D				
E. Other	NA	NA	NA				
<b>6. Other</b>	<b>NA</b>	<b>NA</b>	<b>NA</b>				
<b>Article 3.3 Afforestation and Deforestation</b>	<b>CS</b>	<b>D</b>	<b>D</b>				
<b>International Bunkers</b>							
Aviation	CS	M	M				
Marine	CS	D	D				
<b>Multilateral Operations</b>	<b>NA</b>	<b>NA</b>	<b>NA</b>				
<b>CO<sub>2</sub> Emissions from Biomass</b>	<b>CS, D</b>	<b>D, M, CR</b>	<b>D, M, CR</b>				
<b>CO<sub>2</sub> captured</b>	<b>NA</b>	<b>NA</b>	<b>NA</b>				
<b>Long-term storage of C in waste disposal sites</b>	<b>NA</b>	<b>NA</b>	<b>NA</b>				
<b>Indirect N<sub>2</sub>O</b>	<b>NA</b>	<b>NA</b>	<b>NA</b>				
<b>Indirect CO<sub>2</sub></b>	<b>CS, CR, D</b>	<b>NA</b>	<b>NA</b>				

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 2019 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 1990-2019 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 2019 key category analysis are provided in Tables 1.A-D in Annex 1.

The results of the level and trend assessments for 2019 **excluding LULUCF** categories may be summarised as follows:

- (i) The **level assessment** identifies 29 key categories, 24 of which are also key categories by trend assessment. CH<sub>4</sub> emissions in *3.B.1 Manure Management – Non-Dairy Cattle*; CH<sub>4</sub> emissions in *3.B.1 Manure Management – Dairy Cattle*; N<sub>2</sub>O emissions in *3.D.2 Agricultural Soils – Indirect Soil Emissions*; CO<sub>2</sub> emissions in *3.G.1 Liming* and CO<sub>2</sub> emissions in *1.A.3.d Navigation* are key categories by level assessment only.
- (ii) There are 19 key categories of CO<sub>2</sub> in level assessment, accounting for 60.8 per cent of total emissions;
- (iii) There are 6 key categories of CH<sub>4</sub>, 3 key categories of N<sub>2</sub>O and one category of HFC in level assessment, which account for 23.2 per cent, 10.0 per cent and 1.1 per cent, respectively, of total emissions;
- (iv) Energy accounts for 17 key categories, Agriculture for 9, while Industrial Processes and Product Use contributes two and Waste contributes one;
- (v) The **trend assessment** identifies 25 key categories, all of which but three (CO<sub>2</sub> emissions in *1.A.4.a Commercial/Institutional – Gaseous Fuels*; CO<sub>2</sub> emissions in *1.A.4.c Agriculture/Fishing – Liquid Fuels* and CO<sub>2</sub> emissions in *1.A.4.b Residential – Peat Fuels*) are key categories for 2019 level assessment;
- (vi) There are 18 key categories of CO<sub>2</sub> in trend assessment, accounting for 84.4 per cent of the total trend;
- (vii) There are 5 key categories of CH<sub>4</sub>, one key category of N<sub>2</sub>O and one key categories of HFC in trend assessment, which account for 7.2 per cent, 1.7 per cent and 1.8 per cent, respectively, of the total trend.

The results of the level and trend assessment for 2019 **including LULUCF** categories may be summarised as follows:

- (i) The **level assessment** identifies 35 key categories, 24 of these are sources of CO<sub>2</sub> emissions, accounting for 67.3 per cent of total emissions;
- (ii) There are 6 additional categories that are not present in the assessment excluding LULUCF, all 5 of which are LULUCF categories.
- (iii) The 6 additional categories are: CO<sub>2</sub> emissions from, *4.C. Grassland, 4.A.2 Land Converted to Forest Land, 4.A.1 Forest Land Remaining Forest Land, 4.D. Wetlands, 4.G Harvested Wood Products*, and CH<sub>4</sub> emissions from, *3.B.1.3 Manure Management- Swine*.
- (iv) There are 7 key categories from sources of CH<sub>4</sub>, 3 key categories of N<sub>2</sub>O and one category of HFC, which account for 18.8 per cent, 8.0 per cent and 0.9 per cent, respectively, of total emissions;
- (v) Energy accounts for 17 key categories, Agriculture for 10, LULUCF for 5, while Industrial Processes contributes 2 and Waste contributes 1;
- (vi) The **trend assessment** identifies 32 key categories, 6 of which were not present in the assessment excluding LULUCF: CO<sub>2</sub> emissions from LULUCF categories: *4.A.2 Land converted to Forest Land, 4.A.1 Forest land Remaining Forest Land, , 4.C. Grassland, 4.D. Wetlands and 4.G Harvested Wood Products*; N<sub>2</sub>O emissions from *4.A Drained organic soils from Forest Land*.
- (vii) There are 24 key categories of CO<sub>2</sub> in the trend assessment, accounting for 86.0 per cent of the total trend;
- (viii) There are 5 key categories of CH<sub>4</sub>, 2 key categories of N<sub>2</sub>O and 1 key category of HFC in the trend assessment, which account for 5.8 per cent, 1.8 per cent and 1.4 per cent, respectively, of the total trend.

The list of key categories given by level assessment in 2019 is very similar to that for 1990. However, the higher ranking of the main CO<sub>2</sub> emissions from road transport is notable in 2019. Six out of the top ten key categories in 1990 (excluding LULUCF) were in the top ten in 2019 but in a different order. The remaining 4 key categories in 2019 are: CO<sub>2</sub> emissions from *1.A.1 Energy Industries – Gaseous Fuels, 1.A.2. Manufacturing Industries & Construction - Gaseous Fuels, 1.A.1 Energy Industries – Peat Fuels and 2.A.1 Cement Production*. These sectors replaced 4 key sectors in 1990: CO<sub>2</sub> emissions from *1.A.1 Energy Industries – Solid Fuels, 1.A.4.b. Residential – Peat Fuel, 1.A.4.b. Residential - Solid Fuels and 1.A.2. Manufacturing Industries & Construction – Liquid Fuels*.

Those six key categories contributed 44.5 and 59.3 per cent, of total emissions in 1990 and 2019, respectively. The emissions of CO<sub>2</sub> from the use of liquid fuels by road traffic (*1.A.3.b*) and CH<sub>4</sub> emissions from *3.A.1. Enteric Fermentation - Non-Dairy Cattle* were the largest source categories of greenhouse gas emissions in Ireland in 2019, accounting for 19.2 and 11.5 per cent of the total, respectively.

The CO<sub>2</sub> emissions/removals in 5 categories (*4.C. Grassland, 4.A.2 Forest Land Converted to Forest Land, 4.D. Wetlands, 4.A.1 Forest Land remaining Forest Land and 4.G Harvested Wood Products*) are key categories in level assessment when the LULUCF sector is included in the detailed analysis for 2019.

CO<sub>2</sub> emissions in *KP B.3 Grazing Land Management, KP A.1 Afforestation/Reforestation and KP B.1 Forest Management* are also key categories in 2019 when Article 3, paragraph 3 and paragraph 4, activities are included in the analysis.

## 1.7 Use of Key Category Analysis

The approach 1 used to 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 26 of the 35 key categories in 2019 each accounted for less than 3 per cent of the total emissions and that only six 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<sub>2</sub> 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 57.0 per cent of total emissions in 2019. While key categories determined by CO<sub>2</sub> 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<sub>2</sub> 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<sub>4</sub> from enteric fermentation in cattle (dairy and non-dairy) and the use of verified estimates for CO<sub>2</sub> emissions from cement production means that the contributions from these 3 additional key categories (ranked 5, 2 and 9 in Table 1.7, respectively), making up a further 22.1 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<sub>2</sub>O emissions from *3.D.1 Agricultural Soils – direct soil emissions* and CH<sub>4</sub> 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 2019 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 2019 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<sub>2</sub> 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<sub>2</sub> 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<sub>4</sub> and N<sub>2</sub>O released from combustion sources are high and not well established quantitatively. For CH<sub>4</sub> and N<sub>2</sub>O 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<sub>4</sub> and N<sub>2</sub>O 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<sub>4</sub> 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<sub>4</sub> emissions outside Agriculture. Under the methodology used, the component uncertainties for both activity data and emission factor for CH<sub>4</sub> 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 and for activities under Article 3, paragraph 3 and paragraph 4, of the Kyoto Protocol. 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 and Article 3, paragraph 3 and paragraph 4, separately. Additional information on uncertainties for LULUCF is provided in chapters 6 and 11.

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 2019 inventory under the Convention gives an overall uncertainty of 3.85 per cent in total emissions and a trend uncertainty of 2.33 per cent for the period 1990 to 2019. This equates to an increase on level and in trend as compared to the values reported in the 2020 submission (for 1990 to 2018) of 3.79 and 2.30 per cent, respectively.

The reason for the overall increase from 2018 to 2019 is primarily due to higher emissions share of methane and nitrous oxide from Agriculture in the overall level of emissions in 2019 as these gases have higher associated level uncertainty.

The reason for the trend increase from 2018 to 2019 is mainly due to increasing emissions from agricultural categories; agricultural soils which are more in line with emission levels for those categories in 1990, and solid fuel use in Energy Industries which reduced significantly in 2019.

Relatively low estimates are determined largely by the low uncertainties in the estimate of CO<sub>2</sub> emissions, which account for 62.4 per cent of total national emissions in 2019 and which are estimated to contribute to 10.9 per cent of the level uncertainty (excluding LULUCF). When CH<sub>4</sub> is included, bringing the proportion of total emissions up to 87.0 per cent, the contribution to the level of uncertainty is 43.1 per cent (excluding LULUCF), with 32.2 per cent due to CH<sub>4</sub>. However, it is the influence of N<sub>2</sub>O that contributes 56.1 per cent of the total level of uncertainty, whereas it accounts for only 11.5 per cent of national total emissions. The impact of HFCs, PFCs, SF<sub>6</sub> and NF<sub>3</sub> on inventory uncertainty remains negligible (0.8 per cent contribution) because these gases account for only 1.5 per cent of total emissions in Ireland.

The approach 1 uncertainty analysis (including LULUCF) for Ireland's 2019 inventory under the Convention (Table 1.13) gives an overall level uncertainty of 12.98 per cent in total emissions and a trend uncertainty of 10.64 per cent for the period 1990 to 2019.

## 1.9 Completeness and Time-Series Consistency

Table 1.14 gives an overview of the level of completeness of the 2018 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 and Article 3, paragraph 3 and 4, activities under the Kyoto Protocol. 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 <sub>2</sub> eq)	Level assessment (%)	Cumulative Total (%)
1	3.A.1	Enteric Fermentation - Non-Dairy Cattle	CH4	5,811.98	10.68	10.68
2	3.D.1	Agricultural Soils - Direct Soil Emissions	N2O	5,264.61	9.68	20.36
3	1.A.1	Energy Industries - Solid Fuels	CO2	4,844.66	8.91	29.27
4	1.A.3.b	Road Transport - Liquid Fuels	CO2	4,690.42	8.62	37.89
5	3.A.1	Enteric Fermentation - Dairy Cattle	CH4	3,398.51	6.25	44.14
6	1.A.1	Energy Industries - Peat Fuel	CO2	3,164.78	5.82	49.95
7	1.A.4.b	Residential - Peat Fuel	CO2	3,123.37	5.74	55.70
8	1.A.4.b	Residential - Solid Fuels	CO2	2,483.42	4.57	60.26
9	1.A.2	Manufacturing Industries & Construction - Liquid Fuels	CO2	2,333.98	4.29	64.55
10	1.A.1	Energy Industries - Gaseous Fuels	CO2	1,880.66	3.46	68.01
11	1.A.4.a	Commercial/Institutional - Liquid Fuels	CO2	1,736.82	3.19	71.20
12	5.A	Solid Waste Disposal	CH4	1,318.08	2.42	73.62
13	1.A.1	Energy Industries - Liquid Fuels	CO2	1,254.90	2.31	75.93
14	3.A.2	Enteric Fermentation - Sheep	CH4	1,176.34	2.16	78.09
15	1.A.4.b	Residential - Liquid Fuels	CO2	1,172.99	2.16	80.25
16	2.B.2	Chemical Industry - Nitric Acid Production	N2O	995.32	1.83	82.08
17	2.B.1	Chemical Industry - Ammonia Production	CO2	990.23	1.82	83.90
18	2.A.1	Cement Production	CO2	884.00	1.62	85.52
19	1.A.2	Manufacturing Industries & Construction - Gaseous Fuels	CO2	873.02	1.60	87.13
20	1.A.2	Manufacturing Industries & Construction - Solid Fuels	CO2	871.24	1.60	88.73
21	1.A.4.c	Agriculture/Fishing - Liquid Fuels	CO2	747.23	1.37	90.10
22	3.D.2	Agricultural Soils - Indirect Soil Emissions	N2O	555.89	1.02	91.13
23	3.B.1.1	Manure Management - Non-Dairy Cattle	CH4	545.22	1.00	92.13
24	3.B.1.1	Manure Management - Dairy Cattle	CH4	375.67	0.69	92.82
25	3.G.1	Liming - Limestone CaCO <sub>3</sub>	CO2	355.04	0.65	93.47
26	1.A.4.b	Residential - Gaseous Fuels	CO2	269.73	0.50	93.97
27	1.A.4.b	Residential - Peat Fuel	CH4	227.65	0.42	94.39
28	1.A.4.a	Commercial/Institutional - Gaseous Fuels	CO2	223.49	0.41	94.80
29	2.A.2	Lime Production	CO2	214.08	0.39	95.19

**Table 1.7 Key Category Analysis Level Assessment 2019 (excluding LULUCF)**

Ranking	IPCC Category code	IPCC Category	Greenhouse Gas	2019 Estimate (kt CO <sub>2</sub> eq)	Level assessment (%)	Cumulative Total (%)
1	1.A.3.b	Road Transport - Liquid Fuels	CO2	11,488.20	19.22	19.22
2	3.A.1	Enteric Fermentation - Non-Dairy Cattle	CH4	6,892.34	11.53	30.75
3	1.A.1	Energy Industries - Gaseous Fuels	CO2	5,384.62	9.01	39.76
4	3.D.1	Agricultural Soils - Direct Soil Emissions	N2O	5,150.93	8.62	48.37
5	3.A.1	Enteric Fermentation - Dairy Cattle	CH4	4,453.18	7.45	55.82
6	1.A.4.b	Residential - Liquid Fuels	CO2	3,487.53	5.83	61.66
7	1.A.2	Manufacturing Industries & Construction - Gaseous Fuels	CO2	2,821.08	4.72	66.38
8	1.A.1	Energy Industries - Peat Fuel	CO2	2,100.07	3.51	69.89
9	2.A.1	Cement Production	CO2	1,892.60	3.17	73.05
10	1.A.4.b	Residential - Gaseous Fuels	CO2	1,387.40	2.32	75.38
11	1.A.2	Manufacturing Industries & Construction - Liquid Fuels	CO2	1,234.17	2.06	77.44
12	1.A.4.a	Commercial/Institutional - Gaseous Fuels	CO2	986.12	1.65	79.09
13	1.A.4.b	Residential - Peat Fuel	CO2	786.97	1.32	80.41
14	1.A.4.a	Commercial/Institutional - Liquid Fuels	CO2	778.66	1.30	81.71
15	3.B.1.1	Manure Management - Non-Dairy Cattle	CH4	726.63	1.22	82.92
16	1.A.4.b	Residential - Solid Fuels	CO2	712.44	1.19	84.12
17	3.A.2	Enteric Fermentation - Sheep	CH4	710.65	1.19	85.31
18	5.A	Solid Waste Disposal	CH4	676.88	1.13	86.44
19	2.F.1	Product Uses as Substitutes for ODS -Refrigeration and air-con	HFC	671.60	1.12	87.56
20	1.A.1	Energy Industries - Other Fuels	CO2	633.34	1.06	88.62
21	1.A.4.c	Agriculture/Fishing - Liquid Fuels	CO2	610.70	1.02	89.64
22	1.A.1	Energy Industries - Solid Fuels	CO2	583.16	0.98	90.62
23	3.D.2	Agricultural Soils - Indirect Soil Emissions	N2O	572.39	0.96	91.58
24	1.A.1	Energy Industries - Liquid Fuels	CO2	516.79	0.86	92.44
25	3.B.1.1	Manure Management - Dairy Cattle	CH4	413.96	0.69	93.13
26	3.G.1	Liming - Limestone CaCO3	CO2	343.90	0.58	93.71
27	1.A.2	Manufacturing Industries & Construction - Solid Fuels	CO2	314.07	0.53	94.23
28	1.A.3.d	Navigation - Liquid Fuels	CO2	274.27	0.46	94.69
29	3.B.2.1	Manure Management - Non-Dairy Cattle	N2O	272.59	0.46	95.15

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

Ranking	IPCC Category code	IPCC Category	Greenhouse Gas	1990 Estimate (kt CO <sub>2</sub> eq)	1990 Estimate for LULUCF (kt CO <sub>2</sub> eq)	Absolute Values (kt CO <sub>2</sub> eq)	Level assessment (%)	Cumulative Total (%)
1	4.C	LULUCF - Grassland	CO2	0.00	6,964.36	6,964.36	10.23	10.23
2	3.A.1	Enteric Fermentation - Non-Dairy Cattle	CH4	5,811.98	0.00	5,811.98	8.54	18.77
3	3.D.1	Agricultural Soils - Direct Soil Emissions	N2O	5,264.61	0.00	5,264.61	7.73	26.50
4	1.A.1	Energy Industries - Solid Fuels	CO2	4,844.66	0.00	4,844.66	7.12	33.61
5	1.A.3.b	Road Transport - Liquid Fuels	CO2	4,690.42	0.00	4,690.42	6.89	40.50
6	4.A.1	LULUCF - Forest land Remaining Forest Land	CO2	0.00	-3,855.65	3,855.65	5.66	46.17
7	3.A.1	Enteric Fermentation - Dairy Cattle	CH4	3,398.51	0.00	3,398.51	4.99	51.16
8	1.A.1	Energy Industries - Peat Fuel	CO2	3,164.78	0.00	3,164.78	4.65	55.81
9	1.A.4.b	Residential - Peat Fuel	CO2	3,123.37	0.00	3,123.37	4.59	60.40
10	1.A.4.b	Residential - Solid Fuels	CO2	2,483.42	0.00	2,483.42	3.65	64.04
11	1.A.2	Manufacturing Industries & Construction - Liquid Fuels	CO2	2,333.98	0.00	2,333.98	3.43	67.47
12	1.A.1	Energy Industries - Gaseous Fuels	CO2	1,880.66	0.00	1,880.66	2.76	70.23
13	1.A.4.a	Commercial/Institutional - Liquid Fuels	CO2	1,736.82	0.00	1,736.82	2.55	72.78
14	4.D	LULUCF - Wetlands	CO2	0.00	1,735.30	1,735.30	2.55	75.33
15	5.A	Solid Waste Disposal	CH4	1,318.08	0.00	1,318.08	1.94	77.27
16	1.A.1	Energy Industries - Liquid Fuels	CO2	1,254.90	0.00	1,254.90	1.84	79.11
17	3.A.2	Enteric Fermentation - Sheep	CH4	1,176.34	0.00	1,176.34	1.73	80.84
18	1.A.4.b	Residential - Liquid Fuels	CO2	1,172.99	0.00	1,172.99	1.72	82.56
19	2.B.2	Chemical Industry - Nitric Acid Production	N2O	995.32	0.00	995.32	1.46	84.02
20	2.B.1	Chemical Industry - Ammonia Production	CO2	990.23	0.00	990.23	1.45	85.48
21	2.A.1	Cement Production	CO2	884.00	0.00	884.00	1.30	86.78
22	1.A.2	Manufacturing Industries & Construction - Gaseous Fuels	CO2	873.02	0.00	873.02	1.28	88.06
23	1.A.2	Manufacturing Industries & Construction - Solid Fuels	CO2	871.24	0.00	871.24	1.28	89.34
24	1.A.4.c	Agriculture/Fishing - Liquid Fuels	CO2	747.23	0.00	747.23	1.10	90.44
25	3.D.2	Agricultural Soils - Indirect Soil Emissions	N2O	555.89	0.00	555.89	0.82	91.25
26	3.B.1.1	Manure Management - Non-Dairy Cattle	CH4	545.22	0.00	545.22	0.80	92.05
27	4.G	LULUCF - Harvested wood products	CO2	0.00	-413.04	413.04	0.61	92.66
28	3.B.1.1	Manure Management - Dairy Cattle	CH4	375.67	0.00	375.67	0.55	93.21
29	3.G.1	Liming - Limestone CaCO3	CO2	355.04	0.00	355.04	0.52	93.73
30	1.A.4.b	Residential - Gaseous Fuels	CO2	269.73	0.00	269.73	0.40	94.13
31	4.C	LULUCF - Grassland	CH4	0.00	269.63	269.63	0.40	94.53
32	1.A.4.b	Residential - Peat Fuel	CH4	227.65	0.00	227.65	0.33	94.86
33	1.A.4.a	Commercial/Institutional - Gaseous Fuels	CO2	223.49	0.00	223.49	0.33	95.19

**Table 1.9 Key Category Analysis Level Assessment 2019 (including LULUCF)**

Ranking	IPCC Category code	IPCC Category	Greenhouse Gas	2019 Estimate (kt CO <sub>2</sub> eq)	2019 Estimate for LULUCF (kt CO <sub>2</sub> eq)	Absolute Values (kt CO <sub>2</sub> eq)	Level assessment (%)	Cumulative Total (%)
1	1.A.3.b	Road Transport - Liquid Fuels	CO2	11,488.20	0.00	11,488.20	15.31	15.31
2	3.A.1	Enteric Fermentation - Non-Dairy Cattle	CH4	6,892.34	0.00	6,892.34	9.18	24.49
3	4.C	LULUCF - Grassland	CO2	0.00	6,684.10	6,684.10	8.91	33.40
4	1.A.1	Energy Industries - Gaseous Fuels	CO2	5,384.62	0.00	5,384.62	7.17	40.57
5	3.D.1	Agricultural Soils - Direct Soil Emissions	N2O	5,150.93	0.00	5,150.93	6.86	47.43
6	3.A.1	Enteric Fermentation - Dairy Cattle	CH4	4,453.18	0.00	4,453.18	5.93	53.37
7	4.A.2	LULUCF - Land Converted to Forest Land	CO2	0.00	-3,570.50	3,570.50	4.76	58.12
8	1.A.4.b	Residential - Liquid Fuels	CO2	3,487.53	0.00	3,487.53	4.65	62.77
9	1.A.2	Manufacturing Industries & Construction - Gaseous Fuels	CO2	2,821.08	0.00	2,821.08	3.76	66.53
10	4.D	LULUCF - Wetlands	CO2	0.00	2,212.32	2,212.32	2.95	69.48
11	1.A.1	Energy Industries - Peat Fuel	CO2	2,100.07	0.00	2,100.07	2.80	72.28
12	2.A.1	Cement Production	CO2	1,892.60	0.00	1,892.60	2.52	74.80
13	1.A.4.b	Residential - Gaseous Fuels	CO2	1,387.40	0.00	1,387.40	1.85	76.65
14	1.A.2	Manufacturing Industries & Construction - Liquid Fuels	CO2	1,234.17	0.00	1,234.17	1.64	78.29
15	4.A.1	LULUCF - Forest land Remaining Forest Land	CO2	0.00	-1,117.22	1,117.22	1.49	79.78
16	1.A.4.a	Commercial/Institutional - Gaseous Fuels	CO2	986.12	0.00	986.12	1.31	81.09
17	1.A.4.b	Residential - Peat Fuel	CO2	786.97	0.00	786.97	1.05	82.14
18	1.A.4.a	Commercial/Institutional - Liquid Fuels	CO2	778.66	0.00	778.66	1.04	83.18
19	3.B.1.1	Manure Management - Non-Dairy Cattle	CH4	726.63	0.00	726.63	0.97	84.15
20	1.A.4.b	Residential - Solid Fuels	CO2	712.44	0.00	712.44	0.95	85.10
21	3.A.2	Enteric Fermentation - Sheep	CH4	710.65	0.00	710.65	0.95	86.04
22	5.A	Solid Waste Disposal	CH4	676.88	0.00	676.88	0.90	86.95
23	2.F.1	Product Uses as Substitutes for ODS -Refrigeration and air-con	HFC	671.60	0.00	671.60	0.89	87.84
24	1.A.1	Energy Industries - Other Fuels	CO2	633.34	0.00	633.34	0.84	88.68
25	4.G	LULUCF - Harvested wood products	CO2	0.00	-617.93	617.93	0.82	89.51
26	1.A.4.c	Agriculture/Fishing - Liquid Fuels	CO2	610.70	0.00	610.70	0.81	90.32
27	1.A.1	Energy Industries - Solid Fuels	CO2	583.16	0.00	583.16	0.78	91.10
28	3.D.2	Agricultural Soils - Indirect Soil Emissions	N2O	572.39	0.00	572.39	0.76	91.86
29	1.A.1	Energy Industries - Liquid Fuels	CO2	516.79	0.00	516.79	0.69	92.55
30	3.B.1.1	Manure Management - Dairy Cattle	CH4	413.96	0.00	413.96	0.55	93.10
31	3.G.1	Liming - Limestone CaCO3	CO2	343.90	0.00	343.90	0.46	93.56
32	1.A.2	Manufacturing Industries & Construction - Solid Fuels	CO2	314.07	0.00	314.07	0.42	93.98
33	1.A.3.d	Navigation - Liquid Fuels	CO2	274.27	0.00	274.27	0.37	94.34
34	3.B.2.1	Manure Management - Non-Dairy Cattle	N2O	272.59	0.00	272.59	0.36	94.71
35	3.B.1.3	Manure Management - Swine	CH4	266.38	0.00	266.38	0.35	95.06

**Table 1.10 Key Category Analysis Trend Assessment 1990-2019 (excluding LULUCF)**

Ranking	IPCC Category code	IPCC Category	Greenhouse Gas	1990 Estimate (kt CO <sub>2</sub> eq)	2019 Estimate (kt CO <sub>2</sub> eq)	Trend Assessment (%)	Contribution to Trend (%)	Cumulative total (%)
1	1.A.3.b	Road Transport - Liquid Fuels	CO2	4,690.42	11,488.20	9.64	16.58	16.58
2	1.A.1	Energy Industries - Solid Fuels	CO2	4,844.66	583.16	7.22	12.41	28.98
3	1.A.1	Energy Industries - Gaseous Fuels	CO2	1,880.66	5,384.62	5.05	8.68	37.67
4	1.A.4.b	Residential - Peat Fuel	CO2	3,123.37	786.97	4.03	6.92	44.59
5	1.A.4.b	Residential - Liquid Fuels	CO2	1,172.99	3,487.53	3.35	5.75	50.34
6	1.A.4.b	Residential - Solid Fuels	CO2	2,483.42	712.44	3.07	5.28	55.62
7	1.A.2	Manufacturing Industries & Construction - Gaseous Fuels	CO2	873.02	2,821.08	2.83	4.87	60.49
8	1.A.1	Energy Industries - Peat Fuel	CO2	3,164.78	2,100.07	2.10	3.61	64.10
9	1.A.2	Manufacturing Industries & Construction - Liquid Fuels	CO2	2,333.98	1,234.17	2.03	3.48	67.58
10	1.A.4.a	Commercial/Institutional - Liquid Fuels	CO2	1,736.82	778.66	1.72	2.96	70.54
11	1.A.4.b	Residential - Gaseous Fuels	CO2	269.73	1,387.40	1.66	2.86	73.39
12	2.A.1	Cement Production	CO2	884.00	1,892.60	1.40	2.41	75.80
13	1.A.1	Energy Industries - Liquid Fuels	CO2	1,254.90	516.79	1.31	2.26	78.06
14	5.A	Solid Waste Disposal	CH4	1,318.08	676.88	1.17	2.02	80.08
15	1.A.4.a	Commercial/Institutional - Gaseous Fuels	CO2	223.49	986.12	1.13	1.94	82.02
16	3.A.1	Enteric Fermentation - Dairy Cattle	CH4	3,398.51	4,453.18	1.09	1.88	83.90
17	2.F.1	Product Uses as Substitutes for ODS -Refrigeration and air-con	HFC	-	671.60	1.02	1.76	85.65
18	1.A.2	Manufacturing Industries & Construction - Solid Fuels	CO2	871.24	314.07	0.98	1.68	87.34
19	3.D.1	Agricultural Soils - Direct Soil Emissions	N2O	5,264.61	5,150.93	0.97	1.66	89.00
20	1.A.1	Energy Industries - Other Fuels	CO2	-	633.34	0.96	1.66	90.65
21	3.A.2	Enteric Fermentation - Sheep	CH4	1,176.34	710.65	0.89	1.52	92.18
22	3.A.1	Enteric Fermentation - Non-Dairy Cattle	CH4	5,811.98	6,892.34	0.77	1.32	93.50
23	1.A.4.c	Agriculture/Fishing - Liquid Fuels	CO2	747.23	610.70	0.32	0.55	94.05
24	1.A.2	Manufacturing Industries & Construction - Non-Renewable waste	CO2	-	198.45	0.30	0.52	94.57
25	1.A.4.b	Residential - Peat Fuel	CH4	227.65	57.62	0.29	0.50	95.08

**Table 1.11 Key Category Analysis Trend Assessment 2019 (including LULUCF)**

Ranking	IPCC Category code	IPCC Category	Greenhouse Gas	1990 Estimate (kt CO <sub>2</sub> eq)	2019 Estimate (kt CO <sub>2</sub> eq)	Trend Assessment (%)	Contribution to Trend (%)	Cumulative total (%)
1	1.A.3.b	Road Transport - Liquid Fuels	CO2	4,690.42	11,488.20	7.64	13.38	13.38
2	1.A.1	Energy Industries - Solid Fuels	CO2	4,844.66	583.16	5.75	10.07	23.45
3	4.A.2	LULUCF - Land Converted to Forest Land	CO2	6.77	3,570.50	4.31	7.54	30.99
4	1.A.1	Energy Industries - Gaseous Fuels	CO2	1,880.66	5,384.62	4.00	7.01	38.01
5	4.A.1	LULUCF - Forest land Remaining Forest Land	CO2	3,855.65	1,117.22	3.79	6.63	44.64
6	1.A.4.b	Residential - Peat Fuel	CO2	3,123.37	786.97	3.21	5.62	50.26
7	1.A.4.b	Residential - Liquid Fuels	CO2	1,172.99	3,487.53	2.65	4.65	54.91
8	1.A.4.b	Residential - Solid Fuels	CO2	2,483.42	712.44	2.45	4.29	59.20
9	1.A.2	Manufacturing Industries & Construction - Gaseous Fuels	CO2	873.02	2,821.08	2.25	3.94	63.13
10	1.A.1	Energy Industries - Peat Fuel	CO2	3,164.78	2,100.07	1.68	2.94	66.07
11	1.A.2	Manufacturing Industries & Construction - Liquid Fuels	CO2	2,333.98	1,234.17	1.62	2.83	68.91
12	1.A.4.a	Commercial/Institutional - Liquid Fuels	CO2	1,736.82	778.66	1.37	2.41	71.31
13	1.A.4.b	Residential - Gaseous Fuels	CO2	269.73	1,387.40	1.32	2.31	73.62
14	4.C	LULUCF - Grassland	CO2	6,964.36	6,684.10	1.20	2.10	75.72
15	2.A.1	Cement Production	CO2	884.00	1,892.60	1.11	1.94	77.67
16	1.A.1	Energy Industries - Liquid Fuels	CO2	1,254.90	516.79	1.05	1.83	79.50
17	5.A	Solid Waste Disposal	CH4	1,318.08	676.88	0.94	1.64	81.15
18	1.A.4.a	Commercial/Institutional - Gaseous Fuels	CO2	223.49	986.12	0.89	1.57	82.71
19	3.A.1	Enteric Fermentation - Dairy Cattle	CH4	3,398.51	4,453.18	0.85	1.50	84.21
20	2.F.1	Product Uses as Substitutes for ODS -Refrigeration and air-con	HFC	-	671.60	0.81	1.42	85.63
21	3.D.1	Agricultural Soils - Direct Soil Emissions	N2O	5,264.61	5,150.93	0.79	1.38	87.01
22	1.A.2	Manufacturing Industries & Construction - Solid Fuels	CO2	871.24	314.07	0.78	1.37	88.38
23	1.A.1	Energy Industries - Other Fuels	CO2	-	633.34	0.77	1.34	89.72
24	3.A.2	Enteric Fermentation - Sheep	CH4	1,176.34	710.65	0.71	1.24	90.96
25	3.A.1	Enteric Fermentation - Non-Dairy Cattle	CH4	5,811.98	6,892.34	0.59	1.03	91.99
26	4.D	LULUCF - Wetlands	CO2	1,735.30	2,212.32	0.36	0.63	92.63
27	1.A.4.c	Agriculture/Fishing - Liquid Fuels	CO2	747.23	610.70	0.26	0.45	93.08
28	1.A.2	Manufacturing Industries & Construction - Non-Renewable waste	CO2	-	198.45	0.24	0.42	93.50
29	1.A.4.b	Residential - Peat Fuel	CH4	227.65	57.62	0.23	0.41	93.91
30	4.A	LULUCF - Drained organic soils from forest land	N2O	-	182.03	0.22	0.39	94.29
31	1.A.3.d	Navigation - Liquid Fuels	CO2	84.90	274.27	0.22	0.38	94.67
32	4.G	LULUCF - Harvested wood products	CO2	413.04	617.93	0.20	0.34	95.02

Table 1.12 Tier 1 Uncertainty Estimates 2019 excluding LULUCF (continued on following pages)

	CATEGORIES OF EMISSIONS AND REMOVALS	Gas	Emissions in 1990 (kt CO2eq)	Emissions in 2019 (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 2019	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	5384.62	1.00	2.50	2.69	0.01	0.06	0.14	0.15	0.04
2	1.A.1 Fuel combustion - Energy Industries - Liquid Fuels	CO2	1254.90	516.79	1.00	2.50	2.69	0.00	0.00	0.01	0.04	0.00
3	1.A.1 Fuel combustion - Energy Industries - Other Fossil Fuels	CO2	0.00	633.34	1.00	5.00	5.10	0.00	0.00	0.02	0.06	0.00
4	1.A.1 Fuel combustion - Energy Industries - Peat	CO2	3164.78	2100.07	1.00	5.00	5.10	0.09	0.03	0.05	0.13	0.02
5	1.A.1 Fuel combustion - Energy Industries - Solid Fuels	CO2	4844.66	583.16	1.00	5.00	5.10	0.21	0.00	0.02	0.44	0.19
6	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Gaseous Fuels	CO2	873.02	2821.08	2.50	2.50	3.54	0.00	0.03	0.18	0.09	0.04
7	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	CO2	2333.98	1234.17	10.00	2.50	10.31	0.20	0.05	0.32	0.06	0.11
8	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Other Fossil Fuels	CO2	0.00	198.45	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	314.07	2.00	5.00	5.39	0.01	0.00	0.02	0.06	0.00
11	1.A.3.a Domestic Aviation	CO2	47.98	17.49	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	11488.20	1.25	3.00	3.25	0.08	0.39	0.37	0.35	0.26
13	1.A.3.c Railways	CO2	133.19	122.17	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	274.27	1.00	2.00	2.24	0.00	0.00	0.01	0.01	0.00
15	1.A.3.e Other Transportation	CO2	73.32	143.81	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	2373.51	2.50	2.50	3.54	0.00	0.02	0.15	0.08	0.03
17	1.A.4 Other Sectors - Liquid Fuels	CO2	3657.03	4876.88	10.00	5.00	11.18	0.56	0.83	1.27	0.08	1.61
18	1.A.4 Other Sectors - Peat	CO2	3259.11	786.97	10.00	20.00	22.36	1.79	0.09	0.20	1.03	1.10
19	1.A.4 Other Sectors - Solid Fuels	CO2	2485.97	714.58	5.00	10.00	11.18	0.26	0.02	0.09	0.37	0.15
20	1.B.2.b Fugitive Emissions from Fuels - Oil and Natural Gas - Natural Gas	CO2	0.01	0.28	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	1892.60	1.50	1.50	2.12	0.00	0.00	0.07	0.03	0.01
22	2.A.2 Lime Production	CO2	214.08	163.65	1.50	1.50	2.12	0.00	0.00	0.01	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	1.42	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	114.87	165.89	30.00	5.00	30.41	0.00	0.01	0.13	0.00	0.02
28	3.G Liming	CO2	355.04	343.90	5.00	50.00	50.25	0.11	0.08	0.04	0.04	0.00
29	3.H Urea Application	CO2	96.68	91.98	5.00	50.00	50.25	0.01	0.01	0.01	0.01	0.00
30	5.C Incineration and Open Burning of Waste	CO2	95.59	31.97	10.00	5.00	11.18	0.00	0.00	0.01	0.01	0.00
<b>Total CO2</b>			<b>32943.60</b>	<b>37275.32</b>				<b>3.343</b>	<b>1.619</b>			<b>3.593</b>
							<b>Level uncertainty, CO2</b>	<b>1.828</b>	<b>1.272</b>	<b>Trend uncertainty, CO2</b>		<b>1.896</b>

	CATEGORIES OF EMISSIONS AND REMOVALS	Gas	Emissions in 1990 (kt CO2eq)	Emissions in 2019 (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 2019	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	3.91	1.00	66.00	66.01	0.00	0.00	0.00	0.00	0.00
2	1.A.1 Fuel combustion - Energy Industries - Gaseous Fuels	CH4	3.43	2.49	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	0.39	0.16	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	2.78	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	1.90	1.38	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	0.91	0.11	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	1.91	4.71	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	0.40	1.26	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	2.20	1.04	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	0.18	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	2.30	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	0.03	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	48.81	9.12	1.25	71.00	71.01	0.00	0.00	0.00	0.06	0.00
15	1.A.3.c Railways	CH4	0.19	0.17	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	0.20	0.65	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00
17	1.A.3.e Other Transportation	CH4	0.03	0.06	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00
18	1.A.4 Other Sectors - Biomass	CH4	14.08	12.80	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	1.12	5.29	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	10.81	15.36	10.00	66.00	66.75	0.00	0.00	0.00	0.00	0.00
21	1.A.4 Other Sectors - Peat	CH4	227.98	57.62	10.00	50.00	50.99	0.05	0.00	0.01	0.18	0.03
22	1.A.4 Other Sectors - Solid Fuels	CH4	196.51	55.02	5.00	50.00	50.25	0.03	0.00	0.01	0.15	0.02
23	1.B.1 Fugitive emissions from Solid Fuels	CH4	55.56	18.35	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	0.21	0.30	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	48.65	58.33	10.00	50.00	50.99	0.00	0.00	0.02	0.00	0.00
26	3.A.1 Enteric Fermentation-Dairy Cattle	CH4	3398.51	4453.18	1.00	15.00	15.03	0.88	1.25	0.12	0.20	0.05
27	3.A.1 Enteric Fermentation-Non-Dairy Cattle	CH4	5811.98	6892.34	1.00	15.00	15.03	2.58	3.00	0.18	0.14	0.05
28	3.A.2 Enteric Fermentation-Sheep	CH4	1176.34	710.65	1.00	30.00	30.02	0.42	0.13	0.02	0.32	0.10
29	3.A.3 Enteric Fermentation-Swine	CH4	41.37	54.00	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	37.87	41.04	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	375.67	413.96	1.00	15.00	15.03	0.01	0.01	0.01	0.00	0.00
32	3.B.1.1 Manure Management-Non-Dairy Cattle	CH4	545.22	726.63	1.00	15.00	15.03	0.02	0.03	0.02	0.04	0.00
33	3.B.1.2 Manure Management-Sheep	CH4	99.19	62.50	1.00	30.00	30.02	0.00	0.00	0.00	0.03	0.00
34	3.B.1.3 Manure Management-Swine	CH4	206.49	266.38	1.00	30.00	30.02	0.01	0.02	0.01	0.02	0.00
35	3.B.1.4 Manure Management-Other Animals	CH4	61.58	102.80	1.00	30.00	30.02	0.00	0.00	0.00	0.02	0.00
36	5.A Solid Waste Disposal	CH4	1318.08	676.88	34.64	34.64	48.99	1.41	0.31	0.61	0.49	0.61
37	5.B Biological treatment of solid waste: Composting and AD	CH4	0.00	26.87	10.00	30.00	31.62	0.00	0.00	0.01	0.01	0.00
38	5.C Incineration and Open Burning of Waste	CH4	1.05	0.22	10.00	30.00	31.62	0.00	0.00	0.00	0.00	0.00
39	5.D Wastewater Treatment and Discharge	CH4	61.10	51.14	10.00	30.00	31.62	0.00	0.00	0.01	0.01	0.00
<b>Total CH4</b>			<b>13752.06</b>	<b>14730.52</b>				<b>5.432</b>	<b>4.769</b>			<b>0.883</b>
								<b>Level uncertainty, CH4</b>	<b>2.331</b>	<b>2.184</b>	<b>Trend uncertainty, CH4</b>	<b>0.940</b>
<b>Combined CO2 and CH4</b>			<b>46695.66</b>	<b>52005.84</b>				<b>8.775</b>	<b>6.388</b>			<b>4.476</b>
								<b>Level uncertainty, CO2 and CH4</b>	<b>2.962</b>	<b>2.527</b>	<b>Trend uncertainty, CO2 &amp; CH4</b>	<b>2.116</b>

	CATEGORIES OF EMISSIONS AND REMOVALS	Gas	Emissions in 1990 (kt CO2eq)	Emissions in 2019 (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 2019	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	11.30	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	10.21	84.34	1.00	50.00	50.01	0.00	0.00	0.00	0.07	0.00
3	1.A.1 Fuel combustion - Energy Industries - Liquid Fuels	N2O	1.47	0.42	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	4.42	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	52.07	37.77	1.00	50.00	50.01	0.00	0.00	0.00	0.02	0.00
6	1.A.1 Fuel combustion - Energy Industries - Solid Fuels	N2O	7.74	0.95	1.00	50.00	50.01	0.00	0.00	0.00	0.01	0.00
7	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Biomass	N2O	3.04	7.59	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	0.47	1.50	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	5.16	2.42	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	0.42	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	4.12	1.48	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00
13	1.A.3.a Domestic Aviation	N2O	0.39	0.14	1.00	66.00	66.01	0.00	0.00	0.00	0.00	0.00
14	1.A.3.b Road Transportation	N2O	52.78	127.19	1.25	68.00	68.01	0.00	0.02	0.00	0.09	0.01
15	1.A.3.c Railways	N2O	15.49	14.21	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	0.67	2.23	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	0.08	1.00	25.00	25.02	0.00	0.00	0.00	0.00	0.00
18	1.A.4 Other Sectors - Biomass	N2O	2.23	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	0.27	1.26	2.50	50.00	50.06	0.00	0.00	0.00	0.00	0.00
20	1.A.4 Other Sectors - Liquid Fuels	N2O	76.59	67.01	10.00	50.00	50.99	0.01	0.00	0.02	0.02	0.00
21	1.A.4 Other Sectors - Peat	N2O	13.22	3.21	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	11.72	3.29	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	995.32	0.00	1.00	10.00	10.05	0.03	0.00	0.00	0.20	0.04
25	2.G Other Product Manufacture and Use	N2O	31.34	44.00	5.00	5.00	7.07	0.00	5.00	0.00	0.01	0.00
26	3.B.2.1 Manure Management -Dairy Cattle	N2O	56.13	55.58	11.22	50.00	51.24	0.00	0.00	0.02	0.01	0.00
27	3.B.2.1 Manure Management -Non-Dairy Cattle	N2O	201.51	272.59	11.22	50.00	51.24	0.04	0.05	0.08	0.05	0.01
28	3.B.2.2 Manure Management -Sheep	N2O	22.67	15.34	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	10.08	12.57	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	0.24	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	0.65	0.32	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	3.44	4.58	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	0.32	0.37	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	3.81	5.59	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	2.72	1.01	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	187.40	229.03	11.22	100.00	100.63	0.12	0.15	0.07	0.04	0.01
37	3.D.1.1 Inorganic N Fertilizer	N2O	2158.39	2115.32	1.00	50.00	50.01	3.94	3.13	0.05	0.24	0.06
38	3.D.1.2 Organic N Fertilizers	N2O	666.31	858.76	11.22	100.00	100.63	1.52	2.09	0.25	0.23	0.12
39	3.D.1.3 Urine and Dung Deposited by Grazing Animals	N2O	1273.13	1265.92	11.18	50.00	51.23	1.44	1.18	0.37	0.12	0.15
40	3.D.1.4 Crop Residues	N2O	388.22	218.14	10.00	100.00	100.50	0.51	0.13	0.06	0.38	0.15
41	3.D.1.5 Mineralization/Immobilization Associated with Loss/Gain of Soil Organic Matter	N2O	20.11	18.95	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	758.45	673.83	12.22	100.00	100.74	1.97	1.29	0.21	0.29	0.13
43	3.D.2 Indirect N2O Emissions From Managed Soils	N2O	555.89	572.39	11.18	50.00	51.23	0.27	0.24	0.17	0.04	0.03
44	5.B Biological treatment of solid waste: Composting	N2O	0.00	17.50	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	1.10	0.34	10.00	10.00	14.14	0.00	0.00	0.00	0.00	0.00
46	5.D Wastewater Treatment and Discharge	N2O	75.14	99.94	10.00	10.00	14.14	0.00	0.00	0.03	0.00	0.00
<b>Total N2O</b>			<b>7670.06</b>	<b>6855.33</b>				<b>9.863</b>	<b>8.302</b>			<b>0.706</b>
								<b>Level uncertainty, N2O</b>	<b>3.141</b>	<b>2.881</b>		<b>0.841</b>
<b>Combined CO2, CH4 and N2O</b>			<b>54365.73</b>	<b>58861.17</b>				<b>18.638</b>	<b>14.690</b>			<b>5.183</b>
								<b>Level uncertainty, CO2, CH4 &amp; N2O</b>	<b>4.317</b>	<b>3.833</b>	<b>Trend uncertainty, CO2, CH4 &amp; N2O</b>	<b>2.277</b>

	CATEGORIES OF EMISSIONS AND REMOVALS	Gas	Emissions in 1990 (kt CO2eq)	Emissions in 2019 (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 2019	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	1.17	906.01	20.00	10.00	22.36	0.00	0.11	0.47	0.17	0.25
2	2.G Other Product Manufacture and Use	Aggregate F-gases	33.42	10.46	10.00	0.00	10.00	0.00	0.00	0.00	0.00	0.00
<b>Total F-gases</b>			<b>34.59</b>	<b>916.47</b>				<b>0.000</b>	<b>0.115</b>			<b>0.250</b>
								<b>Level uncertainty, F-gases</b>		<b>0.006</b>	<b>0.339</b>	<b>0.500</b>
<b>TOTAL for all gases</b>			<b>54400.32</b>	<b>59777.64</b>				<b>18.638</b>	<b>14.805</b>	<b>Total trend uncertainty for all GHGs</b>		<b>5.432</b>
								<b>Total level uncertainty for all GHGs</b>		<b>4.317</b>	<b>3.848</b>	<b>2.331</b>

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

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

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):

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

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 2019 including LULUCF (continued on following pages)

	CATEGORIES OF EMISSIONS AND REMOVALS	Gas	Emissions in 1990 (kt CO2eq)	Emissions in 2019 (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 2019	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	5384.62	1.00	2.50	2.69	0.01	0.05	0.06	0.09	0.13	0.14	0.04
2	1.A.1 Fuel combustion - Energy Industries - Liquid Fuels	CO2	1254.90	516.79	1.00	2.50	2.69	0.00	0.00	0.01	0.01	0.01	0.04	0.00
3	1.A.1 Fuel combustion - Energy Industries - Other Fossil Fuels	CO2	0.00	633.34	1.00	5.00	5.10	0.00	0.00	0.01	0.01	0.02	0.05	0.00
4	1.A.1 Fuel combustion - Energy Industries - Peat	CO2	3164.78	2100.07	1.00	5.00	5.10	0.07	0.03	0.02	0.04	0.05	0.11	0.01
5	1.A.1 Fuel combustion - Energy Industries - Solid Fuels	CO2	4844.66	583.16	1.00	5.00	5.10	0.17	0.00	0.08	0.01	0.01	0.39	0.15
6	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Gaseous Fuels	CO2	873.02	2821.08	2.50	2.50	3.54	0.00	0.02	0.03	0.05	0.17	0.08	0.03
7	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	CO2	2333.98	1234.17	10.00	2.50	10.31	0.16	0.04	0.02	0.02	0.29	0.05	0.09
8	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Other Fossil Fuels	CO2	0.00	198.45	1.00	5.00	5.10	0.00	0.00	0.00	0.00	0.00	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	314.07	2.00	5.00	5.39	0.01	0.00	0.01	0.01	0.01	0.05	0.00
11	1.A.3.a Domestic Aviation	CO2	47.98	17.49	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	11488.20	1.25	3.00	3.25	0.07	0.34	0.11	0.19	0.34	0.32	0.22
13	1.A.3.c Railways	CO2	133.19	122.17	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	274.27	1.00	2.00	2.24	0.00	0.00	0.00	0.00	0.01	0.01	0.00
15	1.A.3.e Other Transportation	CO2	73.32	143.81	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	2373.51	2.50	2.50	3.54	0.00	0.02	0.03	0.04	0.14	0.08	0.03
17	1.A.4 Other Sectors - Liquid Fuels	CO2	3657.03	4876.88	10.00	5.00	11.18	0.47	0.72	0.02	0.08	1.16	0.08	1.35
18	1.A.4 Other Sectors - Peat	CO2	3259.11	786.97	10.00	20.00	22.36	1.50	0.08	0.05	0.01	0.19	0.92	0.87
19	1.A.4 Other Sectors - Solid Fuels	CO2	2485.97	714.58	5.00	10.00	11.18	0.22	0.02	0.03	0.01	0.08	0.33	0.12
20	1.B.2.b Fugitive Emissions from Fuels - Oil and Natural Gas - Natural Gas	CO2	0.01	0.28	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	1892.60	1.50	1.50	2.12	0.00	0.00	0.02	0.03	0.07	0.02	0.01
22	2.A.2 Lime Production	CO2	214.08	163.65	1.50	1.50	2.12	0.00	0.00	0.00	0.00	0.01	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	1.42	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	114.87	165.89	30.00	5.00	30.41	0.00	0.01	0.00	0.00	0.12	0.00	0.01
28	3.G Liming	CO2	355.04	343.90	5.00	50.00	50.25	0.09	0.07	0.00	0.01	0.04	0.03	0.00
29	3.H Urea Application	CO2	96.68	91.98	5.00	50.00	50.25	0.01	0.01	0.00	0.00	0.01	0.01	0.00
30	4.A.1 Forest Land Remaining Forest Land	CO2	-3855.65	-1117.22	51.00	114.00	124.89	65.43	4.72	0.05	0.02	1.35	5.83	35.81
31	4.A.2 Land Converted to Forest Land	CO2	-6.77	-3570.50	51.00	114.00	124.89	0.00	48.21	0.06	0.06	4.33	6.82	65.27
32	4.B.1 Cropland Remaining Cropland	CO2	20.24	-110.14	20.59	69.15	72.15	0.00	0.02	0.00	0.00	0.05	0.15	0.03
33	4.C. Grassland	CO2	6964.36	6684.10	12.22	90.00	90.83	112.90	89.36	0.01	0.11	1.94	1.25	5.33
34	4.D. Wetlands	CO2	1735.30	2212.32	21.49	101.45	103.70	9.14	12.76	0.01	0.04	1.13	0.58	1.61
35	4.E.2 Land Converted to Settlements	CO2	80.46	129.39	39.97	81.83	91.07	0.02	0.03	0.00	0.00	0.12	0.06	0.02
36	4.F.2 Land Converted to Other Land	CO2	0.81	9.71	51.93	75.00	91.23	0.00	0.00	0.00	0.00	0.01	0.01	0.00
37	4.G Harvested Wood Products	CO2	-413.04	-617.93	25.00	26.92	36.74	0.06	0.12	0.00	0.01	0.37	0.08	0.14
38	5.C Incineration and Open Burning of Waste	CO2	95.59	31.97	10.00	5.00	11.18	0.00	0.00	0.00	0.00	0.01	0.01	0.00
	<b>Total CO2</b>		<b>37469.31</b>	<b>40895.04</b>				<b>190.33</b>	<b>156.63</b>					<b>111.16</b>
								<b>Level uncertainty, CO2</b>	<b>13.80</b>	<b>12.52</b>			<b>Trend uncertainty, CO2</b>	<b>10.54</b>

	CATEGORIES OF EMISSIONS AND REMOVALS	Gas	Emissions in 1990 (kt CO2eq)	Emissions in 2019 (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 2019	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	3.91	1.00	66.00	66.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
2	1.A.1 Fuel combustion - Energy Industries - Gaseous Fuels	CH4	3.43	2.49	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	0.39	0.16	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	2.78	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	1.90	1.38	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	0.91	0.11	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	1.91	4.71	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	0.40	1.26	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	2.20	1.04	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	0.18	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	2.30	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	0.03	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	48.81	9.12	1.25	71.00	71.01	0.00	0.00	0.00	0.00	0.00	0.05	0.00	
15	1.A.3.c Railways	CH4	0.19	0.17	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	0.20	0.65	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	0.03	0.06	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	14.08	12.80	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	1.12	5.29	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	10.81	15.36	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	227.98	57.62	10.00	50.00	50.99	0.04	0.00	0.00	0.00	0.01	0.16	0.03	
22	1.A.4 Other Sectors - Solid Fuels	CH4	196.51	55.02	5.00	50.00	50.25	0.03	0.00	0.00	0.00	0.01	0.13	0.02	
23	1.B.1 Fugitive emissions from Solid Fuels	CH4	55.56	18.35	10.00	50.00	50.99	0.00	0.00	0.00	0.00	0.00	0.03	0.00	
24	1.B.2.a Fugitive Emissions from Fuels - Oil and Natural Gas - Oil	CH4	0.21	0.30	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	48.65	58.33	10.00	50.00	50.99	0.00	0.00	0.00	0.00	0.01	0.00	0.00	
26	3A1 Enteric Fermentation-Dairy Cattle	CH4	3398.51	4453.18	1.00	15.00	15.03	0.74	1.09	0.01	0.07	0.11	0.20	0.05	
27	3A1 Enteric Fermentation-Non-Dairy Cattle	CH4	5811.98	6892.34	1.00	15.00	15.03	2.15	2.60	0.01	0.12	0.16	0.16	0.05	
28	3A2 Enteric Fermentation-Sheep	CH4	1176.34	710.65	1.00	30.00	30.02	0.35	0.11	0.01	0.01	0.02	0.28	0.08	
29	3A3 Enteric Fermentation-Swine	CH4	41.37	54.00	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	37.87	41.04	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	375.67	413.96	1.00	15.00	15.03	0.01	0.01	0.00	0.01	0.01	0.00	0.00	
32	3B1.1 Manure Management-Non-Dairy Cattle	CH4	545.22	726.63	1.00	15.00	15.03	0.02	0.03	0.00	0.01	0.02	0.03	0.00	
33	3B1.2 Manure Management-Sheep	CH4	99.19	62.50	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	206.49	266.38	1.00	30.00	30.02	0.01	0.02	0.00	0.00	0.01	0.02	0.00	
35	3B1.4 Manure Management-Other Animals	CH4	61.58	102.80	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	58.51	71.91	30.00	100.00	104.40	0.01	0.01	0.00	0.00	0.05	0.01	0.00	
37	4.B LULUCF - Cropland	CH4	0.05	0.01	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	269.63	253.37	96.40	91.20	132.70	0.36	0.27	0.00	0.00	0.58	0.06	0.34	
39	4.D LULUCF - Wetlands	CH4	131.42	99.93	86.00	66.50	108.71	0.06	0.03	0.00	0.00	0.20	0.05	0.04	
40	5.A Solid Waste Disposal	CH4	1318.08	676.88	34.64	34.64	48.99	1.18	0.27	0.01	0.01	0.56	0.43	0.50	
41	5.B Biological treatment of solid waste: Composting and AD	CH4	0.00	26.87	10.00	30.00	31.62	0.00	0.00	0.00	0.00	0.01	0.01	0.00	
42	5.C Incineration and Open Burning of Waste	CH4	1.05	0.22	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	61.10	51.14	10.00	30.00	31.62	0.00	0.00	0.00	0.00	0.01	0.01	0.00	
<b>Total CH4</b>			<b>14211.65</b>	<b>15155.74</b>				<b>4.97</b>	<b>4.45</b>					<b>1.12</b>	
								<b>Level uncertainty, CH4</b>	<b>2.23</b>	<b>2.11</b>				<b>Trend uncertainty, CH4</b>	<b>1.06</b>
<b>Combined CO2 and CH4</b>			<b>51680.97</b>	<b>56050.78</b>				<b>195.30</b>	<b>161.08</b>				<b>Trend uncertainty, CO2 &amp; CH4</b>	<b>112.28</b>	
								<b>Level uncertainty, CO2 and CH4</b>	<b>13.97</b>	<b>12.69</b>					<b>10.60</b>

	CATEGORIES OF EMISSIONS AND REMOVALS	Gas	Emissions in 1990 (kt CO2eq)	Emissions in 2019 (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 2019	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	11.30	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	10.21	84.34	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	1.47	0.42	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	4.42	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	52.07	37.77	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.02	0.00
6	1.A.1 Fuel combustion - Energy Industries - Solid Fuels	N2O	7.74	0.95	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00
7	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Biomass	N2O	3.04	7.59	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	0.47	1.50	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	5.16	2.42	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	0.42	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	4.12	1.48	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	0.39	0.14	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	52.78	127.19	1.25	68.00	68.01	0.00	0.02	0.00	0.00	0.00	0.08	0.01
15	1.A.3.c Railways	N2O	15.49	14.21	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	0.67	2.23	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	0.08	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	2.23	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	0.27	1.26	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	N2O	76.59	67.01	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	13.22	3.21	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	11.72	3.29	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	995.32	0.00	1.00	10.00	10.05	0.03	0.00	0.02	0.00	0.00	0.18	0.03
25	2.G Other Product Manufacture and Use	N2O	31.34	44.00	5.00	5.00	7.07	0.00	0.00	0.00	0.00	0.01	0.00	0.00
26	3.B.2.1 Manure Management -Dairy Cattle	N2O	56.13	55.58	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	201.51	272.59	11.22	50.00	51.24	0.03	0.05	0.00	0.00	0.07	0.05	0.01
28	3.B.2.2 Manure Management -Sheep	N2O	22.67	15.34	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	10.08	12.57	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	0.24	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	0.65	0.32	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	3.44	4.58	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	0.32	0.37	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	3.81	5.59	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	2.72	1.01	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	187.40	229.03	11.22	100.00	100.63	0.10	0.13	0.00	0.00	0.06	0.05	0.01
37	3.D.1.1 Inorganic N Fertilizer	N2O	2158.39	2115.32	1.00	50.00	50.01	3.29	2.71	0.00	0.04	0.05	0.18	0.03
38	3.D.1.2 Organic N Fertilizers	N2O	666.31	858.76	11.22	100.00	100.63	1.27	1.81	0.00	0.01	0.23	0.24	0.11
39	3.D.1.3 Urine and Dung Deposited by Grazing Animals	N2O	1273.13	1265.92	11.18	50.00	51.23	1.20	1.02	0.00	0.02	0.34	0.09	0.12
40	3.D.1.4 Crop Residues	N2O	388.22	218.14	10.00	100.00	100.50	0.43	0.12	0.00	0.00	0.05	0.34	0.12
41	3.D.1.5 Mineralization/Immobilization Associated with Loss/Gain of Soil Organic Matter	N2O	20.11	18.95	22.57	100.00	102.52	0.00	0.00	0.00	0.00	0.01	0.00	0.00
42	3.D.1.6 Cultivation of Organic Soils	N2O	758.45	673.83	12.22	100.00	100.74	1.65	1.12	0.00	0.01	0.20	0.24	0.10
43	3.D.2 Indirect N2O Emissions From Managed Soils	N2O	555.89	572.39	11.18	50.00	51.23	0.23	0.21	0.00	0.01	0.15	0.02	0.02
44	4.A LULUCF - Forest Land	N2O	92.86	182.12	30.00	100.00	104.40	0.03	0.09	0.00	0.00	0.13	0.14	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	15.46	76.50	91.02	100.00	135.22	0.00	0.03	0.00	0.00	0.17	0.10	0.04
47	4.D LULUCF - Wetlands	N2O	31.08	19.30	86.00	100.00	131.89	0.00	0.00	0.00	0.00	0.04	0.02	0.00
48	4.E.1. LULUCF-Settlements remaining settlements	N2O	6.29	74.92	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	6.29	74.92	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	0.08	39.31	30.00	100.00	104.40	0.00	0.00	0.00	0.00	0.03	0.07	0.01
51	5.B Biological treatment of solid waste: Composting	N2O	0.00	17.50	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	1.10	0.34	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	75.14	99.94	10.00	10.00	14.14	0.00	0.00	0.00	0.00	0.02	0.00	0.00

Total N2O	7815.84	7253.01			8.27	7.32								0.65
					Level uncertainty, N2O		2.88	2.71					Trend uncertainty, N2O	0.81
Combined CO2, CH4 and N2O	59496.81	63303.79					203.57	168.40	0.00	0.00				112.93
					Level uncertainty, CO2, CH4 & N2O		14.27	12.98	0.00	0.00			Trend uncertainty, CO2, CH4 & N2O	10.63

	CATEGORIES OF EMISSIONS AND REMOVALS	Gas	Emissions in 1990 (kt CO2eq)	Emissions in 2019 (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 2019	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	1.17	906.01	20.00	10.00	22.36	0.00	0.10	0.02	0.02	0.43	0.15	0.21
2	2.G Other Product Manufacture and Use	Aggregate F-gases	33.42	10.46	10.00	0.00	10.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<b>Total F-gases</b>			<b>34.59</b>	<b>916.47</b>				<b>0.00</b>	<b>0.10</b>					<b>0.21</b>
													<b>Trend uncertainty, F-gases</b>	<b>0.46</b>
								<b>0.01</b>	<b>0.32</b>					<b>0.46</b>
<b>TOTAL for all gases</b>			<b>59531.40</b>	<b>64220.26</b>				<b>203.57</b>	<b>168.50</b>					<b>113.13</b>
					<b>Total level uncertainty for all GHGs</b>			<b>14.27</b>	<b>12.98</b>				<b>Total trend uncertainty for all GHGs</b>	<b>10.64</b>

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

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

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):

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

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 <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O	HFC	PFC	SF <sub>6</sub>	NF <sub>3</sub>
<b>1. Energy</b>							
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
<b>2. Industrial Processes and Product Use</b>							
A. Mineral Industry	All	Part	Part	NA	NA	NA	NA
B. Chemical Industry	Part	NO	Part	NO	NO	NO	NO
C. Metal Production	NO	NO	NO	NO	NO	NO	NO
D. Non-Energy Products from Fuels and Solvent Use	Part	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
<b>3. Agriculture</b>							
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
<b>4. Land-Use Land-Use Change and Forestry</b>							
A. Forest Land	All	Part	Part	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
<b>5. Waste</b>							
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
<b>6. Other</b>	NO	NO	NO	NA	NA	NA	NA
<b>KP A.1-A.2 Afforestation and Deforestation</b>	All	All	All	NA	NA	NA	NA
<b>KP B.1 Forest management</b>	All	All	All	NA	NA	NA	NA
<b>KP B.2 Cropland management</b>	All	NO	NO	NA	NA	NA	NA
<b>KP B.3 Grazing land management</b>	All	All	All	NA	NA	NA	NA
<b>Memo Items:</b>							
<b>International Bunkers</b>							
Aviation	All	All	All	NA	NA	NA	NA
Navigation	All	All	All	NA	NA	NA	NA
<b>Multilateral Operations</b>	NO	NO	NO	NA	NA	NA	NA
CO <sub>2</sub> Emissions from Biomass	All	NA	NA	NA	NA	NA	NA
CO <sub>2</sub> 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 <sub>2</sub> O	NO	NO	NE	NA	NA	NA	NA
Indirect CO <sub>2</sub>	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 1990-2018 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<sub>2</sub> 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<sub>2</sub> emissions without land use, land use change and forestry) increased steadily from 54,400.3 kt CO<sub>2</sub> eq in 1990 to 70,487.2 kt CO<sub>2</sub> eq in 2001, which is the highest level of GHG emissions ever reported in Ireland. Emissions then plateaued until 2008 with estimates ranging from 68,131.5 kt CO<sub>2</sub> eq to 70,264.3 kt CO<sub>2</sub> eq. There was then a sharp decrease from 68,131.5 kt CO<sub>2</sub> eq in 2008 to 57,793.6 kt CO<sub>2</sub> eq in 2011. There was a rise in emissions between 2014 and 2015 of 4.1 per cent to 60,432.0 kt CO<sub>2</sub> eq, and there was a further increase between 2015 and 2016 of 3.4 per cent to 62,475.1 kt CO<sub>2</sub> eq. Emissions in 2019 at 59,777.6 kt CO<sub>2</sub> eq are 4.4 per cent lower than 2018.

The largest annual change occurred from 2008 to 2009 when emissions decreased by 5,775.1 kt CO<sub>2</sub> eq from 68,131.5 kt CO<sub>2</sub> eq to 62,356.4 kt CO<sub>2</sub> eq a reduction of 8.5 per cent. Total emissions in 2019 were 9.9 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.

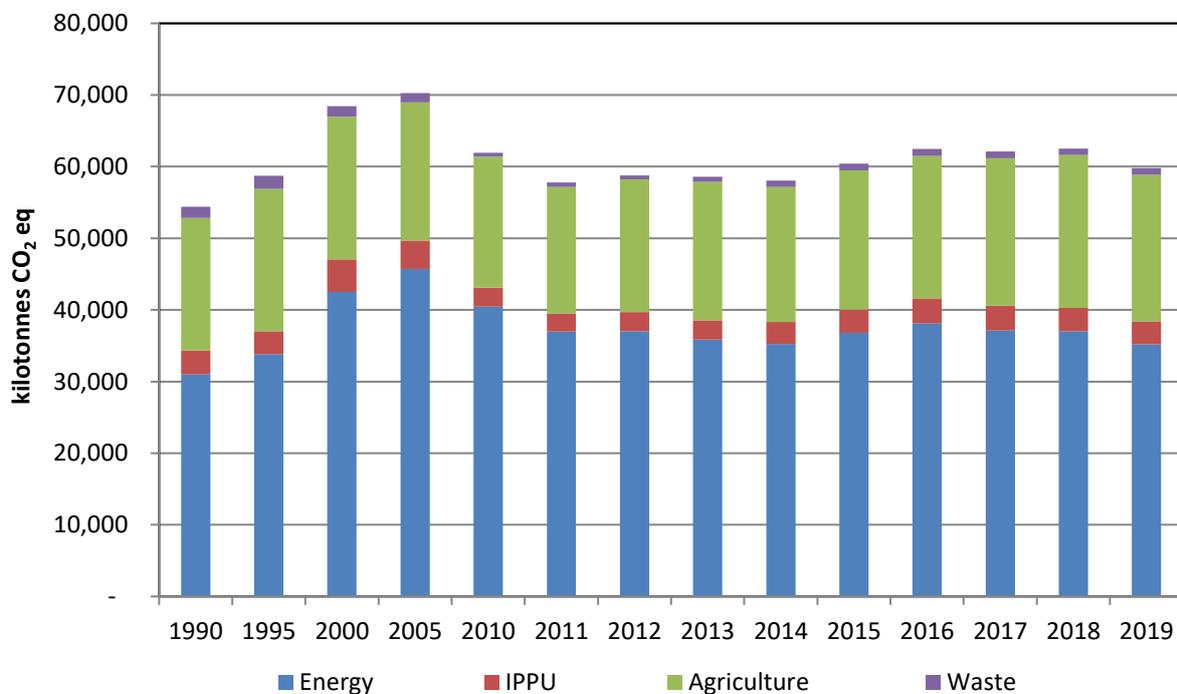
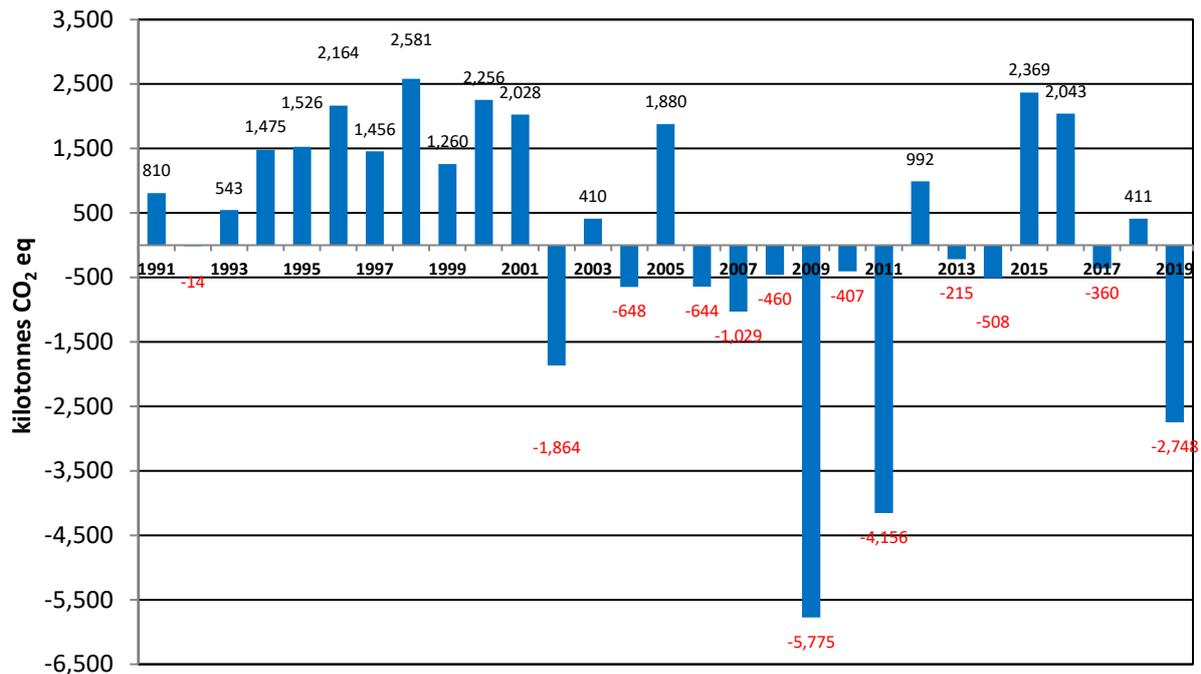


Figure 2.1 National total Greenhouse Gas emissions (excluding LULUCF) 1990-2019



*Figure 2.2 Inter annual changes*

In 2019, the total Energy sector accounted for 58.9 per cent of total emissions, Agriculture contributed 34.3 per cent while a further 5.3 per cent emanated from Industrial Processes and Product Use and 1.5 per cent was due to Waste.

The Energy sector accounted for the bulk of the CO<sub>2</sub> emissions in 2019 (92.8 per cent), IPPU and Agriculture sectors contributed further 6.0 per cent and 1.2 per cent, respectively and Waste contributed the remainder 0.1 per cent. CH<sub>4</sub> emissions are produced mainly in the Agriculture sector (93.2 per cent) and Waste sector (5.1 per cent), the Energy sector contributed the remainder 1.7 per cent. Most of the N<sub>2</sub>O emissions are generated in Agriculture (92.2 per cent) and Energy (5.4 per cent) with Waste and IPPU contributing a further 1.7 per cent and 0.6 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<sub>2</sub> emissions from energy use. CO<sub>2</sub> from the Energy sector increased its share of national total emissions from 55.4 per cent in 1990 to 62.2 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<sub>2</sub> emissions increasing by an average of 4.6 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 4.4 per cent mainly due to reduced coal consumption in electricity generation.

Table 2.1. Greenhouse Gas Emissions 1990-2019 (kt CO<sub>2</sub> equivalent)

(a) Emissions by Gas

Greenhouse Gas Emissions	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Percentage change (1990-2019)
CO <sub>2</sub> emissions without net CO <sub>2</sub> from LULUCF	32,943.6	35,852.2	45,248.5	48,155.8	41,793.9	38,097.3	38,242.0	37,291.8	36,909.0	38,687.8	40,155.8	39,133.4	39,195.2	37,275.3	13.1%
CO <sub>2</sub> emissions with net CO <sub>2</sub> from LULUCF	37,469.3	40,891.4	50,495.8	53,398.5	46,876.7	42,680.6	41,924.0	40,983.9	41,770.1	43,401.1	44,332.8	44,481.8	43,115.5	40,895.0	9.1%
CH <sub>4</sub> emissions without CH <sub>4</sub> from LULUCF	13,752.1	14,556.7	14,386.9	14,019.7	12,576.7	12,523.8	13,155.8	13,439.1	13,512.0	14,037.6	14,423.1	14,825.5	15,139.3	14,730.5	7.1%
CH <sub>4</sub> emissions with CH <sub>4</sub> from LULUCF	14,211.7	15,014.8	14,820.4	14,474.0	13,272.2	13,017.0	13,530.7	13,890.8	14,117.3	14,478.1	14,831.7	15,500.8	15,599.6	15,155.7	6.6%
N <sub>2</sub> O emissions without N <sub>2</sub> O from LULUCF	7,670.1	8,105.7	8,054.6	6,891.8	6,451.0	6,026.8	6,264.7	6,680.6	6,409.6	6,471.1	6,575.7	6,909.6	7,253.9	6,855.3	-10.6%
N <sub>2</sub> O emissions with N <sub>2</sub> O from LULUCF	7,815.8	8,298.9	8,258.5	7,178.9	6,915.1	6,435.9	6,660.5	7,110.8	6,879.9	6,895.7	6,974.1	7,371.6	7,659.3	7,253.0	-7.2%
HFCs	0.6	45.2	270.0	855.5	1,048.1	1,084.3	1,075.0	1,106.3	1,190.0	1,169.5	1,242.9	1,158.7	845.5	818.5	138154.9%
PFCs	0.1	97.6	397.8	216.4	46.6	15.9	9.6	8.3	3.6	20.5	37.4	47.2	49.9	63.1	52544.0%
SF <sub>6</sub>	33.9	79.1	51.8	96.8	33.1	45.5	37.4	43.6	37.4	44.5	39.3	39.2	40.9	33.6	-0.9%
NF <sub>3</sub>	NO	4.4	49.2	28.4	NO	NO	0.8	0.9	1.0	1.0	1.0	1.3	1.3	1.4	-
<b>Total (without LULUCF)</b>	<b>54,400.3</b>	<b>58,740.9</b>	<b>68,458.7</b>	<b>70,264.3</b>	<b>61,949.4</b>	<b>57,793.6</b>	<b>58,785.1</b>	<b>58,570.6</b>	<b>58,062.6</b>	<b>60,432.0</b>	<b>62,475.1</b>	<b>62,114.9</b>	<b>62,526.0</b>	<b>59,777.6</b>	<b>9.9%</b>
<b>Total (with LULUCF)</b>	<b>59,531.4</b>	<b>64,431.4</b>	<b>74,343.4</b>	<b>76,248.5</b>	<b>68,191.9</b>	<b>63,279.0</b>	<b>63,238.0</b>	<b>63,144.6</b>	<b>63,999.3</b>	<b>66,010.2</b>	<b>67,459.2</b>	<b>68,600.5</b>	<b>67,312.0</b>	<b>64,220.3</b>	<b>7.9%</b>
<b>Total (without LULUCF, with indirect)</b>	<b>NA</b>														
<b>Total (with LULUCF, with indirect)</b>	<b>NA</b>														

(b) Emissions by IPCC Source Category (kt CO<sub>2</sub> equivalent)

Greenhouse Gas Source and Sink Categories	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Percentage change (1990-2019)
1. Energy	31,023.7	33,825.1	42,491.7	45,716.9	40,473.4	36,970.5	37,031.5	35,878.3	35,245.6	36,820.8	38,135.8	37,120.0	37,030.0	35,209.1	13.5%
2. Industrial Processes	3,309.2	3,217.4	4,558.3	3,962.6	2,594.7	2,482.6	2,686.8	2,639.9	3,057.8	3,246.3	3,474.7	3,488.3	3,236.0	3,184.0	-3.8%
3. Agriculture	18,515.4	19,869.2	19,915.9	19,292.8	18,349.9	17,718.5	18,527.2	19,356.0	18,876.0	19,410.9	19,899.8	20,567.8	21,351.2	20,479.7	10.6%
4. LULUCF	5,131.1	5,690.5	5,884.7	5,984.2	6,242.4	5,485.5	4,452.9	4,574.1	5,936.8	5,578.3	4,984.0	6,485.7	4,786.0	4,442.6	-13.4%
5. Waste	1,552.1	1,829.2	1,492.8	1,292.0	531.4	621.9	539.7	696.4	883.1	953.9	964.9	938.7	908.8	904.9	-41.7%
6. Other	NO														
<b>Total (including LULUCF)</b>	<b>59,531.4</b>	<b>64,431.4</b>	<b>74,343.4</b>	<b>76,248.5</b>	<b>68,191.9</b>	<b>63,279.0</b>	<b>63,238.0</b>	<b>63,144.6</b>	<b>63,999.3</b>	<b>66,010.2</b>	<b>67,459.2</b>	<b>68,600.5</b>	<b>67,312.0</b>	<b>64,220.3</b>	<b>7.9%</b>

## 2.2 Trends by Gas

Emissions of CO<sub>2</sub> accounted for 62.4 per cent of the total (excluding LULUCF) of 59,777.6 kt CO<sub>2</sub> eq in 2019, with CH<sub>4</sub> and N<sub>2</sub>O contributing 24.6 per cent and 11.5 per cent, respectively. The combined emissions of HFC, PFC, SF<sub>6</sub> and NF<sub>3</sub> accounted for 1.5 per cent of total emissions in 2019. In 1990 emissions of CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O and the combined emissions of HFCs, PFCs, SF<sub>6</sub> and NF<sub>3</sub> accounted for 60.6, 25.3, 14.1 and less than 0.1 per cent, respectively of total emissions of 54,400.3 kt CO<sub>2</sub> eq as presented in Figure 2.3.

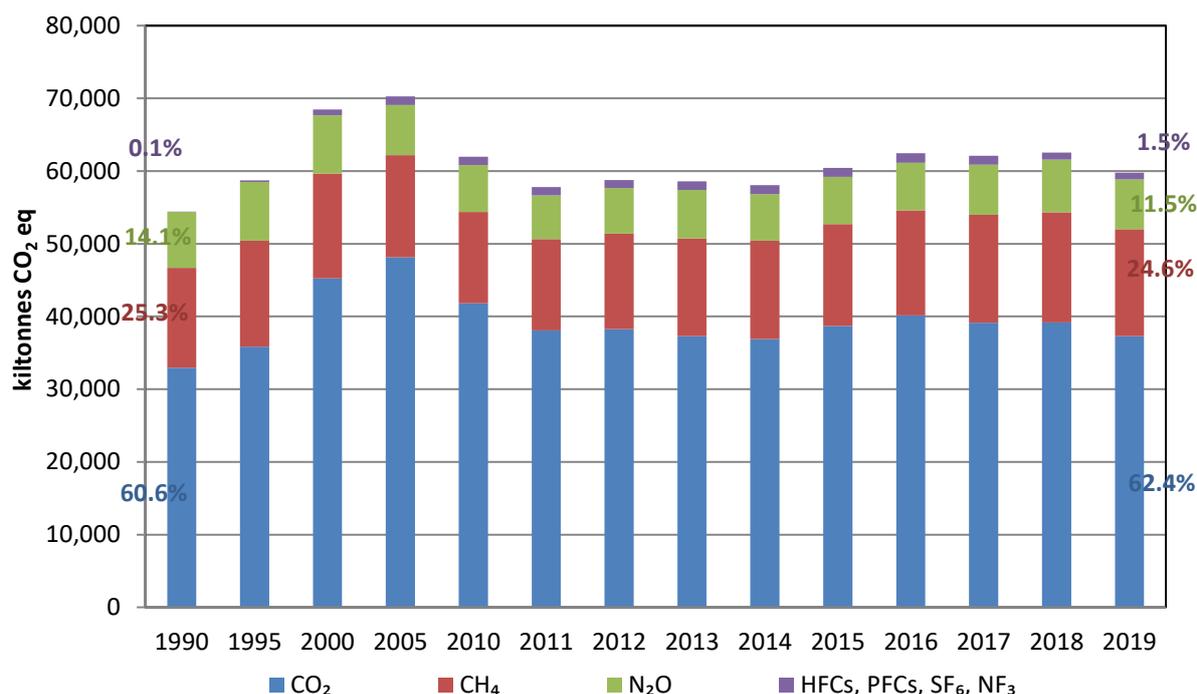


Figure 2.3 Greenhouse Gas emissions-by Gas (excluding LULUCF) 1990-2019

### 2.2.1 Trends in Carbon Dioxide

CO<sub>2</sub> is the most significant contributor to the greenhouse gas emissions with 1.A.1 Energy Industries and 1.A.3 Transport sectors responsible for 24.7 per cent and 32.3 per cent of total CO<sub>2</sub> emissions (excluding LULUCF) in 2019, respectively. 1.A.4 Other Sectors represents a share of 23.5 per cent, 1.A.2 Manufacturing Industries and Construction has a 12.3 per cent share and the remainder of CO<sub>2</sub> emissions (7.2 per cent share) fall into other categories.

Emissions of CO<sub>2</sub> increased from 32,943.6 kt in 1990 to 37,275.3 kt in 2019, which equates to an increase of 13.1 per cent. The main driver behind this increase in emissions is primarily fuel combustion in Transport followed by Energy Industries. Over the period 1990-2019, emissions of CO<sub>2</sub> from transport, predominantly road traffic in Ireland, increased by 139.5 per cent. This trend is exaggerated somewhat in later years by so-called fuel-tourism. In 2019, it is estimated that 0.4 per cent of petrol and 8.1 per cent of diesel sold in Ireland was used in vehicles in the UK and other countries.

Over the time-series, emissions of CO<sub>2</sub> from 1.A.1 Energy Industries increased in the first decade by 54.7 per cent until they peaked in 2001 and decreased by 46.5 per cent to 2019, showing an overall decrease of 17.3 per cent CO<sub>2</sub> over the 1990-2019 period. In addition, even though Ireland has only a small number of energy intensive industries, CO<sub>2</sub> emissions from combustion in the industrial sector 1.A.2 Manufacturing Industries and Construction increased by 12.0 per cent between 1990 and 2019.

### 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 2019 emissions of CH<sub>4</sub> were 14,730.5 kt CO<sub>2</sub> eq, indicating a decrease of 7.1 per cent on the 1990 level of 13,752.1 kt CO<sub>2</sub> eq. Emissions of CH<sub>4</sub> increased progressively from 1990, reaching a peak in 1998 of 15,282.9 kt CO<sub>2</sub> 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<sub>4</sub> emissions decreased because of falling livestock numbers due to reform of the Common Agricultural Policy (CAP). However, total CH<sub>4</sub> emissions in the period 2001-2014 fluctuated to some extent on a yearly basis. This trend is a direct result of fluctuating CH<sub>4</sub> emissions from 1.A.4 Other Sectors and 1.B Fugitive Emissions from Fuels. The main contributor to the CH<sub>4</sub> trend has been Agriculture and in 2019 the sector accounted for 93.2 per cent of the total methane emissions (compared to 85.5 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 16.8 per cent between 1990 (11,754.2 kt CO<sub>2</sub> eq) and 2019 (13,723.5 kt CO<sub>2</sub> eq).

Another significant source of methane emissions is Waste sector, especially from landfill gas in category 5.A Solid Waste Disposal on Land. CH<sub>4</sub> emissions from Waste decreased from 9.6 per cent share of total methane emissions (1,318.1 kt CO<sub>2</sub> eq) in 1990 to 4.6 per cent share (676.9 kt CO<sub>2</sub> eq) in 2019. 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 10.6 per cent from their 1990 level of 7,670.1 kt CO<sub>2</sub> eq in 1990 to 6,855.3 kt CO<sub>2</sub> eq in 2019. Similar to CH<sub>4</sub>, emissions of N<sub>2</sub>O increased during the 1990s to reach peak level of 8,578.0 kt CO<sub>2</sub> 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<sub>2</sub>O 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 92.2 per cent share of the total N<sub>2</sub>O emissions (6,320.3 kt CO<sub>2</sub> eq) in 2019. This reflects an increase from 85.5 per cent share (6,309.5 kt CO<sub>2</sub> eq) in 1990. Emissions from IPPU in chemical industry used to be the second largest contributor to the trend contributing 13.4 per cent to total N<sub>2</sub>O emissions in 1990 and an average of 10.1 per cent share to the trend between 1990 and 2000, before falling to 3.9 per cent share in 2002 – the year of nitric acid plant closure.

Energy and Waste sectors contribute 5.4 per cent and 1.7 per cent, respectively to total N<sub>2</sub>O emissions in 2019.

## 2.2.4 Trends in Fluorinated Gases (HFCs, PFCs, SF<sub>6</sub>, NF<sub>3</sub>)

Emissions of F-gases (HFCs, PFCs, SF<sub>6</sub> and NF<sub>3</sub>) were 916.5 kt CO<sub>2</sub> eq in 2019 compared to 34.6 kt CO<sub>2</sub> eq in 1990, a 26-fold increase over the time series. However, F-gas emissions only account for 1.5 per cent of the national total in 2019. 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 0.6 kt CO<sub>2</sub> eq in 1990 to 818.5 kt CO<sub>2</sub> eq in 2019.

Emissions of PFCs increased from 0.12 kt CO<sub>2</sub> eq in 1990 up to their peak of 397.8 kt CO<sub>2</sub> 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 2019 (49.2 kt CO<sub>2</sub> eq in 2019).

SF<sub>6</sub> is used in a diverse number of 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<sub>6</sub> were 33.9 kt CO<sub>2</sub> eq and 33.6 kt CO<sub>2</sub> eq in 1990 and 2019, respectively. However, total emissions of SF<sub>6</sub> 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<sub>6</sub> grew steadily from 1990, peaking at 126.1 kt CO<sub>2</sub> eq in 1997. The increase over the period 1990-1997 was largely due to increased use of SF<sub>6</sub> 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<sub>6</sub> through gas substitution and new process technologies. In 2.E.1 Electrical Equipment, where SF<sub>6</sub> 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<sub>3</sub> are solely released from 2.E.1 Semiconductor Manufacture. Emissions of NF<sub>3</sub> were reported since 1995 (4.4 kt CO<sub>2</sub> eq.) when use of this gas commenced in the industry and peaked in 2000 (49.2 kt CO<sub>2</sub> eq.), followed by fluctuations until 2008 when NF<sub>3</sub> was phased out from Semiconductor Manufacture for four consecutive years. Since 2012 small amounts of NF<sub>3</sub> were used again in Semiconductor Manufacture resulting in low emission levels averaging 1.1 kt CO<sub>2</sub> eq per year.

## 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 2019 contributes 58.9 per cent of total greenhouse gas emissions (excluding LULUCF). The second largest sector is Agriculture, which accounted for 34.3 per cent of total greenhouse gas emissions in 2019. Emissions from Industrial Processes and Product Use accounted for 5.3 per cent and Waste accounted for 1.5 per cent of total emissions in 2019. 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 13.5 per cent from 31,023.7 kt CO<sub>2</sub> eq in 1990 to 35,209.1 kt CO<sub>2</sub> eq in 2019. 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 45,716.9 kt CO<sub>2</sub> eq. A major decrease occurred between 2008 and 2009 when the sectoral emissions fell by 9.9 per cent. A further reduction of 13.7 per cent has occurred between 2009 and 2019.

Energy Industries (1.A.1) accounted for 20.6 per cent and 15.7 per cent of total national greenhouse gas emissions excluding LULUCF in 1990 and 2019, respectively. Total greenhouse gas emissions from this sub-sector increased by 54.5 per cent from 11,223.1 kt CO<sub>2</sub> eq in 1990 to 17,334.2 kt CO<sub>2</sub> 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 15,335.4 kt CO<sub>2</sub> eq in 2004. Emissions subsequently increased in 2005 to 15,828.5 kt CO<sub>2</sub> 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 15,076.6 kt CO<sub>2</sub> 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 (14,583.0 kt CO<sub>2</sub> eq) are largely a result of the displacement of oil by natural gas. In 2008, emissions increased by 0.9 per cent or 127.5 kt CO<sub>2</sub> eq to 14,710.5 kt CO<sub>2</sub> eq, then decreased in 2009 by 10.8 per cent to 13,119.1 kt CO<sub>2</sub> 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 13,380.2 kt CO<sub>2</sub> 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 6.9 per cent between 2011 and 2012, from 11,980.0 kt CO<sub>2</sub> eq to 12,810.1 kt CO<sub>2</sub> eq, respectively. In 2013 emissions from this sector decreased by 10.7 per cent on 2012 levels to reach 11,434.1 kt CO<sub>2</sub> 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 11,252.1 kt CO<sub>2</sub> eq (1.6 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 5.5 per cent above those in 2014 at 11,875.5 kt CO<sub>2</sub> 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 12,589.3 kt CO<sub>2</sub> eq, a 6.0 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 2019 were 9,368.0 kt CO<sub>2</sub> eq, a decrease of 11.2 per cent on 2018 per cent mainly due to a decrease in coal combustion and an increase in renewable electricity generation.

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

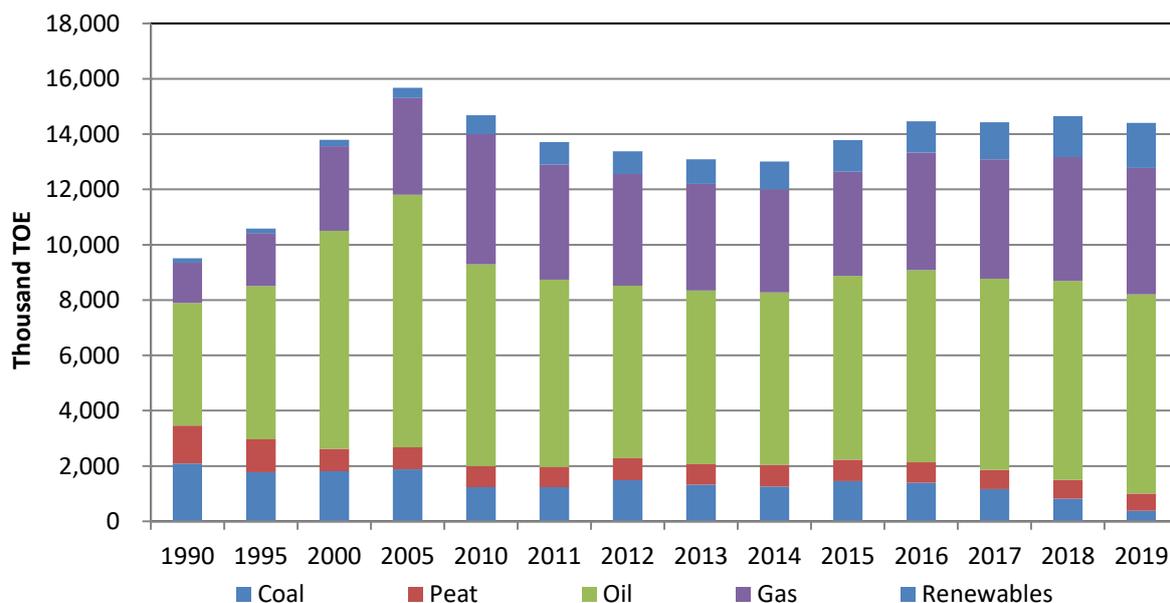


Figure 2.4 Total Primary Energy Requirement (TPER) 1990-2019

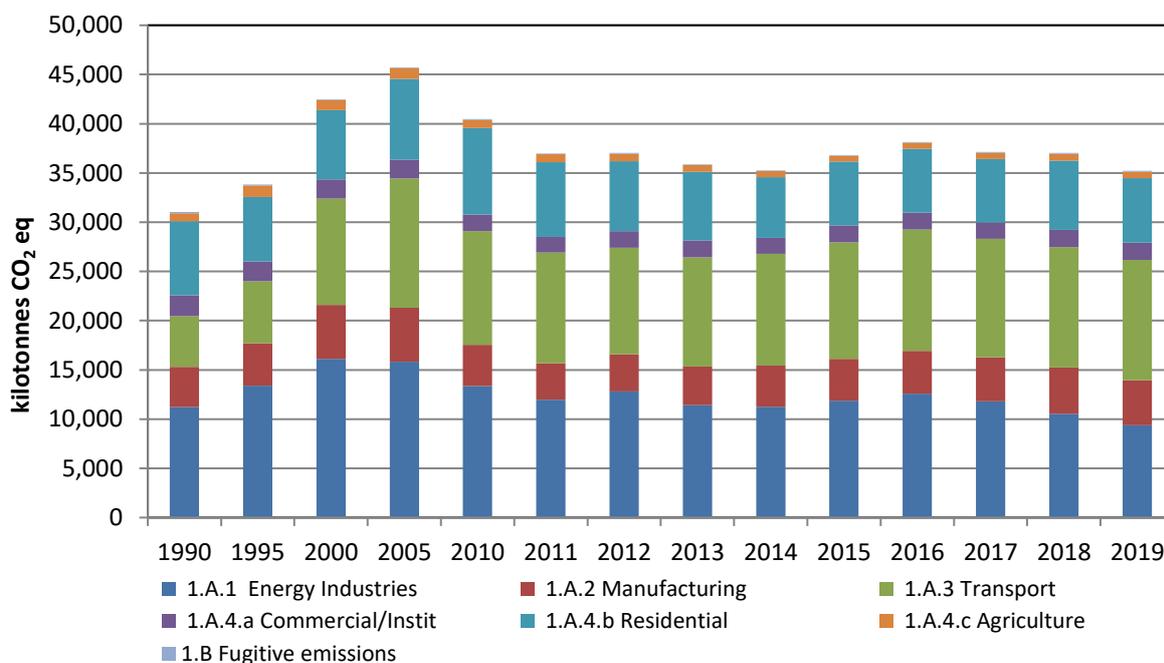
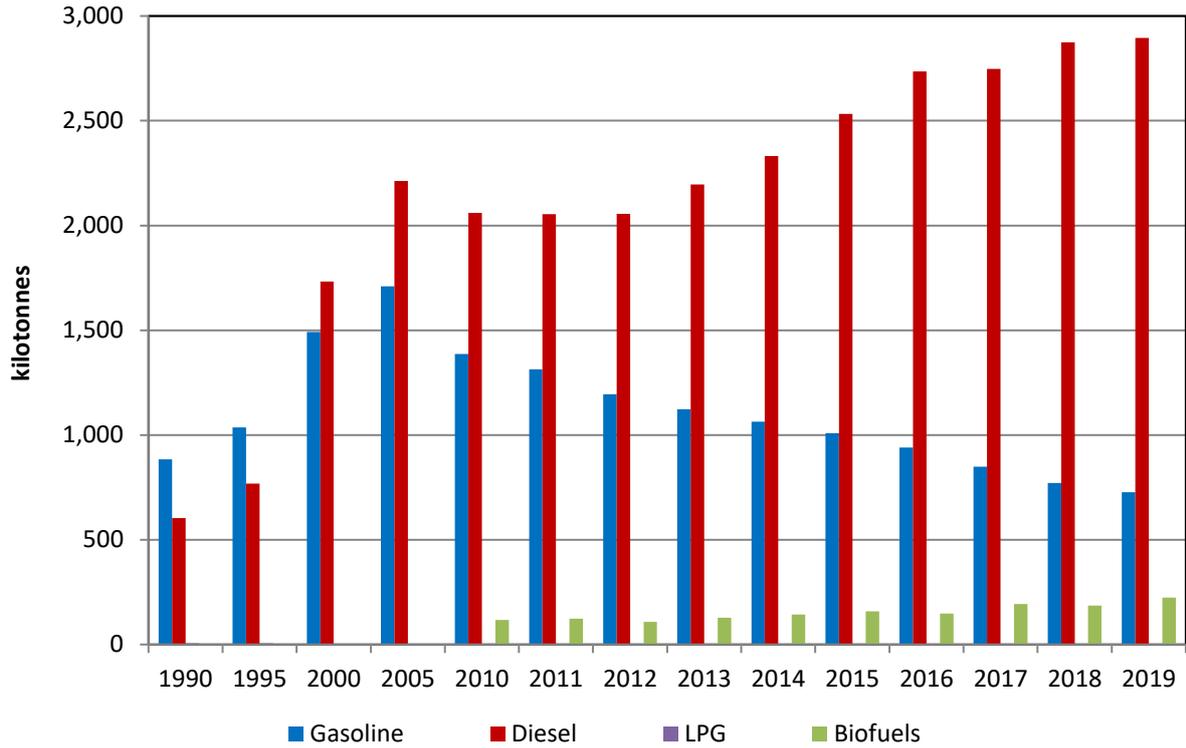


Figure 2.5 Trend in Emissions from Energy 1990-2019

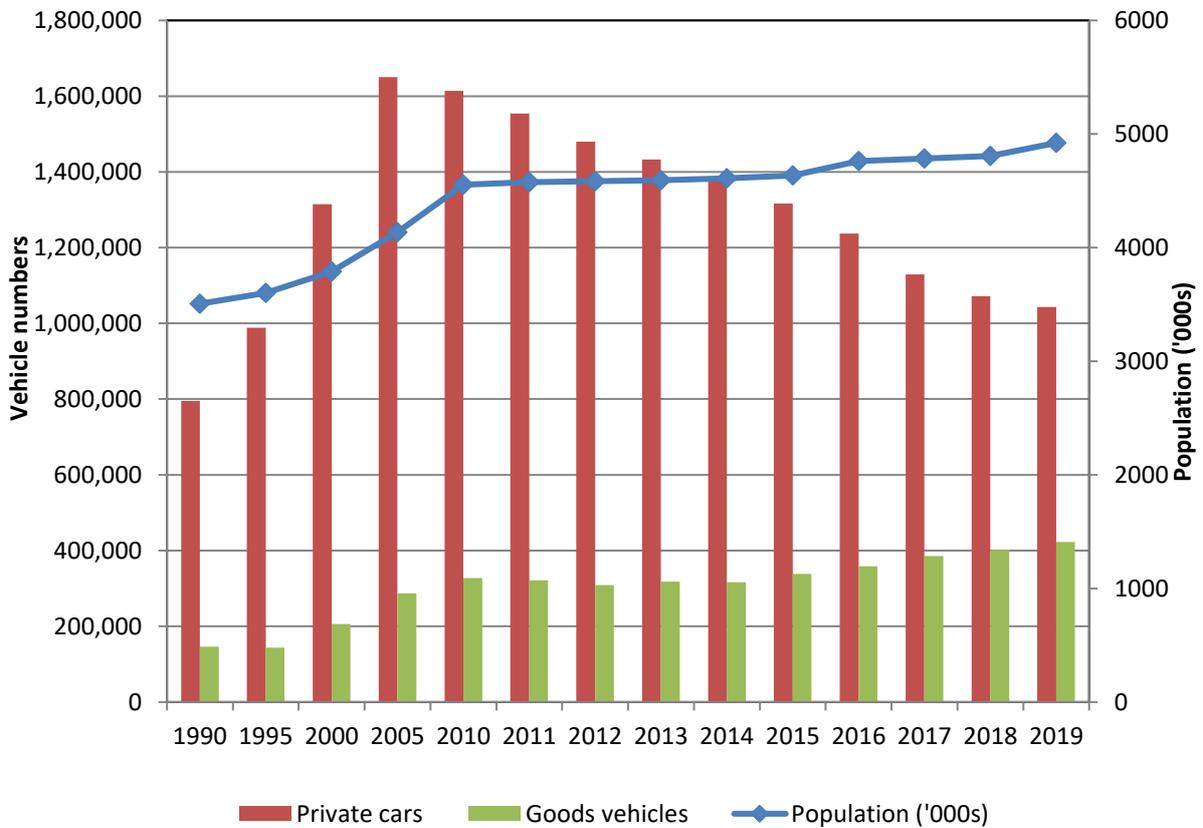
There are only a small number of energy intensive industries in Ireland under sub-category 1.A.2 Manufacturing Industries and Construction. This sub-category accounted for 7.5 per cent (4,097.8 kt CO<sub>2</sub> eq) and 7.3 per cent (4,589.2 kt CO<sub>2</sub> eq) of total national greenhouse gas emissions in 1990 and 2019, respectively. The trend shows an increase of 12.0 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 5,479.8 kt CO<sub>2</sub> eq in 2000. Following an economic downturn, emissions sharply declined by 19.8 per cent between 2008 and 2009, from 5,158.3 kt CO<sub>2</sub> eq to 4,135.4 kt CO<sub>2</sub> eq, respectively and continued to decline until 2012 (3,757.1 kt CO<sub>2</sub> eq), followed by increases in 2013 and 2014, by 4.4 per cent, and 11.2 per cent as compared to 2012 levels when manufacturing industry started to recover from recession. Emissions in 2019 were 22.1 per cent above those in 2012 and 2.0 per cent below last year's emissions. Increased emissions in 1.A.2.e and 1.A.2.f are the main drivers of this relatively large year on year increase in emissions from the category.

Fuel combustion emissions in 1.A.3 Transport accounted for 9.5 per cent and 20.4 per cent of total national greenhouse gas emissions in 1990 and 2019, respectively. The overall sector's emissions increased by 137.0 per cent from 5,148.4 kt CO<sub>2</sub> eq in 1990 to 12,199.8 kt CO<sub>2</sub> eq in 2019. This is largely accounted for by a 142.6 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 0.4 per cent of petrol and 8.1 per cent of diesel sales in 2019. 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 2,211.8 kt CO<sub>2</sub> eq lower in 2019 than in 2007. This represents a decrease of 15.3 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. Emissions from domestic aviation decreased by 63.6 per cent between 1990 (48.4 kt CO<sub>2</sub> eq) and 2019 (17.6 kt CO<sub>2</sub> eq), having peaked in 2006 at 92.0 kt CO<sub>2</sub> eq. However, their overall effect on transport emission trends is negligible.



*Figure 2.6 Fuel use in Road Transport 1990-2019*



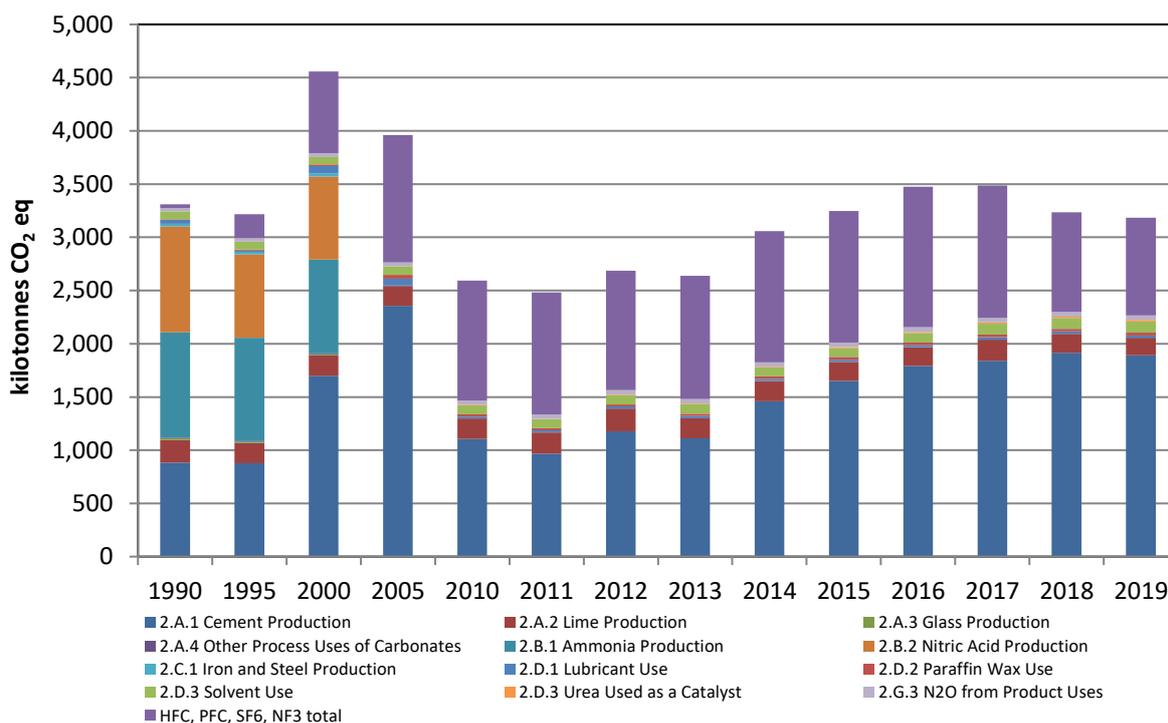
*Figure 2.7 Vehicle numbers and Census of Population 1990-2019*

Emissions from category 1.A.4 Other Sectors decreased by 9.3 per cent from 10,449.9 kt CO<sub>2</sub> eq in 1990 to 8,974.8 kt CO<sub>2</sub> eq in 2019. Emissions from the Commercial (1.A.4.a), Residential (1.A.4.b) and Agriculture/Fishing (1.A.4.c) sub-categories decreased by 15.7, 13.2 and 18.3 per cent, respectively between 1990 and 2019. The emissions of CO<sub>2</sub> from coal and peat use in the residential sector decreased by 71.3 per cent and 74.8 per cent, respectively between 1990 and 2019 while those from oil and natural gas increased by 237.9 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 6.1 per cent of total greenhouse gases in 1990 and 5.3 per cent in 2019. Total emissions from the sector were 3,309.2 kt CO<sub>2</sub> eq in 1990 and 3,184.0 kt CO<sub>2</sub> eq in 2019. This is a decrease of 3.8 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 59.3 per cent. By the late 1990's (1995 to 1999) this proportion had fallen to 49.7 per cent on average of total emissions from the sector. In 1990 emissions from 2.B. Chemical Industry were 1,985.6 kt CO<sub>2</sub> eq, however by 2000 they had reduced by 16.2 per cent to 1,663.3 kt CO<sub>2</sub> eq and by further 34.4 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<sub>2</sub> to 1,700.9 kt CO<sub>2</sub>. 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<sub>2</sub> 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<sub>2</sub>. Emissions have subsequently risen to 1,892.6 kt CO<sub>2</sub> in 2019 (and increase of 95.9 per cent between 2011 and 2019), reflecting economic recovery.



**Figure 2.8 Trend in Emissions from Industrial Processes and Product Use 1990-2019**

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<sub>2</sub> 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<sub>2</sub> eq (and 60.2 per cent share of the IPPU sector). Emissions from cement manufacture then decreased in line with the economic downturn, accounting for 57.5 per cent of total emissions from IPPU sector in 2008, falling to a 38.9 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 2019 is now 59.4 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.7 Other Mineral Products (Bricks, Ceramics, Soda Ash and Limestone use), which collectively accounted for 5.2 per cent of total IPPU sector emissions in 2019. 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<sub>2</sub> emissions from 2.D.3 Solvent use. In 2019 sector 2.D accounted for 5.2 per cent of IPPU sector, having increased by 44.4 per cent from 114.9 kt CO<sub>2</sub> eq in 1990 to 165.9 kt CO<sub>2</sub> eq in 2019. 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 2019 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 813.2 kt CO<sub>2</sub> eq in 2019 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 1998 where it peaked at 143.8 kt CO<sub>2</sub> and dropped by 19.2 per cent in the next year. It showed a gradual increase afterwards to reach its highest contribution in the time series in 2006 (151.6 kt CO<sub>2</sub> eq) and started declining again until 2019 at a level of 109.1 kt CO<sub>2</sub> eq. 2.F.1 Refrigeration and Air Conditioning was reported first in 1993 having an emissions level of 0.5 kt CO<sub>2</sub> eq which increased sharply to 671.6 kt CO<sub>2</sub> eq in 2019. 2.F.3 Fire Protection was reported first in 1996 and showed a slow increase from 1.5 kt CO<sub>2</sub> eq to 32.5 kt CO<sub>2</sub> eq from 1990 to 2019.

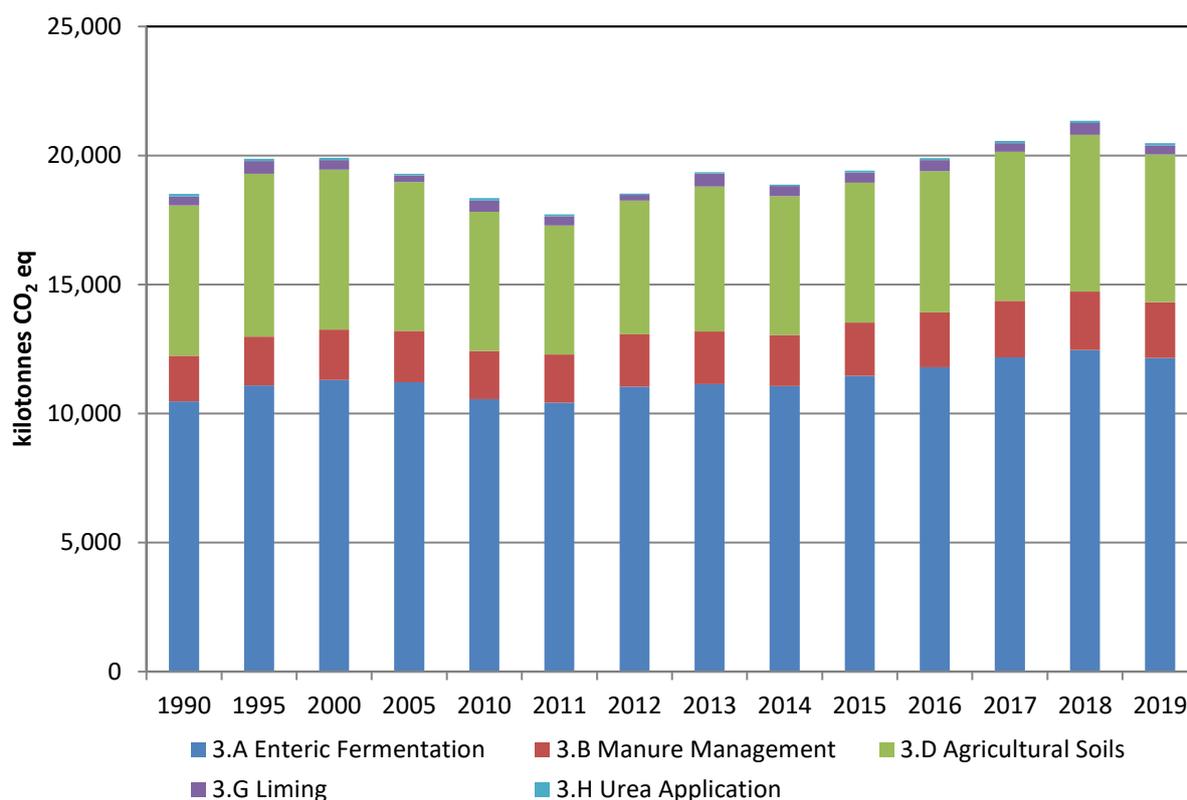
### 2.3.3 Trends in Agriculture (IPCC Sector 3)

The trend in emissions from the Agriculture sector is presented in Figure 2.9. Emissions of greenhouse gases from the Agriculture sector amounted to 18,515.4 kt CO<sub>2</sub> eq in 1990 and 20,479.7 kt CO<sub>2</sub> eq in 2019, an increase of 10.6 per cent. Between 1990 and 1998, the total emissions from the Agriculture sector increased by 13.6 per cent, reflecting an increase in animal numbers and increased synthetic nitrogen use on farms. Following this peak in emission levels of 21,031.9 kt CO<sub>2</sub> eq in 1998, emissions from the sector decreased by 15.8 per cent to 17,718.5 kt CO<sub>2</sub> 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 2019 were 21,479.7 kt CO<sub>2</sub> eq, representing a 15.6 per cent increase on the total emissions in 2011. This was primarily driven by an increase in cattle number of 10.6 per cent between 2011 and 2019.

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 93.0 per cent of total methane emissions in 2019. The combined total of emissions of CH<sub>4</sub> from enteric fermentation and manure management was 11,754.2 kt CO<sub>2</sub> eq in 1990. This increased by 15.2 per cent to reach 13,538.1 kt CO<sub>2</sub> eq in 1998 and subsequently increased by 1.4 per cent to 14,082.9 kt CO<sub>2</sub> eq in 2019. Cattle account for 91.2 per cent of CH<sub>4</sub> emissions in Irish agriculture in 2019.

The emissions of N<sub>2</sub>O from the Agriculture sector follow similar trends to those of CH<sub>4</sub> 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<sub>2</sub>O emissions (92.2 per cent of total N<sub>2</sub>O emissions in 2019). Nitrous oxide emissions in Agriculture increased from 6,309.5 kt CO<sub>2</sub> eq in 1990 by 1.6 per cent yearly in the period 1990-1998 with emissions in 1998 totalling 7,092.8 kt CO<sub>2</sub> eq. Nitrous oxide emissions totalling 6,320.3 kt CO<sub>2</sub> eq in 2019 represent a reduction of 10.9 per cent on the 1998 level and an increase of 0.2 per cent on the 1990 level. Crops contribute very little to N<sub>2</sub>O emissions in Ireland and the amount fluctuates annually in response to varying production of the relevant crops.

Carbon dioxide emissions were 435.9 kt CO<sub>2</sub> in 2019 compared to 451.7 kt CO<sub>2</sub> in 1990, a 3.5 per cent decrease over the time series. 3.G Liming and 3.H Urea Application are the two subsectors responsible for CO<sub>2</sub> emissions from Agriculture sector accounting for 0.7 per cent share of total CO<sub>2</sub> emissions in 2019.



*Figure 2.9 Trend in Emissions from Agriculture 1990-2019*

### 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<sub>2</sub>. 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<sub>2</sub> 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- 2019.

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<sub>2</sub> 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.

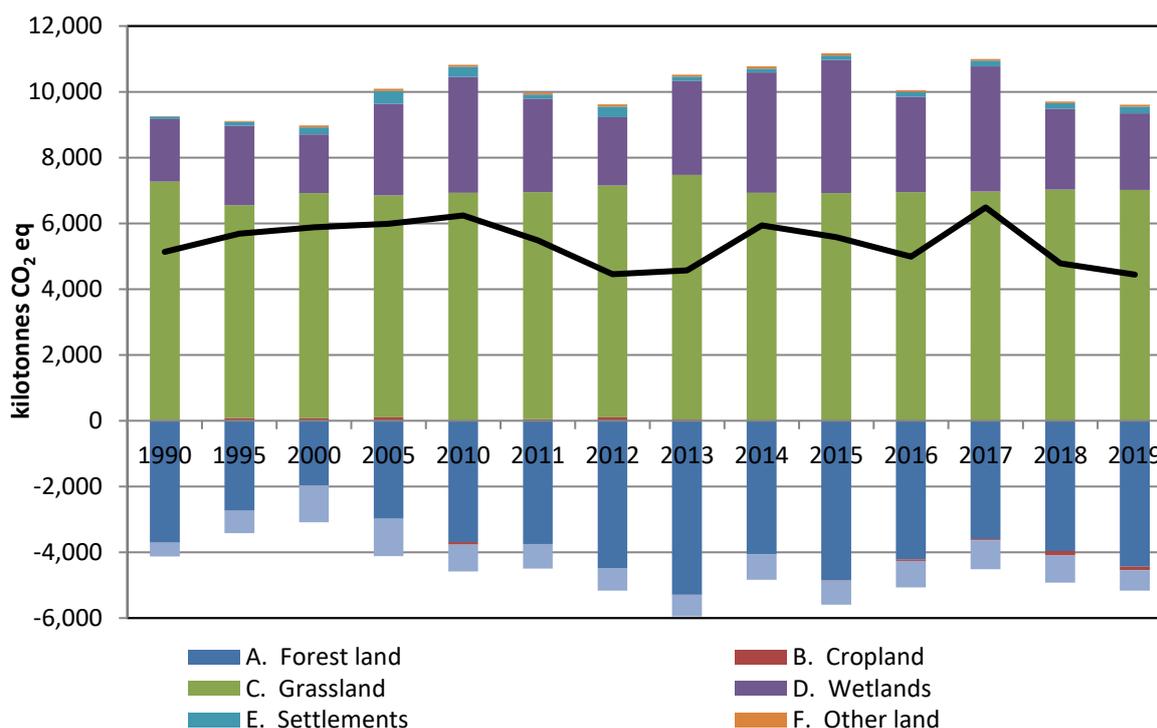


Figure 2.10 Trend in Emissions and Removals from Land Use Land-Use Change and Forestry 1990-2019

### 2.3.5 Trends in Waste (IPCC Sector 5)

The Waste sector remains an important source of CH<sub>4</sub> emissions (Figure 2.11) due to the continued dominance of landfills as a means of solid waste disposal in Ireland. Emissions from the waste sector increased by 13.8 per cent from 1,552.1 kt CO<sub>2</sub> eq in 1990 to 1,765.5 CO<sub>2</sub> eq in 2003 (peak) and then decreased by 48.7 per cent to 904.9 kt CO<sub>2</sub> eq in 2019. Overall, emissions in the Waste sector have decreased by 41.7 per cent from 1990 to 2019.

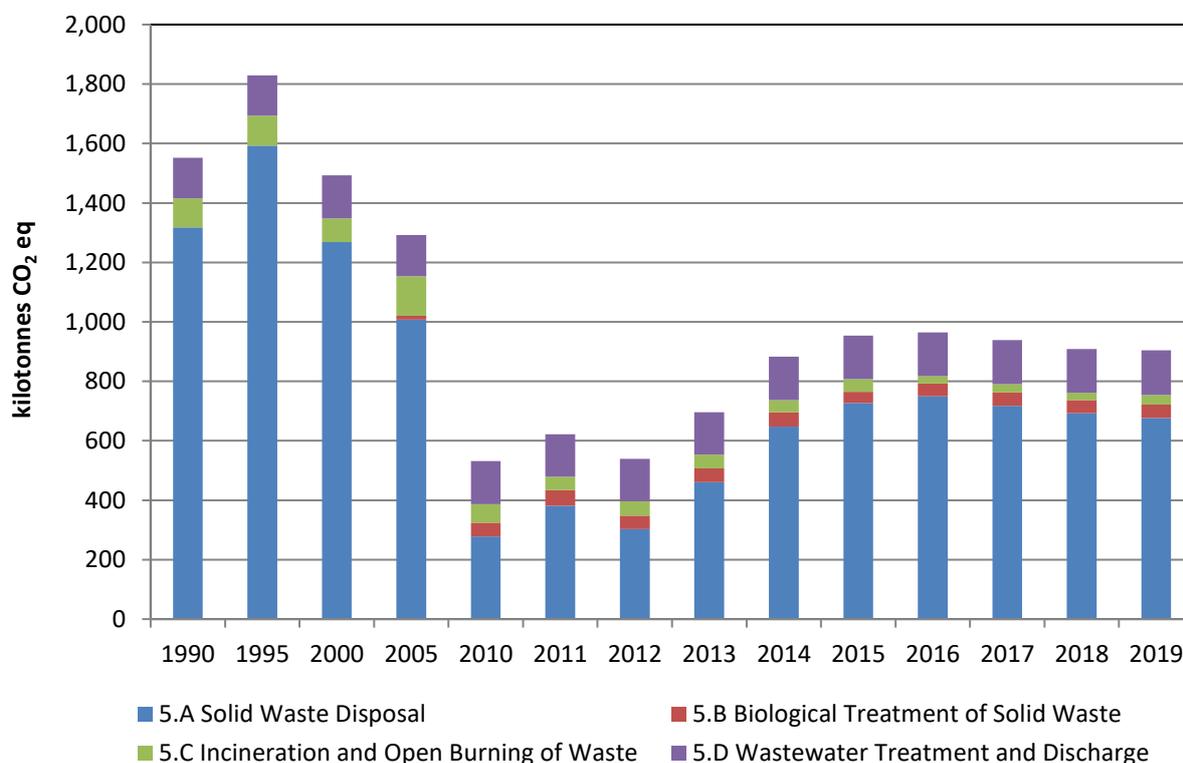
The main contributor to trends in the Waste sector is the CH<sub>4</sub> emissions from municipal solid wastes (MSW) disposed of in solid waste landfills (5.A Solid Waste Disposal on Land) responsible for 74.8 per cent share of Waste emissions in 2019. The decrease in emission levels reflects increasing 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 (3.8 per cent share of Waste emissions in 2019) is a growing source of emissions in Ireland since it commenced in 2001 with emission levels of 3.8 kt CO<sub>2</sub> eq, increasing to 42.0 kt CO<sub>2</sub> eq in 2019. 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 0.4 million tonnes in 2019 due to lower personal consumption and increased recycling rates. Total MSW disposed to landfill decreased by 81.6 per cent between 2007 and 2019. The proportion of organic materials (food and garden waste) in MSW has decreased from 39.3 per cent in 1990 to 22.6 per cent in 2019. The proportions of paper and textiles changed from 29.5 per cent and 9.8 per cent, respectively in 1990 to 19.4 per cent and 21.6 per cent, respectively in 2019, reflecting a significant diversion of paper products from landfills. This reduces CH<sub>4</sub> 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<sub>4</sub> generated. This offset from flares and utilisation was 59.2 per cent in 2019, hence there was a 6-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<sub>2</sub> eq in 1990 and 32.5 kt CO<sub>2</sub> eq in 2019 a decrease of 66.7 per cent which equates to 6.3 and 3.6 per cent of total emissions from the waste sector, respectively in 1990 and 2019. 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 1990-2019. The contribution of this sub-category to the overall sectoral trend is negligible.

Emissions of CH<sub>4</sub> and N<sub>2</sub>O from 5.D Wastewater Treatment and Discharge accounted for 136.2 kt CO<sub>2</sub> eq in 1990 and 151.1 kt CO<sub>2</sub> eq in 2019 (8.8 per cent increase on 1990), which equates to 8.8 and 16.7 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 1990-2019*

## 2.4 Emissions of Indirect Greenhouse Gases

The total emissions of SO<sub>2</sub>, NO<sub>x</sub>, NMVOC and CO for the years 1990 to 2019 are summarised in Table 2.2 and Figure 2.12. As in the case of CO<sub>2</sub>, the emissions of SO<sub>2</sub>, NO<sub>x</sub> 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 2019, substantial decreases occurred in the emissions of SO<sub>2</sub> (94.1 per cent) and CO (80.7 per cent). Significant reductions of NO<sub>x</sub> emissions (41.4 per cent) and NMVOC (21.2 per cent) also occurred in 2019 in comparison to 1990.

*Table 2.2 Emissions of NO<sub>x</sub>, SO<sub>2</sub>, NMVOC and CO 1990-2019 (Tonnes)*

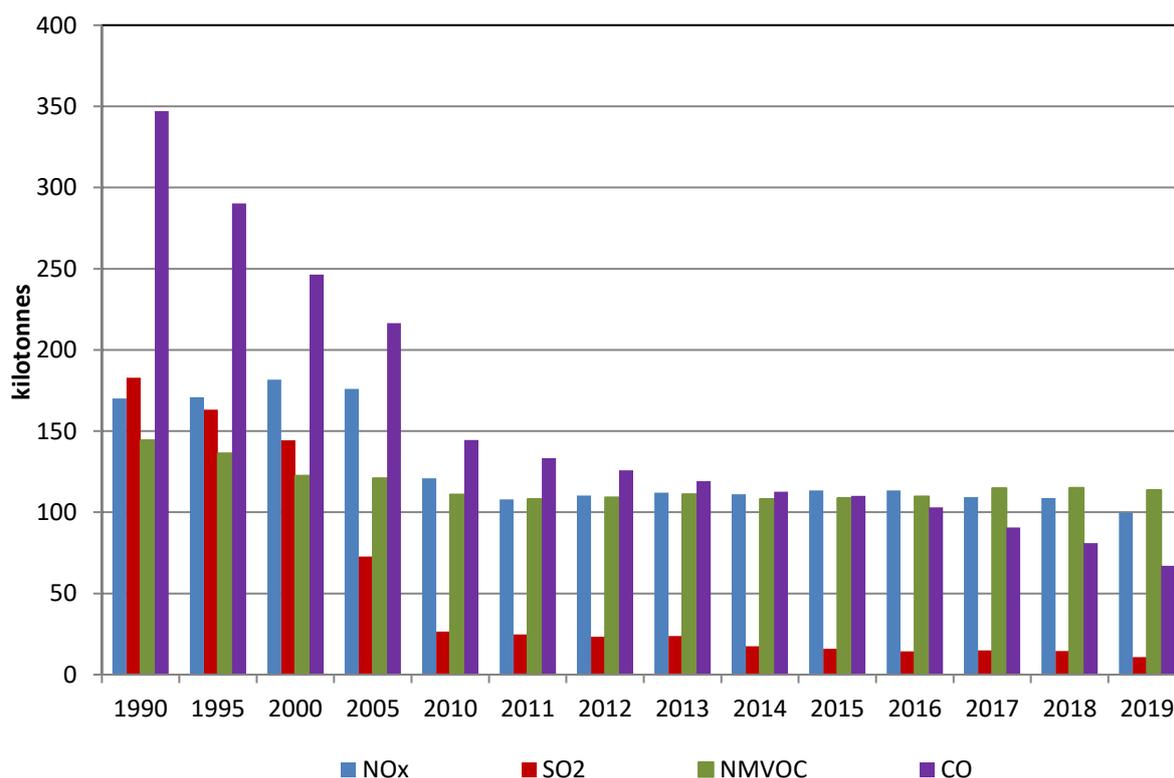
	NO <sub>x</sub>	SO <sub>2</sub>	NMVOC	CO
1990	169,979	182,937	144,302	347,011
1991	172,457	183,150	145,923	340,453
1992	180,772	170,926	142,210	326,589
1993	173,139	161,953	140,019	309,769
1994	172,579	177,097	137,559	294,098
1995	170,845	163,172	136,210	290,294
1996	174,659	150,050	137,133	287,500
1997	169,130	168,930	134,813	268,460
1998	178,844	179,718	137,380	272,791
1999	179,580	161,092	128,941	257,130
2000	181,625	144,220	122,496	246,420
2001	180,772	142,265	122,541	241,605
2002	173,496	106,648	122,671	230,495
2003	172,409	82,634	121,038	221,505
2004	174,506	73,256	120,419	217,941
2005	175,965	72,790	120,998	216,454
2006	171,711	60,725	121,001	199,589
2007	167,333	54,924	120,162	186,624
2008	152,172	45,572	116,360	178,420
2009	127,673	32,601	113,960	157,553
2010	120,881	26,621	110,887	144,527
2011	107,872	24,816	108,038	133,363
2012	110,376	23,447	109,165	125,794
2013	112,130	23,701	111,014	119,118
2014	111,109	17,529	108,060	112,560
2015	113,495	15,824	108,729	110,187
2016	113,393	14,368	109,802	103,041
2017	109,379	14,905	114,758	90,625
2018	108,727	14,530	114,977	81,076
2019	99,599	10,782	113,732	66,988

Total SO<sub>2</sub> emissions decreased from 182,937 tonnes in 1990 to 10,782 tonnes in 2019. 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<sub>2</sub> emissions until 2012. However, residential (1.A.4.b) became the largest source of SO<sub>2</sub> emissions having a share of 60.9 per cent of the total in 2019, whereas Power stations (1.A.1a) contributed 20.8 per cent of the total. Combustion sources in the industrial (1.A.2) sector account for a contribution of 13.5 per cent in 2019. In 1990, coal combustion accounted for 51.4 per cent of SO<sub>2</sub>

emissions and fuel oil contributed 30.3 per cent. By 2019, the share of SO<sub>2</sub> emissions from coal had decreased marginally to 42.0 per cent and that from fuel oil had decreased to 9.9 per cent.

Road transport (1.A.3.b) is the principal source of NO<sub>x</sub> emissions, contributing 30.5 per cent of the total in 2019. The reductions in NO<sub>x</sub> 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<sub>x</sub> emissions, in 2019 accounting for 8.3 per cent of emissions, followed by power generation with 6.0 per cent share and combined commercial/residential sectors' 7.7 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 40.0 per cent share of total in 2019. Solvent use (2.D) was responsible for 16.7 per cent share and combined commercial/residential sectors produced 7.3 per cent of the 2019 total NMVOC emissions in Ireland. Technological controls for NMVOCs in motor vehicles have been more successful than in the case of NO<sub>x</sub> and have given a significant reduction in emissions from road transport over recent years with contributions of transport to the national total of 23.0 per cent in 1990, falling to 3.1 per cent in 2019.



*Figure 2.12 Trend in Indirect Greenhouse Gases 1990-2019*

Emissions of CO continue to decline, driven by major reductions due to catalysts in gasoline cars, which are the principal sources of CO emissions. In 2019, Road transport (1.A.3.b) contributed to 41.9 per cent of the total CO emissions. A substantial decline in the CO emissions figures over the period of 1990 to 2019 was observed due to a reduction of solid fuels for space heating in the residential sector.

The commercial and residential sectors combined are the second largest source and contributed 31.6 per cent to 2019 total. Further reductions in the emissions of SO<sub>2</sub>, NO<sub>x</sub> 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<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O 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 57.0 per cent and 58.9 per cent of total national emissions (including indirect CO<sub>2</sub>, without *LULUCF*) in 1990 and 2019, respectively. This sector accounted for 92.8 per cent of total CO<sub>2</sub> emissions, 1.7 per cent of CH<sub>4</sub> emissions and 5.4 per cent of N<sub>2</sub>O emissions in 2019. CO<sub>2</sub> emissions make up 98.2 per cent of the total for the sector in 2019.

There are 16 key categories by level assessment and 19 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 a peak in the consumption of coal and has since decreased with the increased use of natural gas and renewables. There was an increase in emissions in 2012 and 2015 due to the increasing use of coal, however, Ireland has seen a dramatic reduction in coal use for power generation since 2017. In 2018, a decrease of 44 per cent was seen compared to 2017 and in 2019 a further 69 per cent decrease was seen in coal used for power generation compared to 2018.
- **1.A.2 Manufacturing Industries and Construction** emissions peaked in 2005 with a significant drop between 2008 and 2009 due to the impact of the economic downturn. Emissions have slowly increased since 2011 until a small decrease of 2 per cent was seen in 2019, predominantly as a result of a large reduction in coal use in this 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 aforementioned trends appear to follow Ireland's economic growth patterns whereas the last 3 years, we have seen emissions relatively stable despite increases in vehicle population. This is a result of improved vehicle technologies and increased biofuel penetration.

**1.A.4 Other Sectors** dominated by residential fuel combustion 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. 2019 emissions have declined by approximately 5 per cent compared to 2018 but over the last 5 years, emissions have been relatively stable with 2018 seen as a spike year. The

reasons for the spike were due to 2018 been a particularly cold year with the belief also that there was some stockpiling of coal in advance of expected carbon tax increases. 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 98.2 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 2019 due to a further reduction in coal use in the power generation sector.
- **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 2019.
- **Methane** emissions originate from all combustion sources with emissions from residential combustion being the most significant source.

### 3.1.2 Methodology Overview

The combustion of fossil fuels accounts for the bulk of CO<sub>2</sub> emissions in most countries. The CO<sub>2</sub> 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<sub>2</sub> released from combustion can therefore be readily ascertained.

Only small amounts of CH<sub>4</sub> and N<sub>2</sub>O are associated with fuel combustion activities. The emissions of these gases are generally not quantified with the same reliability as the emissions of CO<sub>2</sub> because the rates of CH<sub>4</sub> and N<sub>2</sub>O 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<sub>2</sub> 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.

In this submission, there are extensive recalculation changes based on significant revisions to the historical energy balances going back as far as 1990. This is because SEAI (providers of national energy balance data) have incorporated a major new data set on business energy use for the first time. This is the Business Energy Use Survey (BEUS), first published by the Central Statistics Office (CSO) in December 2018. This valuable new data source provides a new basis for the breakdown of energy use in the commercial services, public services and industrial sectors, at a level of detail not previously possible. SEAI have revised the National Energy Balances from 1990 to 2018 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 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 2019 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<sub>2</sub> 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<sub>2</sub> emission factors and net calorific values are available for liquid, solid and gaseous fossil fuels in Table 4.C of Annex 4. The CO<sub>2</sub> 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 53 per cent in 2019. The CO<sub>2</sub> 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 2019.

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<sub>2</sub> emissions and emission factors that is now fully utilised for the national inventory compilation. The fuel combustion CO<sub>2</sub> 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<sub>2</sub>

emissions. Default CO<sub>2</sub> 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<sub>4</sub> and N<sub>2</sub>O 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<sub>4</sub> and N<sub>2</sub>O 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 2019, 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 2019 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 1990-2019 underlies the estimates of emissions for *Energy* in this submission.

**Table 3.1 Level 3 Source Methodology for Energy**

<b>1. Energy</b>	<b>CO<sub>2</sub></b>	<b>CH<sub>4</sub></b>	<b>N<sub>2</sub>O</b>
<b>A. Fuel Combustion</b>			
<b>1. Energy Industries</b>			
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
<b>2. Manufacturing Industries and Construction</b>			
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
<b>3. Transport</b>			
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
<b>4. Other Sectors</b>			
a. Commercial/Institutional*	T2*	T1	T1
b. Residential*	T2*	T1*	T1
c. Agriculture/Fishing*	T1, T2*	T1	T1
<b>5. Other</b>			
	NA	NA	NA
<b>B. Fugitive Emissions from Fuels</b>			
<b>1. Solid Fuels</b>			
a. Coal mining and handling	NA	T1	NA
b. Solid Fuel Transformation	NA	NA	NA
c. Other	NA	NA	NA
<b>2. Oil and Natural Gas</b>			
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 1990-2019**

		Gas	Unit	1990	1995	2000	2005	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
1.A.1.a	Public Electricity and Heat Production	CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O	kt CO <sub>2</sub> eq	10953.9	13132.9	15754.4	15244.8	12610.6	12895.1	11557.1	12350.2	10977.5	10837.7	11401.0	12149.5	11379.1	10110.5	8985.0
1.A.1.b	Petroleum Refining	CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O	kt CO <sub>2</sub> eq	168.7	181.3	274.8	411.9	315.4	310.5	285.5	313.6	294.6	279.5	358.7	313.6	311.2	322.2	275.1
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries	CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O	kt CO <sub>2</sub> eq	100.5	69.4	87.2	171.9	193.1	174.7	137.5	146.3	162.0	134.8	115.8	126.3	129.4	119.3	107.9
1.A.2.a	Iron and Steel	CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O	kt CO <sub>2</sub> eq	175.9	18.7	18.8	2.4	2.4	2.4	2.4	2.4	2.3	2.4	2.4	2.3	2.3	2.3	2.3
1.A.2.b	Non-Ferrous Metals	CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O	kt CO <sub>2</sub> eq	811.5	1183.7	1347.3	1134.3	1300.8	1569.4	1355.1	1233.3	1337.2	1296.9	1312.4	1271.2	1314.4	1373.6	1381.6
1.A.2.c	Chemicals	CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O	kt CO <sub>2</sub> eq	411.4	344.5	459.5	447.8	365.4	387.3	376.2	391.1	358.0	365.5	381.8	386.0	394.8	417.0	425.4
1.A.2.d	Pulp, Paper and Print	CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O	kt CO <sub>2</sub> eq	28.5	57.6	96.1	37.3	16.1	13.9	9.7	13.3	11.9	10.9	10.1	12.0	12.5	13.3	13.5
1.A.2.e	Food Processing, Beverages and Tobacco	CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O	kt CO <sub>2</sub> eq	1021.4	1135.0	1525.9	1066.1	928.1	920.9	818.5	914.8	940.4	911.3	948.7	988.9	1036.1	1068.7	983.7
1.A.2.f	Non-metallic minerals	CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O	kt CO <sub>2</sub> eq	822.8	488.3	692.7	1777.1	987.1	777.9	692.2	783.7	797.1	1044.9	1114.8	1154.7	1147.9	1212.6	1166.9
1.A.2.g	Other	CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O	kt CO <sub>2</sub> eq	826.4	1103.4	1339.5	1006.7	535.5	492.6	435.7	418.7	473.6	547.4	490.9	537.2	553.8	597.3	615.8
1.A.3.a	Domestic Aviation	CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O	kt CO <sub>2</sub> eq	48.4	45.7	69.6	80.2	65.6	49.5	24.7	15.0	15.4	14.7	15.6	16.8	17.5	16.8	17.6
1.A.3.b	Road Transportation	CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O	kt CO <sub>2</sub> eq	4792.0	5892.8	10380.3	12567.0	11910.2	10998.2	10750.3	10378.0	10610.5	10860.1	11336.4	11772.7	11528.1	11689.4	11624.5
1.A.3.c	Railways	CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O	kt CO <sub>2</sub> eq	148.9	124.5	137.6	136.6	137.4	136.3	136.5	131.9	131.4	120.5	122.8	125.1	129.1	130.5	136.6
1.A.3.d	Domestic navigation	CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O	kt CO <sub>2</sub> eq	85.8	92.1	152.7	211.2	199.5	200.1	173.7	183.6	179.6	224.8	221.7	266.5	235.3	260.2	277.2
1.A.3.e	Other transportation	CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O	kt CO <sub>2</sub> eq	73.4	125.2	62.0	153.0	148.6	161.3	150.4	138.7	145.1	145.7	137.2	135.4	127.0	140.1	144.0
1.A.4.a	Commercial/Institutional	CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O	kt CO <sub>2</sub> eq	2110.1	2005.2	1942.9	1896.5	1595.9	1694.7	1610.3	1679.0	1722.2	1624.3	1717.3	1714.0	1662.6	1752.4	1778.8
1.A.4.b	Residential	CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O	kt CO <sub>2</sub> eq	7521.3	6565.1	7046.7	8202.6	8513.5	8772.0	7590.0	7102.2	6969.0	6143.9	6480.5	6489.7	6428.9	7042.9	6527.2
1.A.4.c	Agriculture/Fishing	CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O	kt CO <sub>2</sub> eq	818.5	1166.7	1023.0	1098.6	893.6	829.7	785.0	757.8	674.3	608.6	580.1	600.5	631.1	680.3	668.8
1.B.1.a	Coal mining and handling	CH <sub>4</sub>	kt CO <sub>2</sub> eq	55.6	33.3	27.0	23.5	21.7	21.2	20.9	20.5	20.1	19.8	19.5	19.2	18.9	18.6	18.3
1.B.2.a	Oil	CO <sub>2</sub> , CH <sub>4</sub>	kt CO <sub>2</sub> eq	0.2	0.3	0.4	0.4	0.3	0.3	0.3	0.4	0.3	0.3	0.4	0.4	0.4	0.4	0.3
1.B.2.b	Natural gas	CO <sub>2</sub> , CH <sub>4</sub>	kt CO <sub>2</sub> eq	48.7	59.3	53.3	47.0	58.5	65.4	58.4	57.2	55.7	51.7	52.7	53.9	59.6	61.4	58.6
	<b>Total Energy</b>			<b>31,023.7</b>	<b>33,825.1</b>	<b>42,491.7</b>	<b>45,716.9</b>	<b>40,799.3</b>	<b>40,473.4</b>	<b>36,970.5</b>	<b>37,031.5</b>	<b>35,878.3</b>	<b>35,245.6</b>	<b>36,820.8</b>	<b>38,135.8</b>	<b>37,120.0</b>	<b>37,030.0</b>	<b>35,209.1</b>

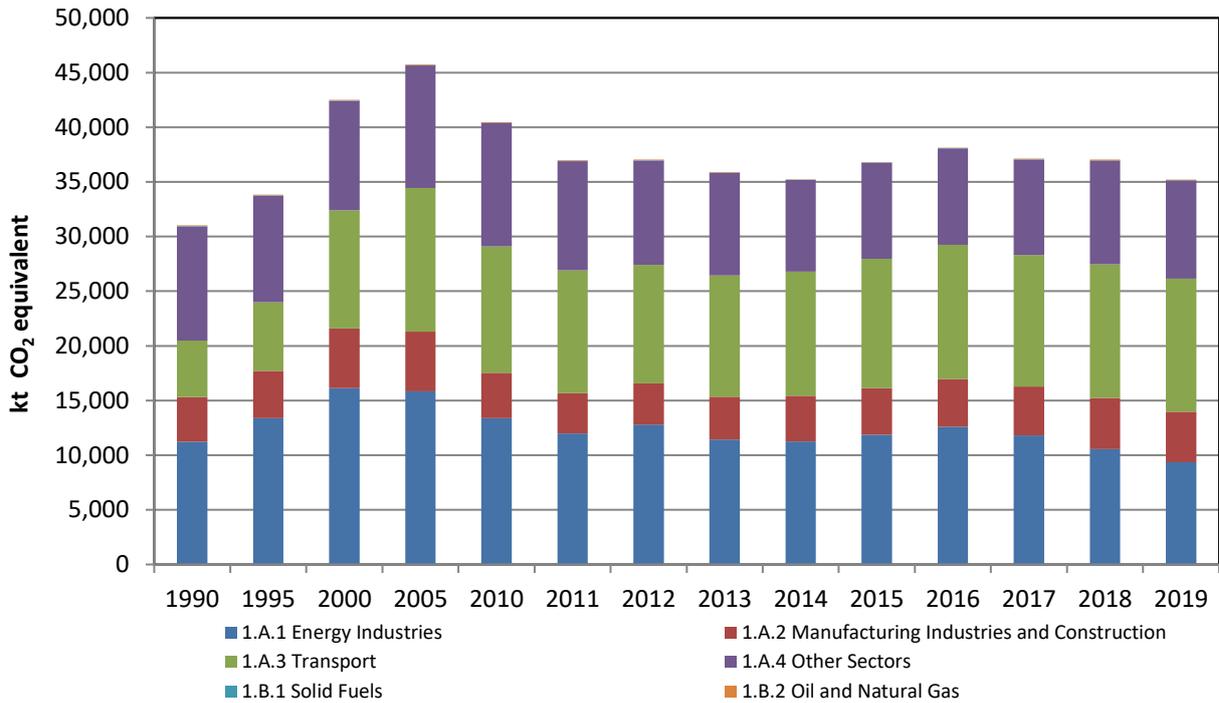


Figure 3.1 Total Emissions from Energy by Category, 1990-2019

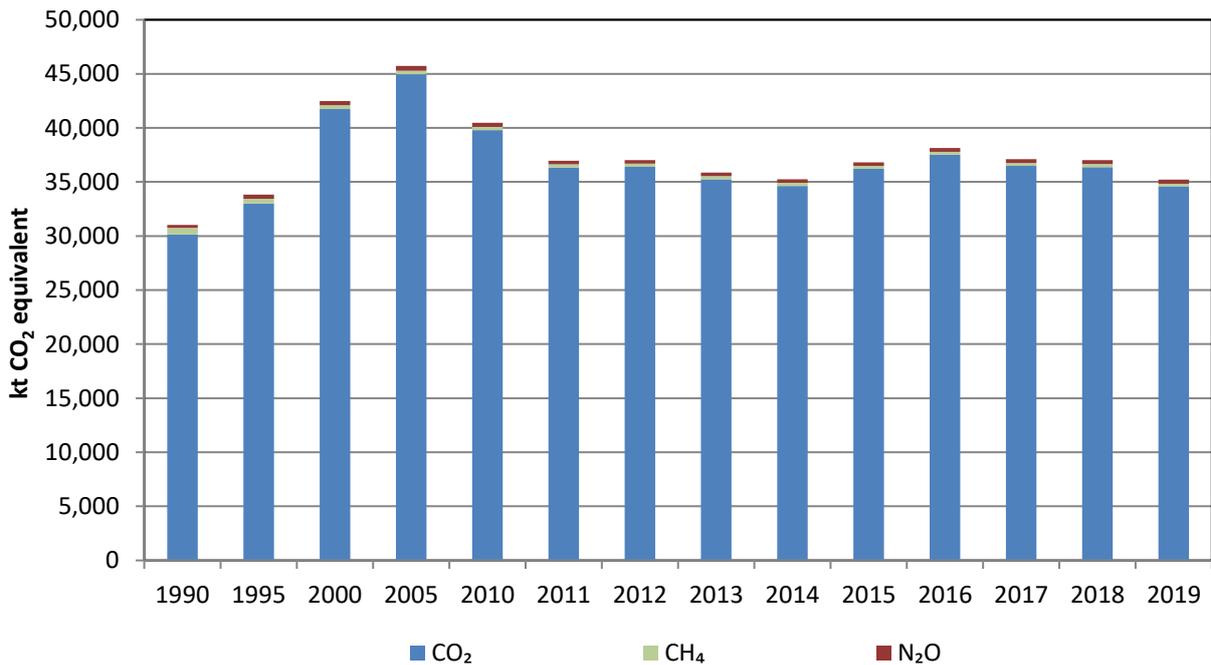


Figure 3.2 Total Emissions from Energy by Gas, 1990-2019

### 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<sub>2</sub> 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<sub>2</sub> values are transferred directly to the national inventory and consistency of results is guaranteed. In the case where the CO<sub>2</sub> 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<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O. 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<sub>2</sub> 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<sub>2</sub> emissions from fuel combustion activities. The calculation sheet for the Reference Approach (Table 1.A (b) of the 2020 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<sub>2</sub> 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<sub>2</sub> 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 2019, energy use (excluding non-energy use, reductants and feedstocks) and CO<sub>2</sub> emissions were; 0.76 lower and 0.16 per cent higher, 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 2018.

### 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<sub>2</sub> 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 2019, the amount of jet kerosene fuel allocated to domestic aviation was 0.47 per cent of the total recorded under air transport in the energy balance. Emissions of CH<sub>4</sub> and N<sub>2</sub>O 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<sub>4</sub> and N<sub>2</sub>O 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<sub>2</sub> emissions from fuel used for non-energy purpose*

CO <sub>2</sub> 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 <sub>2</sub> from NMVOC	NA (RA)	White spirit	20.00	44.00

\*All carbon is stored

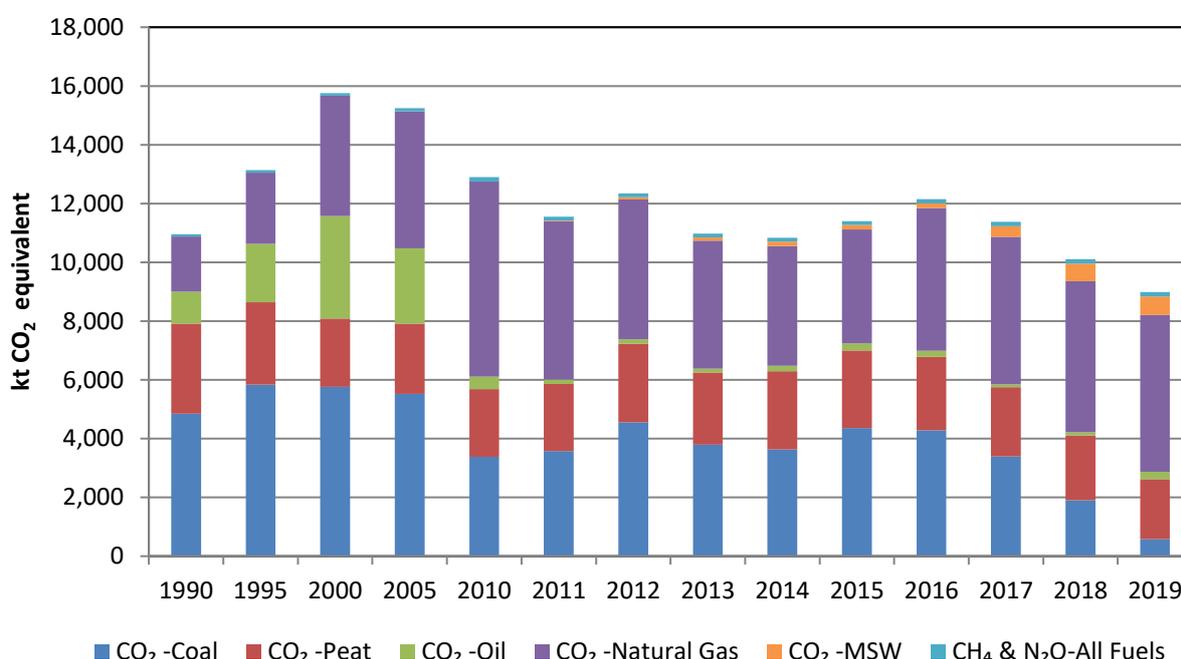
### 3.2.4 Energy Industries (1.A.1)

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)

##### Category Description

The emissions data from a total of 19 electricity generating stations are the basis for compiling the results in this important category. The verified CO<sub>2</sub> 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<sub>4</sub> and N<sub>2</sub>O 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 1990-2019**

##### Methodological Issues

The CO<sub>2</sub> emissions are obtained from 2019 AEMs (Annual Emission Monitoring Reports) are estimated by ETS operators using tier 3 methodologies (as is the case with the years 2005-2018) 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. 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<sub>4</sub> /TJ and 0.1 kg N<sub>2</sub>O /TJ) and municipal waste (30 kg CH<sub>4</sub> /TJ and 4.0 kg N<sub>2</sub>O /TJ) and Table 2.6 (for wood/wood waste boilers 11.00 kg CH<sub>4</sub> /TJ and 7.0 kg N<sub>2</sub>O /TJ) from Vol. 2, Ch. 2 of the 2006 IPCC guidelines.

The bottom-up CO<sub>2</sub> emission estimates received from the ETS participants, along with the emissions of CH<sub>4</sub> and N<sub>2</sub>O 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.

### 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 and 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<sub>2</sub> 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<sub>4</sub> and N<sub>2</sub>O released from combustion sources are high and not well established quantitatively. For CH<sub>4</sub> and N<sub>2</sub>O emission factors for combustion categories, the 2006 IPCC Guidelines are used and an indicative uncertainty of 50 per cent is used for both gases.

### 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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> emissions compiled in the ETS database according to fuel type for all installations that constituted sub-category 1.A.1.a in 2019 are aggregated to report the CO<sub>2</sub> emissions for this category.

The rigour of the monitoring and verification process for CO<sub>2</sub> 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.

#### 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 year 2018 only.

#### Category-specific Planned Improvements

Emissions of CO<sub>2</sub> from this sector, account for 98.3 per cent of this category in 2019, 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)

#### 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.

#### 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<sub>2</sub> emissions originate from ETS the resulting implied emission factors for CO<sub>2</sub> 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 2019. 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 for 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<sub>4</sub> and N<sub>2</sub>O 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.

#### 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<sub>2</sub> 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<sub>4</sub> and N<sub>2</sub>O released from combustion sources are high and not well established quantitatively. For CH<sub>4</sub> and N<sub>2</sub>O emission factors for combustion categories, the 2006 IPCC Guidelines provide an indicative uncertainty of 50 per cent for both gases.

#### Category-specific QA/QC and verification

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

#### Category-specific Recalculations

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

#### Category-specific Planned Improvements

Emissions of CO<sub>2</sub> from this sector, which accounts for 99.9 per cent of this category's emissions in 2019, are accurately quantified and there is therefore little scope for further improvement in the inventories as delivered in the 2021 submission.

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

#### 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.

#### 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<sub>2</sub> 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<sub>2</sub> 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<sub>4</sub> and N<sub>2</sub>O 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.

### Uncertainties and Time-series Consistency

Milled peat is the principal fuel used in this sub-category. While the plant-specific annual CO<sub>2</sub> 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<sub>2</sub> emission are obtained for natural gas and peat fuels, and country-specific emission factors are applied for CO<sub>2</sub> emission for liquid fuels which provide a basis for assigning lower uncertainties for CO<sub>2</sub> emission factors in the uncertainty analysis. Uncertainties in the emission factors for CH<sub>4</sub> and N<sub>2</sub>O 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.

### Category-specific QA/QC and verification

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

#### Category-specific Recalculations

There are no recalculations to emission estimates from *Manufacture of Solid Fuels and Other Energy Industries (1.A.1.c)* in this submission.

#### Category-specific Planned Improvements

Emissions of CO<sub>2</sub> from this sector, which account for 99.7 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 2020 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 1990-2018.

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 have slowly increased since 2011 and a small decrease of 2% was seen in 2019, predominantly as a result of a large reduction in coal use in this sector in 2019.

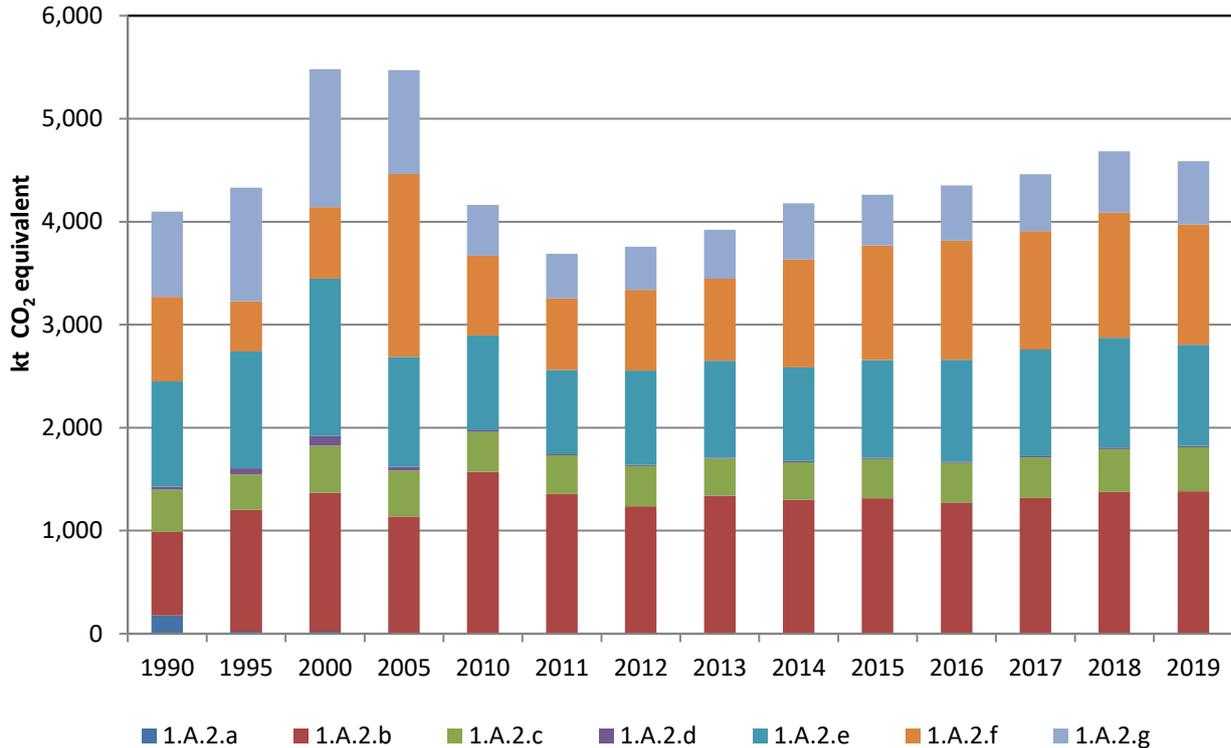


Figure 3.4 Emissions from 1.A.2 Manufacturing Industries and Construction 1990-2019

### 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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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<sub>4</sub> and N<sub>2</sub>O 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<sub>2</sub> 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.e* (1991-2003), *1.A.2.f* (1990-2000, 2002-2019) and *1.A.2.g* (1991-2003, 2008-2009, 2015-2016). The 2006 IPCC Guidelines emission factor of 97.5 t CO<sub>2</sub>/TJ compares well with the year specific emission factors which vary from 92.84 to 95.12 CO<sub>2</sub>/TJ. The average (93.65

CO<sub>2</sub>/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 (70 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<sub>2</sub> 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 80.96 t CO<sub>2</sub>/TJ in 2001. However, the average implied emission factor for years 2004-2019 was 72.28 t CO<sub>2</sub>/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 83.79 t CO<sub>2</sub>/TJ in 1990 to 73.97 t CO<sub>2</sub>/TJ in 2001 as no petroleum coke was consumed that year, subsequently the IEF increases to reach maximum at 91.76 t CO<sub>2</sub>/TJ in 2005 but then decreases to 87.29 t CO<sub>2</sub>/TJ in 2010 reflecting the decline in petroleum coke use in cement production and rises again to 89.36 t CO<sub>2</sub>/TJ in 2019 as result of increase 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 80.49 t CO<sub>2</sub>/TJ in 2001. However, the average implied emission factor for years 2004-2019 is 71.99 t CO<sub>2</sub>/TJ with petroleum coke only used in the years 2008, 2009, 2015 and 2016.

### 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<sub>2</sub> 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<sub>4</sub> and N<sub>2</sub>O from combustion sources are high and not well established quantitatively. For CH<sub>4</sub> and N<sub>2</sub>O 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

In this submission, there are extensive recalculation changes based on significant revisions to the historical energy balances going back as far as 1990. This is because SEAI have incorporated a major new data set on business energy use for the first time. This is the Business Energy Use Survey (BEUS), first published by the Central Statistics Office (CSO) in December 2018. This valuable new data source provides a new basis for the breakdown of energy use in the commercial services, public services and industrial sectors, at a level of detail not previously possible. SEAI have revised the National Energy Balances from 1990 to 2018 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 2017 with the 2018 and 2019 splits based on the latest 2017 splits.

In the Manufacturing Industry and Construction sector 1.A.2, there has been an extensive redistribution of oil and natural gas between the energy sub-sectors. From 1990-1996, oil use in this sector increased as a result of reallocating oil use within the commercial/institutional sector 1.A.4.a to 1.A.2. From 1997-2018, there was a significant redistribution of oil from 1.A.2 to 1.A.4.a and 1.A.4.b. In turn, there was a significant redistribution of natural gas from 1.A.4.a to 1.A.2 from 2001 to 2018 (with the exception of 2004 and 2006, where the quantities in these two years were allocated to 1.A.4.a). Overall, there was an annual average reduction of approximately 3.9 per cent over the time series 1990-2018.

The disaggregated trend differs revolves around the redistribution of oil and natural gas. Generally, there is now less oil allocated to 1A2b, 1A2c, 1A2d, 1A2e and 1A2f across the timeseries with more attributed to 1A2g from 1990-2004 and less thereafter. In terms of Natural gas, the significant changes occur where there is less allocated to 1A2b from 2011 and 1A2g from 2009 onwards. Increases in gas allocation is now attributed to 1A2c and 1A2e from 2007-2019.

### 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.

## 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. Overall Transport emissions have declined between 2007 and 2012 reflecting the impact of the economic downturn in Ireland. However, emissions have been rising since 2012 reflecting a return to economic growth, with a small decrease of 0.3 per cent observed in 2019.

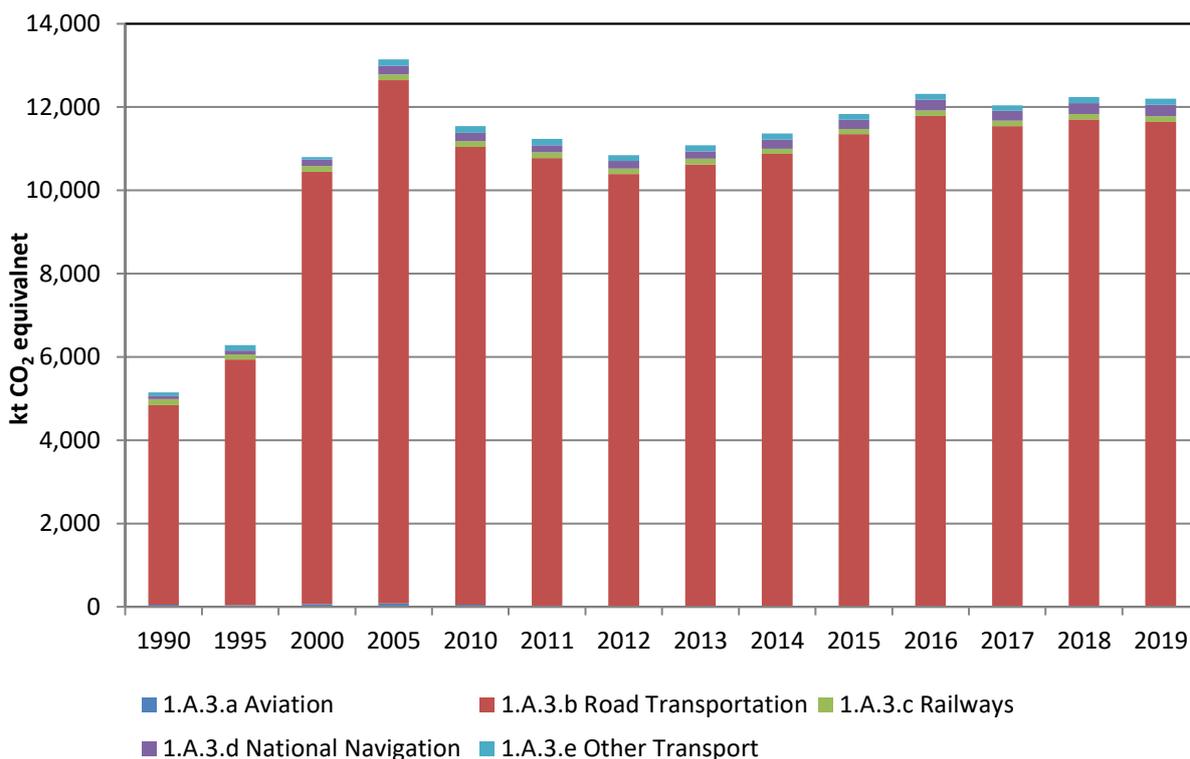


Figure 3.5 Emissions from 1.A.3 Transport 1990-2019

Emissions in 2019 for road transport have decreased slightly despite an increase of approximately 80,000 vehicles. This reduction is a result of increased biofuel penetration and an increasing number of vehicles with improved technologies.

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

#### 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.

#### 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<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O) 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<sub>4</sub> and N<sub>2</sub>O 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<sub>4</sub> and N<sub>2</sub>O emissions from the AEM to jet kerosene. All CH<sub>4</sub> and N<sub>2</sub>O emissions from aviation gasoline are therefore include elsewhere (IE), under jet kerosene. The inventory agency assigns total CO<sub>2</sub> 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 2019 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.

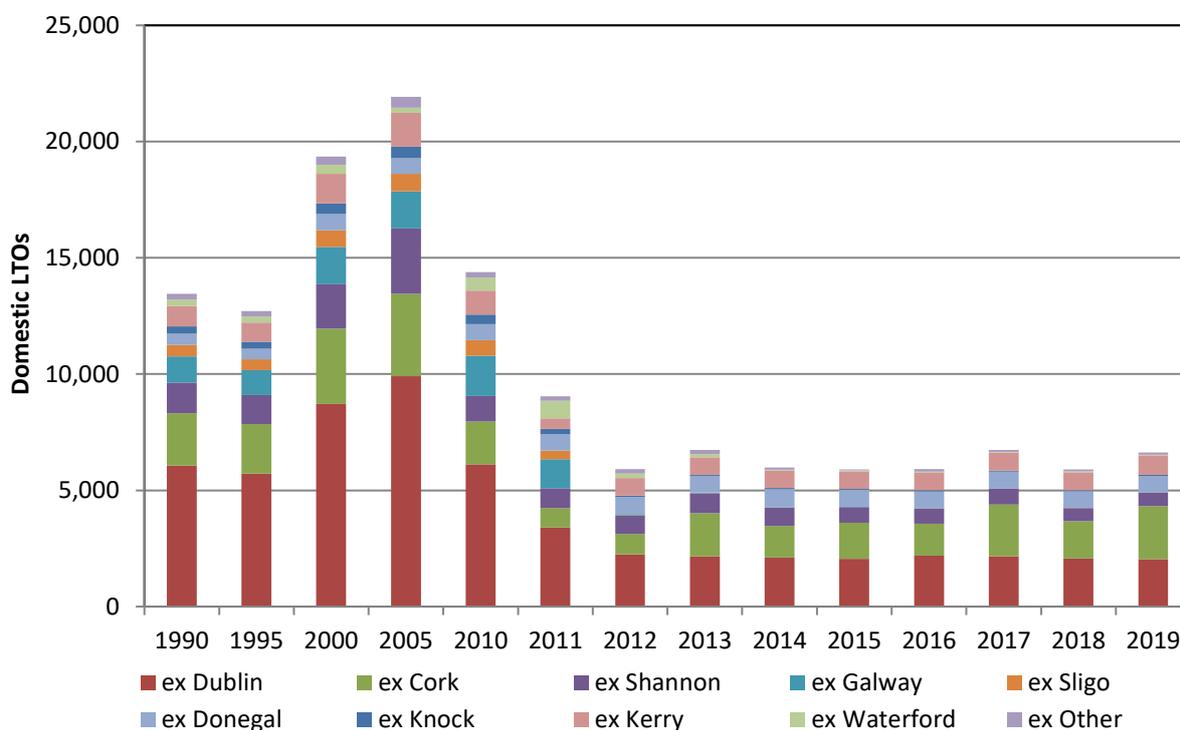


Figure 3.6 Number of LTOs from Irish airports 1990-2019

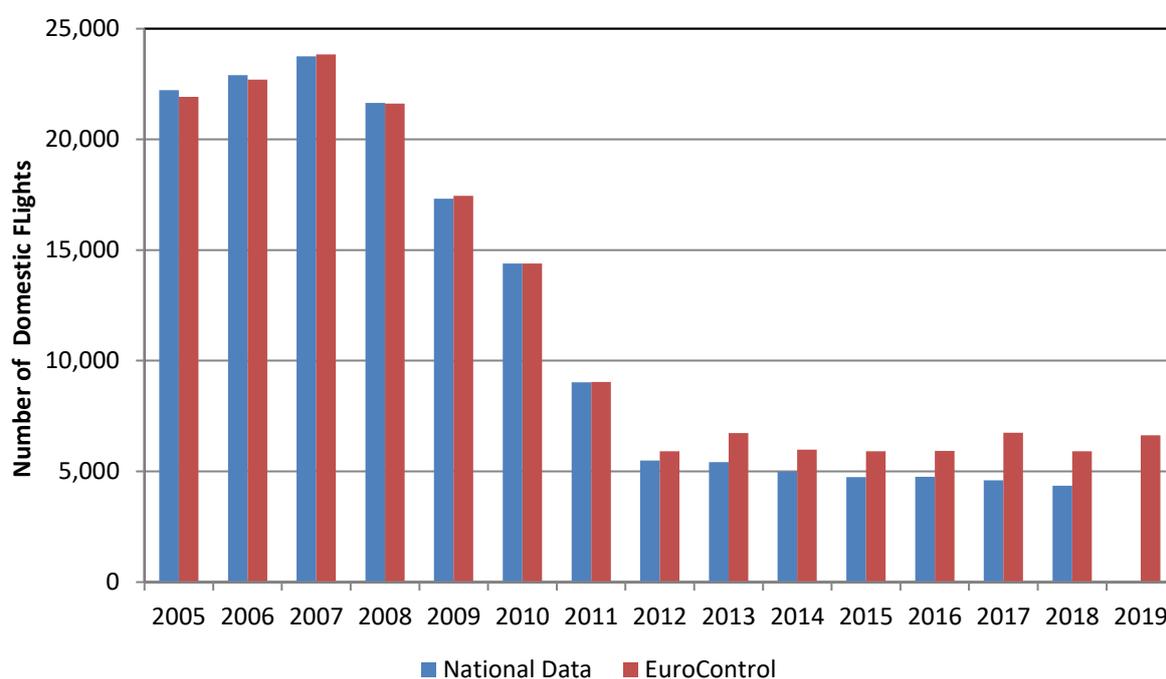
### Uncertainties and Time-series Consistency

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.

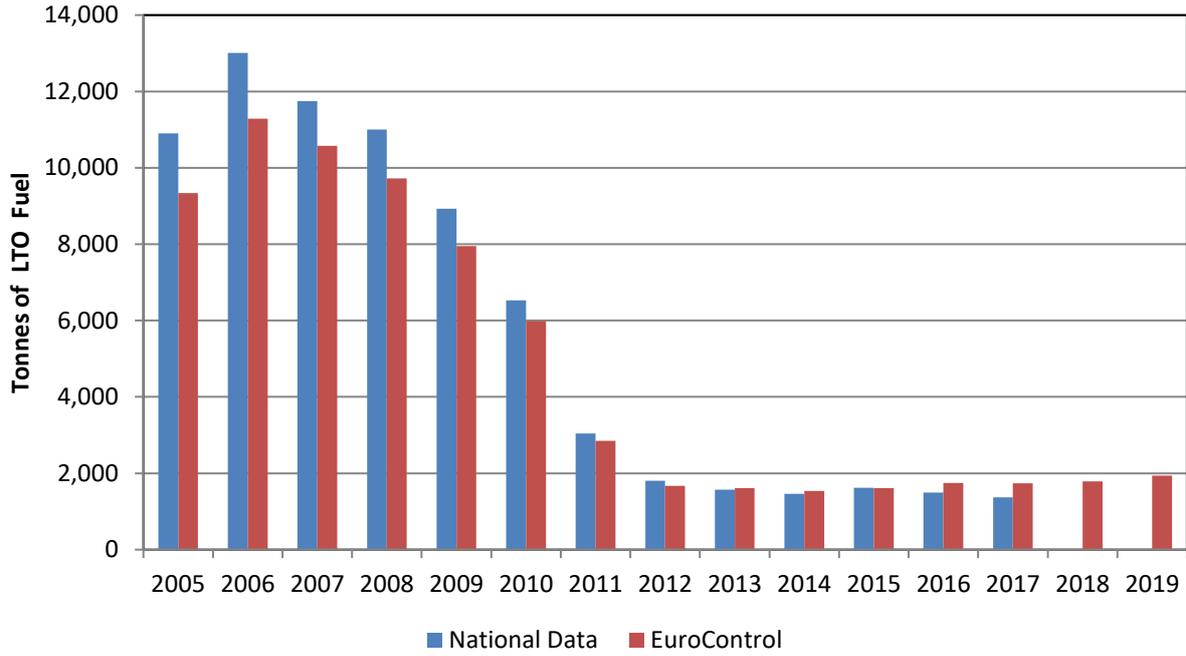
### Category-specific QA/QC and verification

The inventory agency continues to receive annual flight data for all Irish airports from the IAA, for all years from 2004 to 2019. 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.

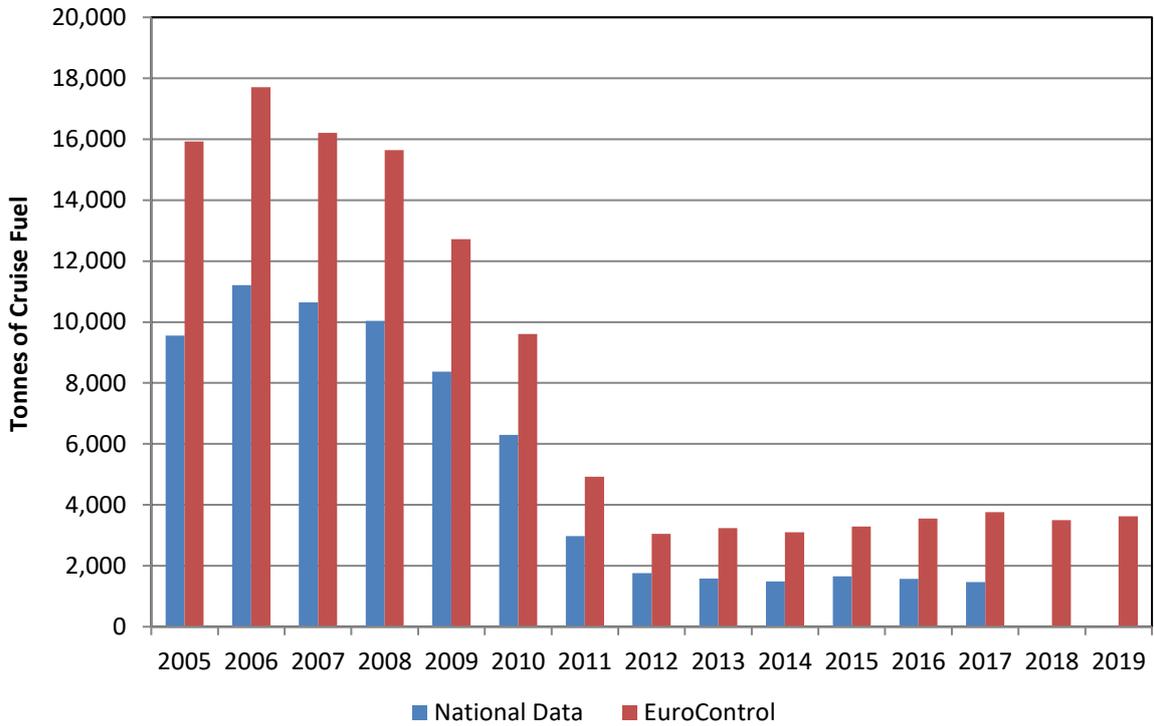
The inventory agency continues to use the EUROCONTROL fuel burn and emissions data (CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O) instead of national data, as mentioned in NIR 2018, and as recommended in previous reviews. The main findings of this verification procedure are outlined in Figures 3.7 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 2005-2019*



*Figure 3.8 National LTO fuel data and EUROCONTROL LTO fuel data for 2005-2019*



*Figure 3.9 National Cruise fuel data and EUROCONTROL Cruise fuel data for 2005-2019*

### Category-specific Recalculations

There are no recalculations to emissions estimates from Domestic Aviation (1.A.3.a) in this submission.

### 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)

### Category Description

Emissions of CO<sub>2</sub> reported under *1.A.3.b Road Transportation* are computed from the amounts of petrol, diesel, LPG 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 7.0 per cent of automotive fuels purchased in Ireland were used outside of Ireland in 2019. For CO<sub>2</sub> 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<sub>4</sub> and N<sub>2</sub>O 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.

### Methodological Issues

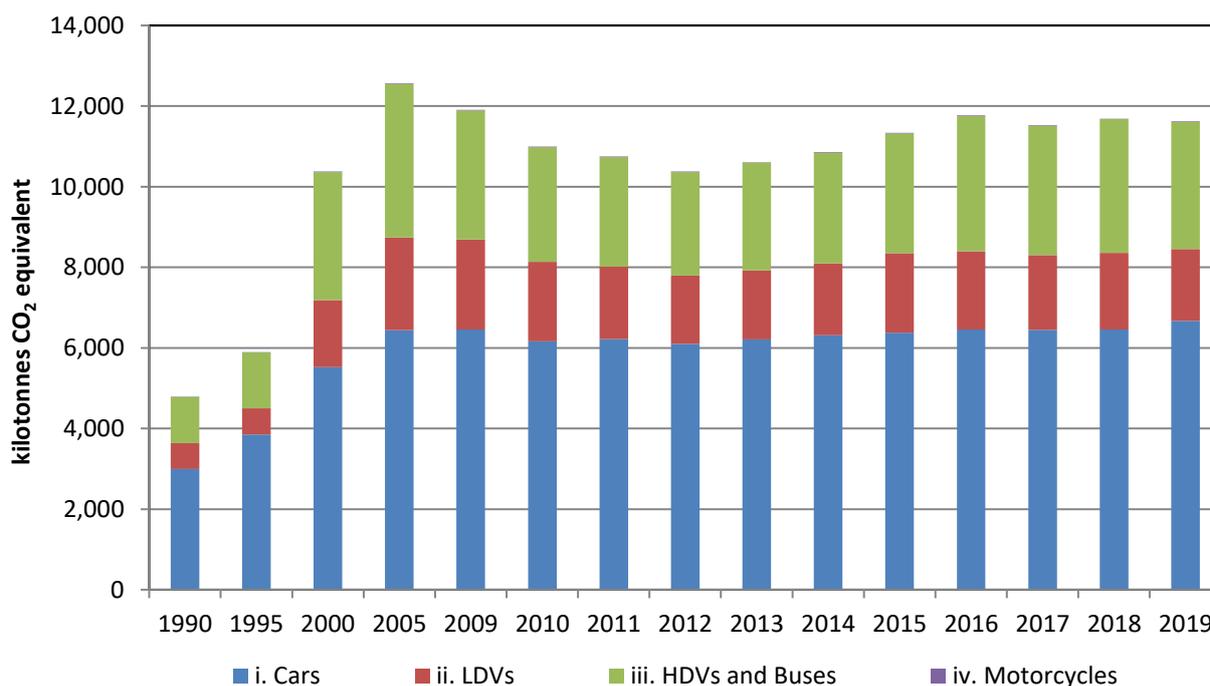
The COPERT 5.4.36 model estimates emissions of CH<sub>4</sub> and N<sub>2</sub>O on the basis of distance travelled using a detailed bottom-up approach (Tier 3) that accounts for such factors as fuel type, fuel consumption, engine capacity, driving speed and a range of applicable technological emission controls that may be applied on the basis of the age of the vehicle. The model is applied annually in Ireland to derive CO<sub>2</sub> emission proportions between vehicle categories and CH<sub>4</sub> and N<sub>2</sub>O emissions estimates. The resultant 2019 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 (<https://www.eea.europa.eu/publications/emep-eea-guidebook-2016>) 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 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. In previous years, the

model was permitted to balance the mileage and distribute the fuel evenly across the various categories. Analysis of this output data highlighted unrealistic km travel for most categories following the COPERT balancing. Therefore, 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 a 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.



*Figure 3.10 Emissions from 1.A.3.b Road Transport 1990-2019*

### 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 2019 from national statistics- Vehicle Bulletin of Driver Statistics (DOE, DELG, DEHLG, DOT, DOTTS, 1990-2019). The structuring of the fleet was consistent with the vehicle category structure and subsequent emissions

by each fuel in given a 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<sub>i</sub>:

$$N_{E_i, q} = \sum_{x=p}^{x=q} N_x$$

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	
Euro-5 /Euro-V	2011-2014	2011-2014	2011-2014	2010-2013	2010-2014	
Euro-6 /Euro-VI	2015-present	2015-present	2015-present	2014-present	2015-present	

**Note:** Euro 5 will apply to passenger cars and light duty vehicles of categories and will be mandatory for vehicles registered from the 1<sup>st</sup> January 2011 or from 1<sup>st</sup> January 2012 for some vehicles. Euro 6 will apply to new vehicle registrations from 2015 (RSA, 2006, 2007, 2008, 2011).

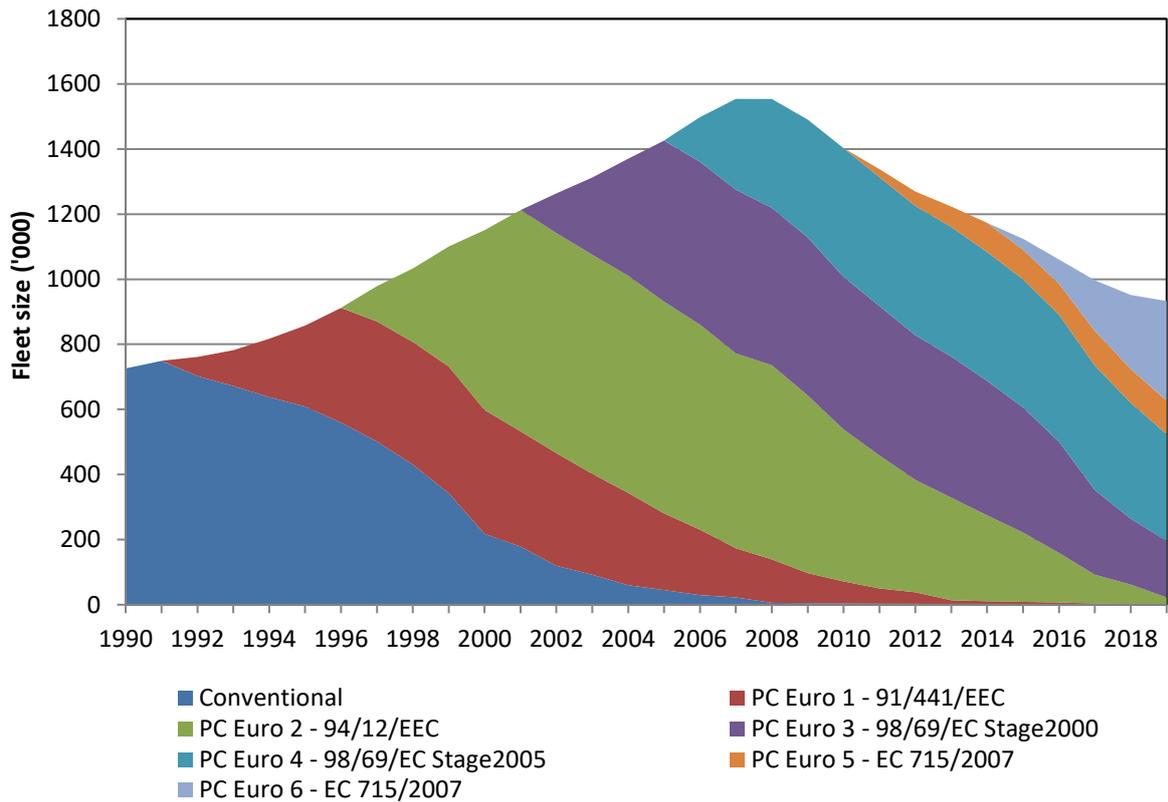


Figure 3.10.1(a) Historic passenger car fleet in Irish transport sector, Petrol

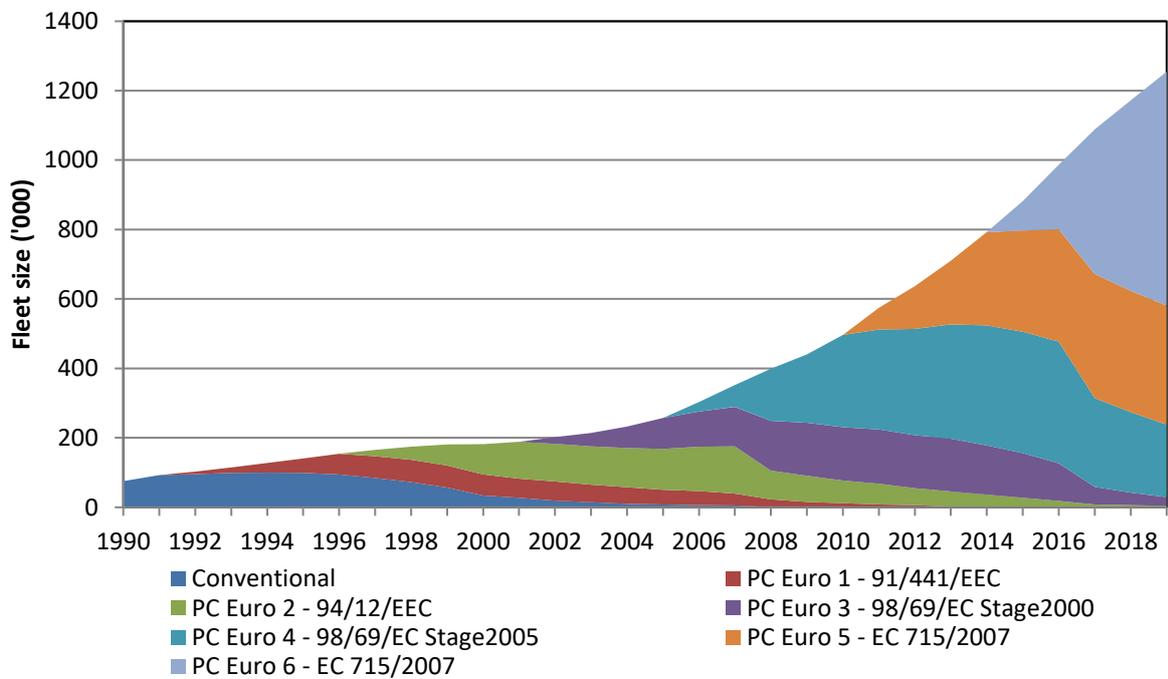


Figure 3.10.1(b) Historic passenger car fleet in Irish transport sector, Diesel

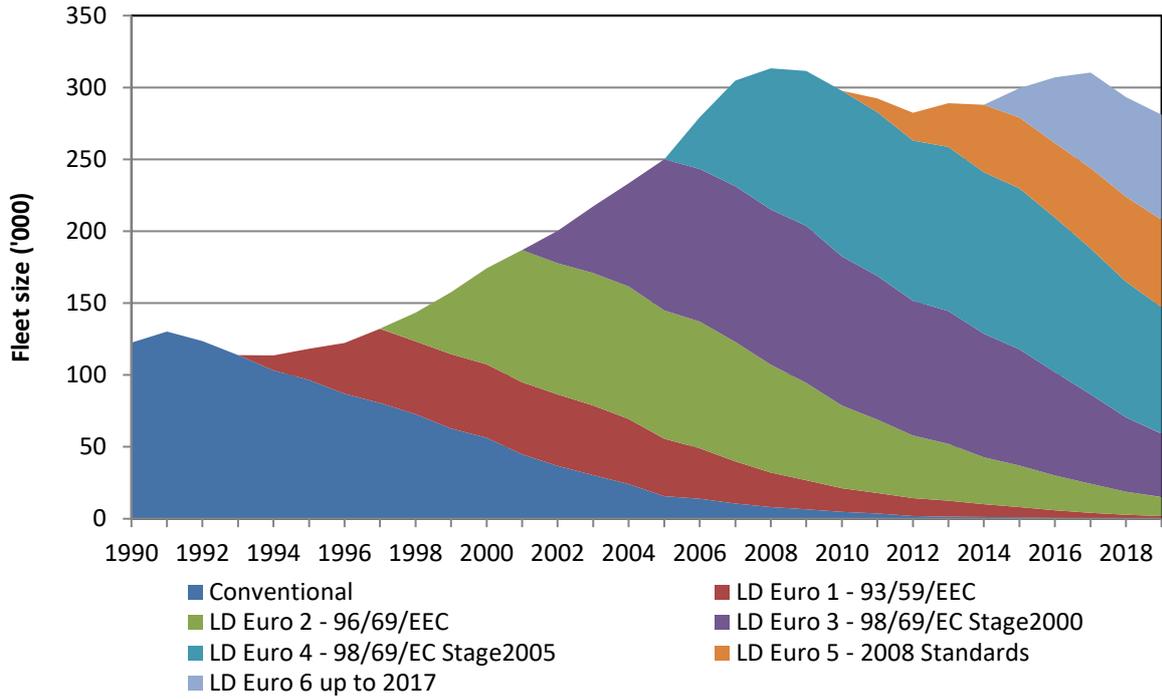


Figure 3.10.2 (a) Historic LDV fleet in Irish transport sector

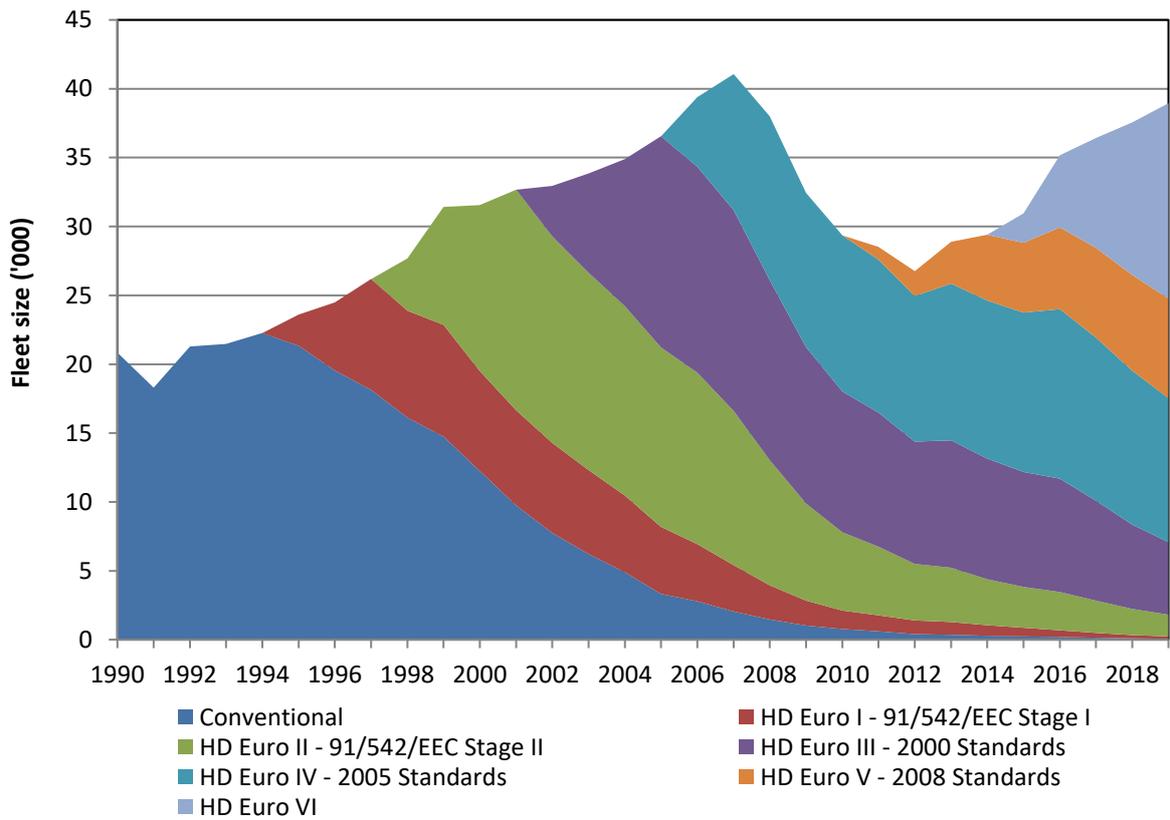


Figure 3.10.2 (b) Historic HDV fleet in Irish transport sector

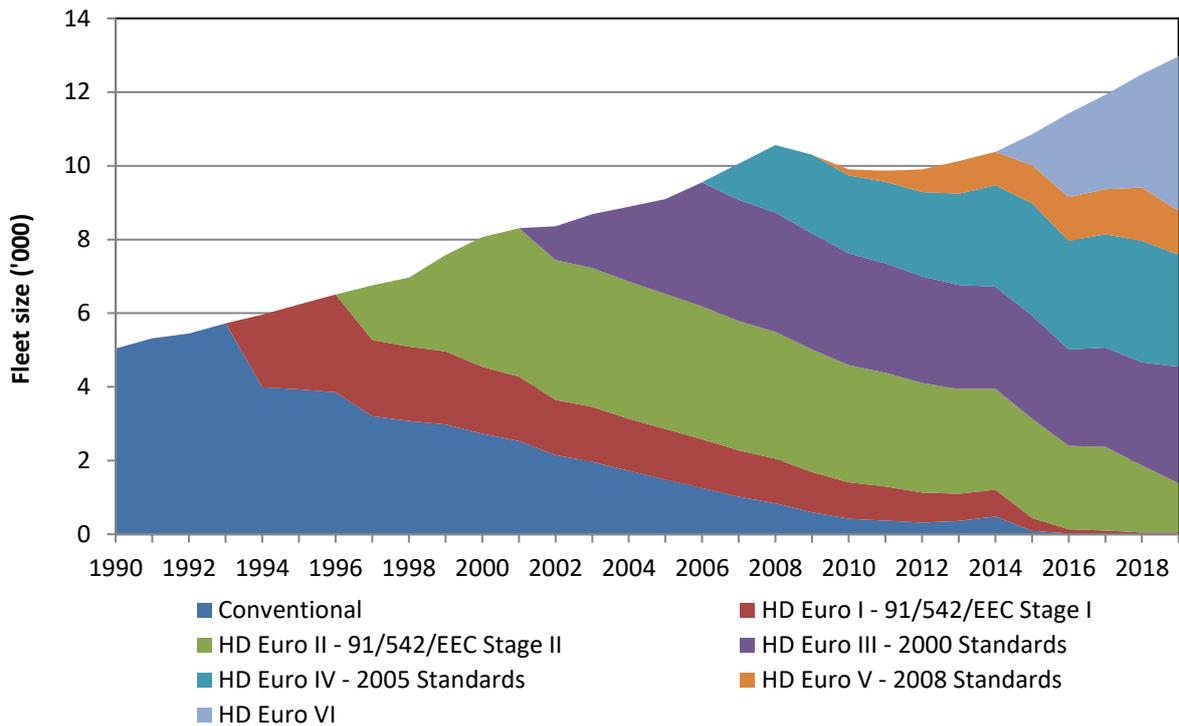


Figure 3.10.3(a) Historic Buses and coaches fleet in Irish transport sector

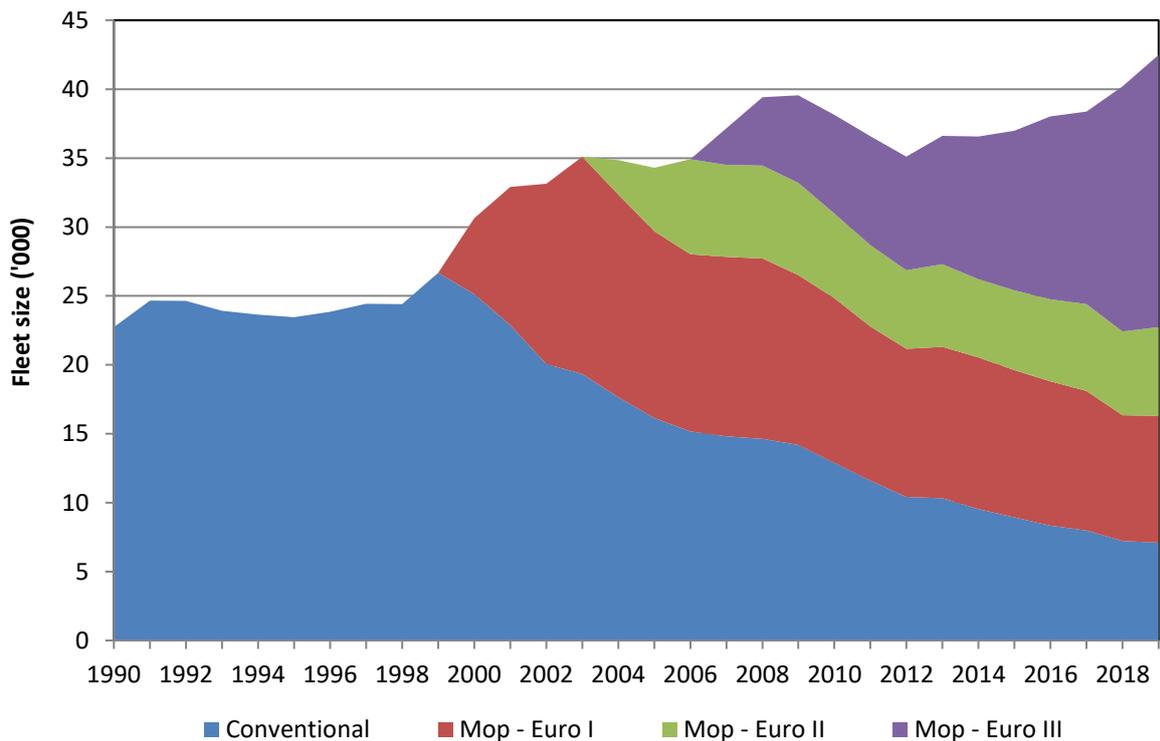


Figure 3.10.3 (b) Historic Mopeds and Motorcycle fleet in Irish transport sector

The estimation of mileage in modelling emissions from 1990-2019 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 (1.45-2L), 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.

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

Where,  $M_{E_{i,q},Y}$  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  $Y=p, p+1, p+2, \dots, p+n=q$  (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'.

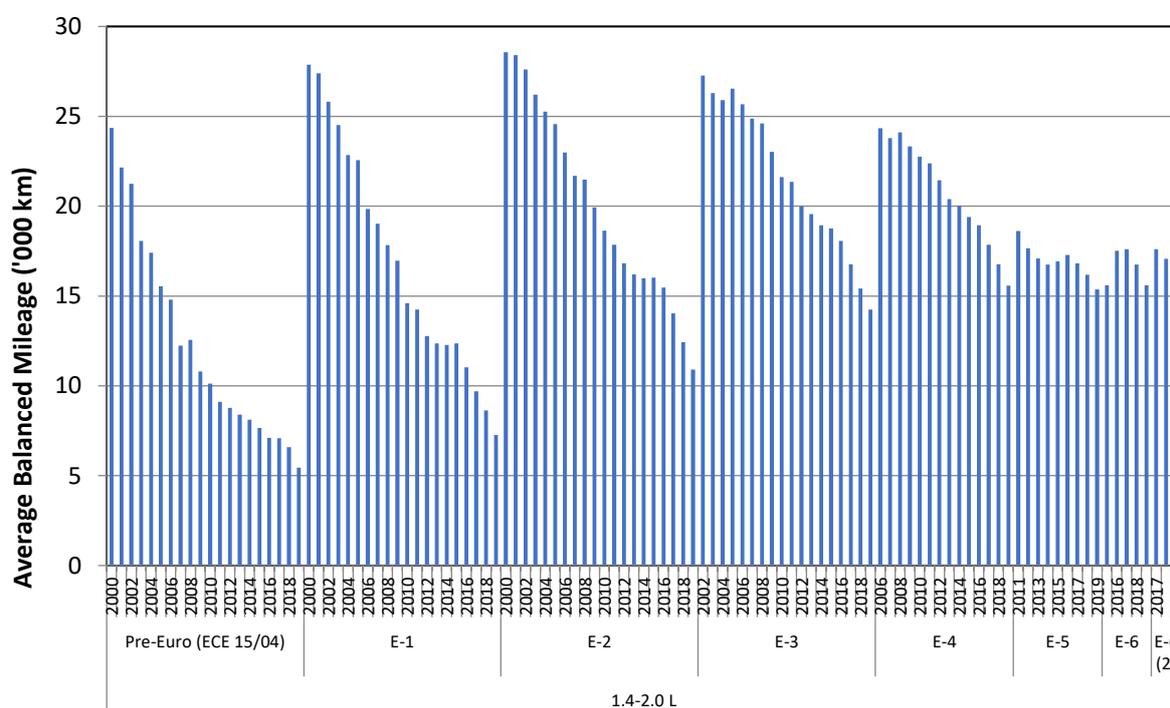


Figure 3.10.4 Average Balanced Vehicle mileage for Petrol PC 1.4-2L (2000-2019)

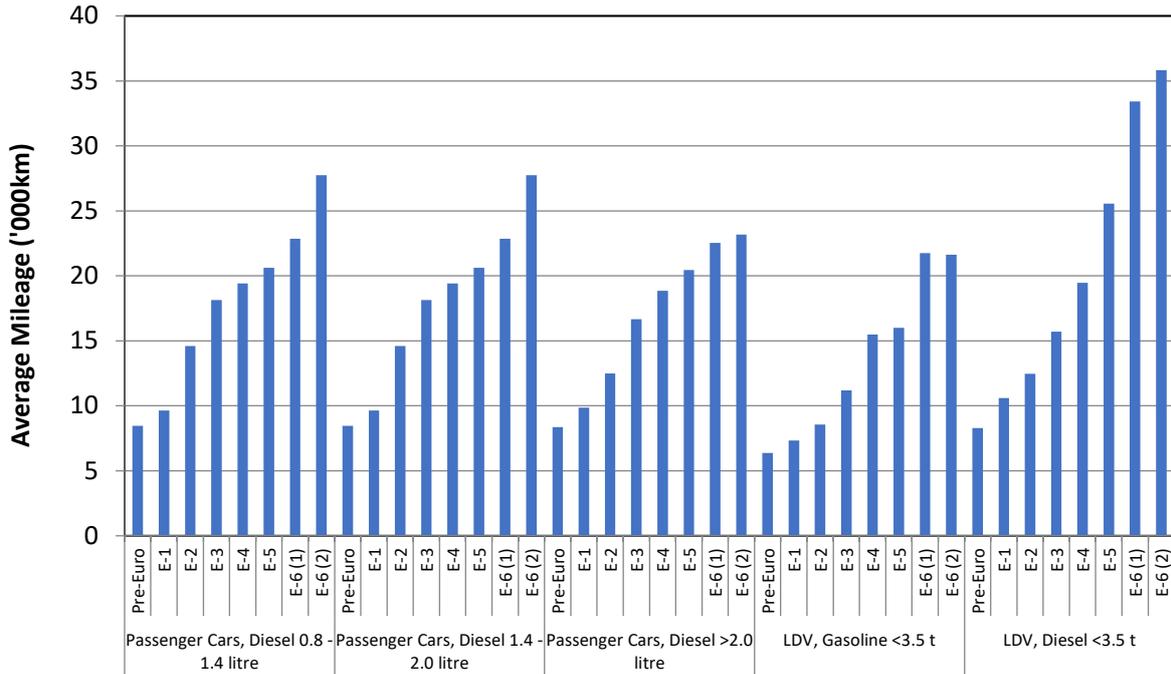


Figure 3.10.5 Average Balanced Vehicle mileage for Diesel Passenger car and LDV (2019)

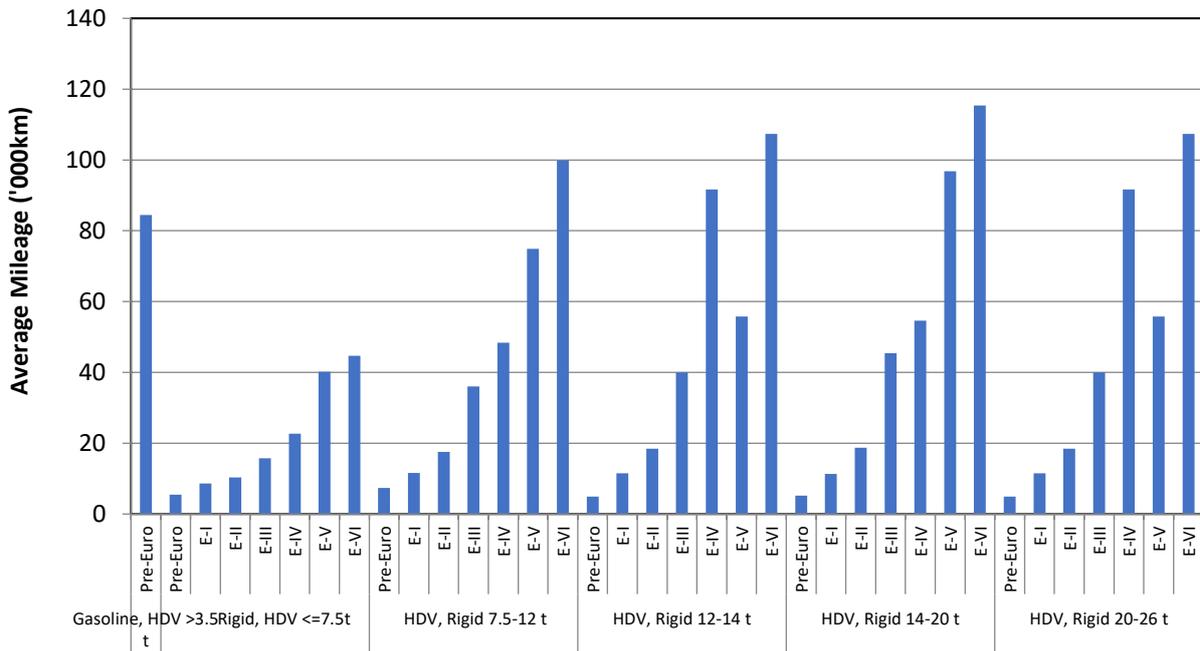


Figure 3.10.6 Average Balanced Vehicle mileage for HD Vehicle categories (2019)

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.

## 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 from last year's emissions inventory reports and applied similarly for this year. The sulphur content of fuels were obtained from the annual survey 2019 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.

### 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 (June, 2015). The current version COPERT 5 (5.4.36 - October 2020) 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.

### COPERT 5 Methodology

The methodology in COPERT 5 is the part of the EMEP/EEA air pollutant emission inventory guidebook 2016 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 & bioethanol) from the fossil portion. Appropriate blends are specified within the model for the relevant vehicle categories (e.g. 95% fossil; 5% 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<sub>2</sub>O and CH<sub>4</sub> 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<sub>2</sub> and two other greenhouse gases (CH<sub>4</sub> and N<sub>2</sub>O) 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 217 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:

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

where,

$E_{\text{TOTAL}}$  = 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°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  $k$ ,

$e^{\text{COLD}} / e^{\text{HOT}}|_{i,k}$  = 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:

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

where,

$E_{\text{URBAN}}$ ,  $E_{\text{RURAL}}$  and  $E_{\text{HIGHWAY}}$  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, 2016.

The fossil fuel content of biofuels was calculated in this submission for the relevant years 2012-2019 using the “Note on fossil carbon content in biofuels” (Sempos, 2018). The fatty acid methyl ester (FAME) content of biodiesel was taken from Ireland's National Oil Reserves Agency (NORA) reports. The carbon content of FAME default value of 76.5% was used and the default fossil part of this carbon content of 5.4% was used to estimate the fossil emissions associated with FAME.

### Uncertainties and Time-series Consistency

The CO<sub>2</sub> 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<sub>4</sub> and N<sub>2</sub>O are in the range of 2 to 3 per cent 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 2019.

The 2021 submission consists of several changes/improvements to the disaggregated fleet data:

- Previously passenger diesel cars were divided between small (<1.4 L) and large (>2.0 L) categories. Diesel cars are now disaggregated into small, medium and large. This should represent a significant improvement in representation given the large proportion of diesel cars falling within the medium (1.4 L-2.0 L) category i.e. approximately 84 per cent over the last 3 years of known data.
- Additionally, the heavy goods vehicle fleet data was improved. The overall fleet numbers did not change over the time series, but the distribution of the disaggregated HGV fleet categories have changed. Following new information, we were now able to improve the distribution of the fleet numbers into a more appropriate category i.e. aligning unladen fleet numbers per weight category into the structured laden categories within COPERT 5.4.36. Further alignment and improvement with this distribution may be required in the future.

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).

#### 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 provided by SEAI was processed and compared with CSO data and knowledge of disaggregation according to published journal articles. 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.

#### Category-specific Recalculations

The most recent submission included a number of improvements in input data specifically related to Ireland's fleet and km travel distribution as outlined above. Overall balanced km travel is now a lot closer to our input mileage data taking into account the unaccounted fuel. The passenger diesel cars now contain a medium category which is a significant improvement in representation given the high proportion of diesel cars that fall into this category in Ireland. The distribution of HGVs is now better aligned to their relevant COPERT laden categories which also provides a more credible output data in terms of output emissions. The result of this change means we now have a greater number of HGVs in the heavier categories.

As a result of the above changes, we have seen numerous recalculations at a disaggregated level for CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O emissions within this submission using COPERT 5.4.36 compared to last previous submission.

- CO<sub>2</sub> equivalent emissions: Overall, CO<sub>2</sub> equivalent emissions have increased by on average 0.04 per cent per annum. CO<sub>2</sub> emissions have reduced by approximately 8.1 per cent and 1.4 per cent per annum for diesel cars and diesel buses respectively. The redistribution has meant that LDV and HGV have both increased. LDV diesel increased by 1.7 per cent per annum and HGV diesel increased by 7.7 per cent each year on average over the time series.
- CH<sub>4</sub> emissions: Overall CH<sub>4</sub> emissions have increased on average of 4.4 per cent per annum. Diesel cars and buses both declined on average 1.4 per cent and 0.8 per cent each year whilst LDV diesel increased by 0.4 per cent and HGV diesel increased by 6.2 per cent each year over the time series.
- N<sub>2</sub>O emissions: Passenger petrol and diesel cars reduced by 0.4 per cent and 7.2 per cent respectively each year on average over the time series. All other categories seen an increase each year.

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

### 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)

#### 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 off-shore natural gas production platforms and in natural gas pipeline compressor stations.

#### Methodological Issues

The CO<sub>2</sub> 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<sub>4</sub> and N<sub>2</sub>O 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 <sub>2</sub> t/TJ	Reference	CH <sub>4</sub> kg/TJ	N <sub>2</sub> O 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 off-shore 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<sub>2</sub> and the default values for CH<sub>4</sub> and N<sub>2</sub>O (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 sub category 1.A.3.e.ii as there are no known emissions related to off road vehicles in category “1.A.3.e Other transportation”.

### Uncertainties and Time-series Consistency

The uncertainties applicable to Railways, Navigation and Other Transportation are provided in Annex 2. The emission time series for 1990-2018 is consistent. Key activity data such as fuel use statistics are available for all years and are used in a consistent manner.

### 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.

### Category-specific Recalculations

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

Other Transport (1A3ei Pipeline transport) has been updated and as a result there is a recalculation for all years. The annual difference is less than 1 kt CO<sub>2</sub>e or approximately 0.6 per cent per annum within this sub-sector. In previous years, the losses accounted for distribution losses whereas now, all transport losses are included (i.e. transmission and distribution).

### 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.

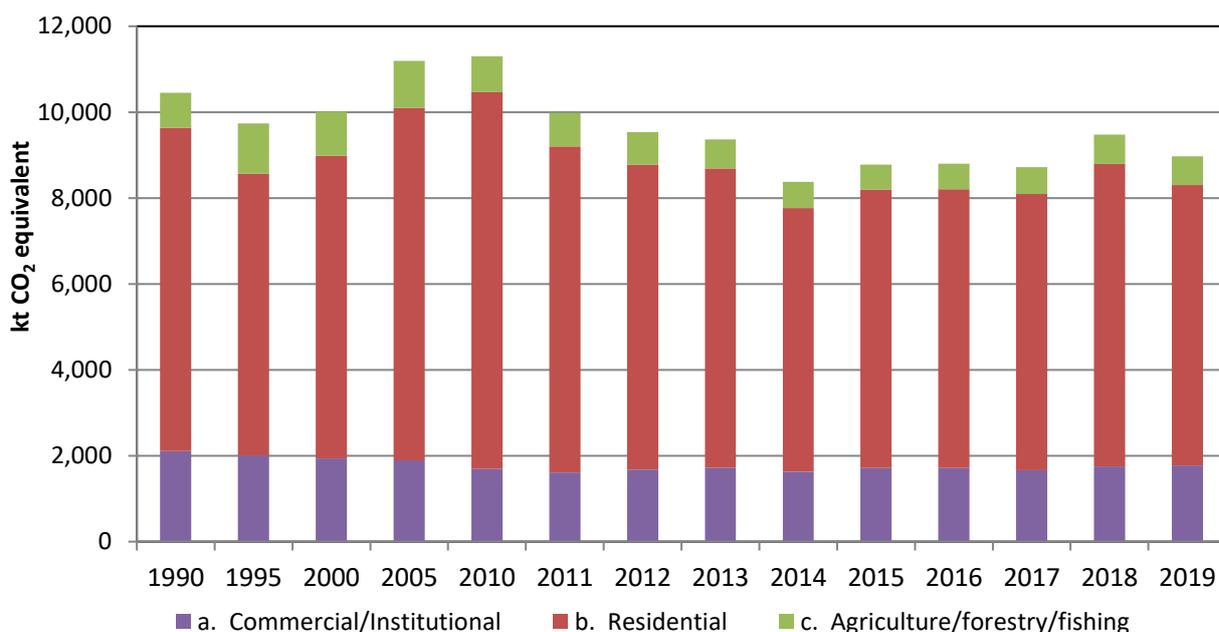


Figure 3.11 Emissions from 1.A.4 Other Sectors 1990-2019

### 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<sub>2</sub>, 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<sub>4</sub> and N<sub>2</sub>O. 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<sub>2</sub>, but it is important in relation to CH<sub>4</sub> or N<sub>2</sub>O 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 extensive recalculation changes based on significant revisions to the historical energy balances going back as far as 1990. This is because SEAI have incorporated a major new data set on business energy use for the first time. This is the Business Energy Use Survey (BEUS), first published by the Central Statistics Office (CSO) in December 2018. This valuable new data source provides a new basis for the breakdown of energy use in the commercial services, public services and industrial sectors, at a level of detail not previously possible. SEAI have revised the National Energy Balances from 1990 to 2018 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 2017 with the 2018 and 2019 splits based on the latest 2017 splits.

Coal use in the residential sector has been increased from 2012 due to new methodology aligned to CSO trade data on imports of manufactured ovoids.

**Table 3.6 Emission factors for fuel use in Agriculture**

IPCC category	Fuel	CO <sub>2</sub> t/TJ	Reference	CH <sub>4</sub> kg/TJ	N <sub>2</sub> O 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 <sub>2</sub>	112,000	2006 IPCC Guidelines Table 2.5
Residential	Charcoal	CH <sub>4</sub>	200	2006 IPCC Guidelines Table 2.5
Residential	Charcoal	N <sub>2</sub> O	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 1990-2018 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 were no significant recalculations in this sub-category for the 2020 submission.

In this submission, there are extensive recalculation changes based on significant revisions to the historical energy balances going back as far as 1990.

- In the Commercial/Institutional sector 1.A.4.a, there was a significant reallocation of oil and natural gas out of the sector over the entire time series from 1990-2018. From 1990-1996, a portion of oil was redistributed from 1.A.4.a to both 1.A.2 and 1.A.4.b. 1997-2018, a substantial quantity of oil was moved into the residential sector 1.A.4.b. In turn, there was a significant redistribution of natural gas from 1.A.4.a to 1.A.2 from 2001 to 2018 (with the exception of 2004 and 2006).

- In the Residential sector 1.A.4.b, there was a significant increase in the overall fuel use throughout the time series. From 1990-1996, oil was reallocated from the Commercial/Institutional sector to the Residential sector. From 1997-2001, the recalculated deficits of oil use for both 1.A.2 and 1.A.4.a are now allocated the Residential sector 1.A.4.b.

### 3.2.7.6 Category-specific Planned Improvements

There are no planned improvements for this category. The use of BEUS data has focused on data from 2009 to 2017 with the 2018 and 2019 splits based on the latest 2017 splits but we plan to attribute more specific updates to the last 2 years as part of the 2022 submission once this particular data is available at a disaggregated level.

### 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.

In 2018, EUROCONTROL report 5,906 domestic LTOs whereas IAA data report only 4,357. The inventory agency now uses EUROCONTROL data for reporting emissions from category 1.A.3.a as discussed in section 3.2.6.1.2 above. The EUROCONTROL PRISME database stores information about air traffic movements in the ECAC area flying IFR, but not flights under VFR. The inventory agency identified for 2018, using the IAA data, 31 military LTOs; including police support helicopter, maritime patrol aircraft and government jet movements. Total civil aviation emissions in 2018 were 16.8 kt of CO<sub>2</sub> equivalent for 5,906 LTOs, therefore military aviation is considered insignificant. Any aviation emissions not estimated and reported using EUROCONTROL AEM results are reported under aviation bunkers.

## 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 1990-2019 and from coal mining for the period 1990-1995 (only emissions from abandoned mines are reported after 1995).

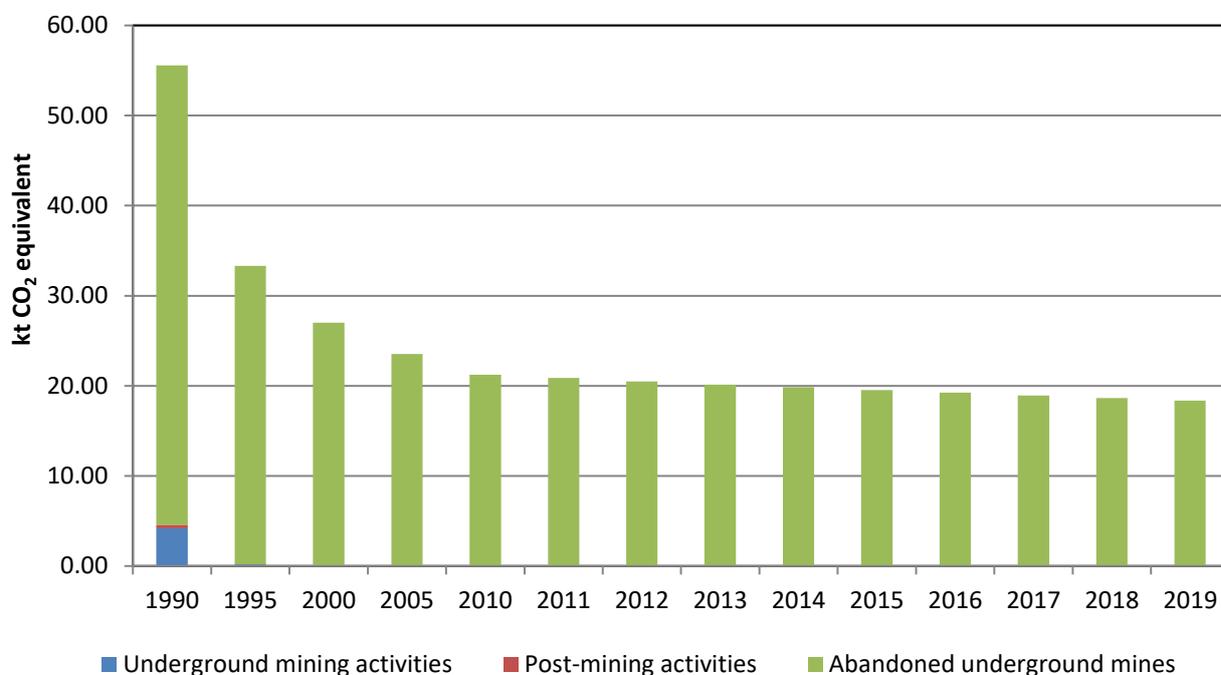
### 3.3.1 Coal Mining and Handling (1.B.1.a)

#### 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<sub>4</sub> 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 1990-2019.

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 a mere 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 1990-2019*

### 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<sub>4</sub> 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 <sub>4</sub> EF	Unit	CH <sub>4</sub> Conversion Factor	Unit	Reference
Underground mining activities	10	m <sup>3</sup> /t	0.67 • 10 <sup>-6</sup>	kt CH <sub>4</sub> /m <sup>3</sup>	2006 IPCC Guidelines Equation 4.1.3
Post-mining activities	0.9	m <sup>3</sup> /t	0.67 • 10 <sup>-6</sup>	kt CH <sub>4</sub> /m <sup>3</sup>	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 1990-2019. This

category is based on the number of existing abandoned mines (remaining unroofed) that were closed-down within the five time-bands:

- Years 1990 – 1925;
- Years 1926 – 1950;
- Years 1951 – 1976;
- Years 1976 – 2000;
- Years 2001 – present.

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-present, 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 (I.B.1.a.1(ii))**

Time band	Number of existing abandoned mines	Fraction of gassy mines (%)	CH <sub>4</sub> EF	Unit	CH <sub>4</sub> Conversion Factor	Unit	Reference
1926 - 1950	9	3	0.343 -0.279	Mm <sup>3</sup> /mine	0.67	kt CH <sub>4</sub> /Mm <sup>3</sup>	2006 IPCC Guidelines, Eq. 4.1.10, Table 4.1.5, Table 4.1.6
1951 - 1975	19	5	0.478 -0.340	Mm <sup>3</sup> /mine	0.67	kt CH <sub>4</sub> /Mm <sup>3</sup>	2006 IPCC Guidelines, Eq. 4.1.10, Table 4.1.5, Table 4.1.6
1976 - 2000	20	8	1.561 - 0.469	Mm <sup>3</sup> /mine	0.67	kt CH <sub>4</sub> /Mm <sup>3</sup>	2006 IPCC Guidelines, Eq. 4.1.10, Table 4.1.5, Table 4.1.6

### 3.3.1.3 Uncertainties and Time-series Consistency

The uncertainties applicable to Coal Mining and Handling are provided in Annex 2. The emission time series for 1990–2019 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.

### 3.3.1.4 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.

### 3.3.1.5 Category-specific Recalculations

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

### 3.3.1.6 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

#### 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 – 2019. During the period 1990-2019 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 wells 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.

CO<sub>2</sub> and CH<sub>4</sub> emissions from exploration are not occurring due to the use of heavy drilling muds preventing hydrocarbons from escaping the well during exploratory drilling. Emissions from exploration are reported as NO.

#### 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 is preparing for decommissioning of the gas fields and facilities<sup>1</sup>. Emissions to the atmosphere from offshore gas production platforms are reported to the Department of Communications Climate Action and Environment (DCCA) 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% CH<sub>4</sub> even though they might contain small amounts of CO<sub>2</sub> and other gases.

A 2018 UNFCCC review determined that these reported emissions should be regarded as CH<sub>4</sub> 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 fugitive CH<sub>4</sub> emission for 2017 was 0.338 tonnes, 2018 was 4.2 tonnes and 2019 was 5.4 tonnes. 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.

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<sup>1</sup> [https://www.kinsale-energy.ie/files/pdf/DecommissioningPlan\\_KinsaleHeadNo.1\\_Issue1\\_120618.pdf](https://www.kinsale-energy.ie/files/pdf/DecommissioningPlan_KinsaleHeadNo.1_Issue1_120618.pdf)

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. In 2019 Kinsale estimate there were no releases.

The 2006 IPCC default methodology and EFs for natural gas production would result in an estimated CH<sub>4</sub> 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 (no fugitive emissions were estimated for 2019) using an IEF for kt CH<sub>4</sub>/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<sub>4</sub> for this facility. Emissions of CO<sub>2</sub> 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 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<sub>2</sub> eq. Ireland's inventory total (excluding LULUCF) was 59,777.64 kt CO<sub>2</sub> eq for 2019, and 0.05 per cent of this is value is 29.89 kt CO<sub>2</sub> eq. As the fugitive emissions for Ireland from natural gas production and processing are 0.14 kt CO<sub>2</sub> 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.

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

In the latest submission fugitive emissions from transmission are reported separately from emissions in 1.B.2.b.5 *Natural Gas Distribution* see section 3.3.2.2.3 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 calculate EFs for each gas stream. The amount of gas transmitted is taken from the energy balance so that weighted averages can be calculated. 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 2014–2019, 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. The Kinsale facility is in the process of being decommissioned. Ireland considers that the default EFs for underground storage of natural gas are not be applicable for this particular 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 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.

#### 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) (1997-2019). 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 2014-2019, networks performance reports<sup>2</sup> (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 was extrapolated using data from national energy balance as consumption in the residential, industrial and commercial sectors.

Gas Networks Ireland also provided an estimate of volumes of gas leakage from the transmission and distribution system for years 2010-2019. 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 0.39 t CH<sub>4</sub>/m<sup>3</sup> 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<sub>2</sub> emissions were also calculated using the amount of gas leaked, the NCV and the weighted average of the percentage of CO<sub>2</sub> 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 2014–2019, 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 distribution portion of fugitive emissions and report these emissions separately.

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<sup>2</sup> <https://www.gasnetworks.ie/corporate/gas-regulation/regulatory-publications/>

Estimates of CO<sub>2</sub> emissions for natural gas distributed is also reported. See table 3.1.15 in Annex 3.1.C for further information on EFs and Natural Gas Distribution emissions estimates.

### 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<sub>2</sub> and CH<sub>4</sub> per unit of gas extracted to estimate the emissions for those years for which no reports were received.

Fugitive CO<sub>2</sub> 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<sub>2</sub> reporting for the years 2015-2019. The CH<sub>4</sub> and N<sub>2</sub>O emissions were estimated using the energy amount of gas flared and the the EFs from Table 2.2 from Vol. 2, Ch. 2 of the 2006 IPCC guidelines (1 and 0.1 kg/TJ for CH<sub>4</sub> and N<sub>2</sub>O 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 1990-2019 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

The following recalculations occur in 1.B.2 Natural gas:

- Ireland has reallocated the emissions from natural gas transmission (category 1.B.2.b.4) and distribution (category 1.B.2.b.5), reporting emissions separately by applying the Gas Networks Ireland splits consistently and as accurately as possible across the whole time series

### 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.

## 3.4 CO<sub>2</sub> Transport and Storage (1.C)

This activity does not occur in Ireland. Emissions are reported as Not Occurring (NO) for all years 1990-2019.

**Table 3.10(a) Previous and current emission estimates in the Energy Sector (1990-2018)**

2021 Submission		Unit	1990	1995	2000	2005	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
1.A.1.a	Public Electricity and Heat Production	kt CO <sub>2</sub> e	10,953.9	13,132.9	15,754.4	15,244.8	12,610.6	12,895.1	11,557.1	12,350.2	10,977.5	10,837.7	11,401.0	12,149.5	11,379.1	10,110.5
1.A.1.b	Petroleum Refining	kt CO <sub>2</sub> e	168.7	181.3	274.8	411.9	315.4	310.5	285.4	313.5	294.5	279.5	358.7	313.6	311.2	322.2
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries	kt CO <sub>2</sub> e	100.5	69.4	87.2	171.9	193.1	174.7	137.5	146.3	162.0	134.8	115.8	126.3	129.4	119.3
1.A.2.a	Iron and Steel	kt CO <sub>2</sub> e	175.9	18.7	18.8	2.4	2.4	2.4	2.4	2.4	2.3	2.4	2.4	2.3	2.3	2.3
1.A.2.b	Non-Ferrous Metals	kt CO <sub>2</sub> e	811.5	1,207.4	1,437.9	1,152.6	1,227.7	1,519.0	1,484.0	1,479.2	1,439.4	1,439.8	1,446.4	1,391.4	1,402.9	1,407.0
1.A.2.c	Chemicals	kt CO <sub>2</sub> e	411.4	352.2	485.1	450.8	282.0	272.1	252.3	245.8	259.2	254.6	263.7	276.1	273.5	292.7
1.A.2.d	Pulp, Paper and Print	kt CO <sub>2</sub> e	28.5	62.6	102.7	50.4	23.2	21.1	17.9	16.1	15.8	14.8	15.2	16.1	16.3	17.2
1.A.2.e	Food Processing, Beverages and Tobacco	kt CO <sub>2</sub> e	1,021.4	1,175.6	1,608.6	1,296.1	1,077.3	977.5	808.8	801.6	864.0	800.7	859.6	860.9	869.1	899.8
1.A.2.f	Non-metallic minerals	kt CO <sub>2</sub> e	822.8	505.3	720.8	1,923.0	1,105.0	920.1	831.4	928.5	933.4	1,123.1	1,182.4	1,224.0	1,235.2	1,304.3
1.A.2.g	Other	kt CO <sub>2</sub> e	690.4	1,020.8	1,268.5	995.2	769.5	764.2	745.6	703.0	725.2	687.7	700.0	755.2	765.4	818.1
1.A.3.a	Domestic Aviation	kt CO <sub>2</sub> e	48.4	45.7	69.6	80.2	65.6	49.5	24.7	15.0	15.4	14.7	15.6	16.8	17.5	16.8
1.A.3.b	Road Transportation	kt CO <sub>2</sub> e	4,792.0	5,892.0	10,374.1	12,562.0	11,907.9	10,996.3	10,747.6	10,375.8	10,606.6	10,855.6	11,330.1	11,764.6	11,517.9	11,677.5
1.A.3.c	Railways	kt CO <sub>2</sub> e	148.9	124.5	137.6	136.6	137.4	136.3	136.5	131.9	131.4	120.5	122.8	125.1	129.1	130.5
1.A.3.d	Domestic navigation	kt CO <sub>2</sub> e	85.8	92.1	152.7	211.2	199.5	200.1	173.7	183.6	179.6	224.8	221.7	266.5	235.3	260.2
1.A.3.e	Other transportation	kt CO <sub>2</sub> e	74.1	125.8	62.7	153.6	150.4	163.4	151.9	139.5	145.6	145.8	137.1	135.1	126.8	139.7
1.A.4.a	Commercial/Institutional	kt CO <sub>2</sub> e	2,244.1	2,101.9	2,364.1	2,428.1	2,290.6	2,308.0	2,094.9	2,098.4	1,919.0	1,752.2	1,799.5	1,854.1	1,977.9	2,108.4
1.A.4.b	Residential	kt CO <sub>2</sub> e	7,523.7	6,452.0	6,462.6	7,271.6	7,467.0	7,800.9	6,609.7	6,232.3	6,395.4	5,745.6	6,041.3	6,046.5	5,740.9	6,197.2
1.A.4.c	Agriculture/Forestry/Fishing	kt CO <sub>2</sub> e	818.5	1,166.7	1,023.0	1,098.6	893.6	829.7	785.0	757.8	674.3	608.6	580.1	600.5	631.1	680.3
1.B.1.a	Coal mining and handling	kt CO <sub>2</sub> e	55.6	33.3	27.0	23.5	21.7	21.2	20.9	20.5	20.1	19.8	19.5	19.2	18.9	18.6
1.B.2.a	Oil	kt CO <sub>2</sub> e	0.2	0.3	0.4	0.4	0.3	0.3	0.3	0.4	0.3	0.3	0.4	0.4	0.4	0.4
1.B.2.b	Natural gas	kt CO <sub>2</sub> e	48.7	59.3	53.3	47.0	58.5	65.4	58.4	57.2	55.7	51.7	52.7	53.9	59.6	61.4
<b>Total Energy</b>			<b>31,023.7</b>	<b>33,825.1</b>	<b>42,491.7</b>	<b>45,716.9</b>	<b>40,799.3</b>	<b>40,473.4</b>	<b>36,970.5</b>	<b>37,031.5</b>	<b>35,878.3</b>	<b>35,245.6</b>	<b>36,820.8</b>	<b>38,135.8</b>	<b>37,120.0</b>	<b>37,030.0</b>
<b>2020 Submission</b>																
1.A.1.a	Public Electricity and Heat Production	kt CO <sub>2</sub> e	10,953.9	13,132.9	15,754.4	15,244.8	12,610.6	12,895.1	11,557.1	12,350.2	10,977.5	10,837.7	11,401.0	12,149.5	11,379.2	10,108.9
1.A.1.b	Petroleum Refining	kt CO <sub>2</sub> e	168.7	181.3	274.8	411.9	315.4	310.5	285.4	313.5	294.5	279.5	358.7	313.6	311.2	322.2
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries	kt CO <sub>2</sub> e	100.5	69.4	87.2	171.9	193.1	174.7	137.5	146.3	162.0	134.8	115.8	126.3	129.4	119.3
1.A.2.a	Iron and Steel	kt CO <sub>2</sub> e	175.9	18.7	18.8	2.4	2.4	2.4	2.4	2.4	2.3	2.4	2.4	2.3	2.3	2.3
1.A.2.b	Non-Ferrous Metals	kt CO <sub>2</sub> e	811.5	1,207.4	1,437.9	1,152.6	1,227.7	1,519.0	1,484.0	1,479.2	1,439.4	1,439.8	1,446.4	1,391.4	1,402.9	1,407.0
1.A.2.c	Chemicals	kt CO <sub>2</sub> e	411.4	352.2	485.1	450.8	282.0	272.1	252.3	245.8	259.2	254.6	263.7	276.1	273.5	292.7
1.A.2.d	Pulp, Paper and Print	kt CO <sub>2</sub> e	28.5	62.6	102.7	50.4	23.2	21.1	17.9	16.1	15.8	14.8	15.2	16.1	16.3	17.2
1.A.2.e	Food Processing, Beverages and Tobacco	kt CO <sub>2</sub> e	1,021.4	1,175.6	1,608.6	1,296.1	1,077.3	977.5	808.8	801.6	864.0	800.7	859.6	860.9	869.1	899.8
1.A.2.f	Non-metallic minerals	kt CO <sub>2</sub> e	822.8	505.3	720.8	1,923.0	1,105.0	920.1	831.4	928.5	933.4	1,123.1	1,182.4	1,224.0	1,235.2	1,304.3
1.A.2.g	Other	kt CO <sub>2</sub> e	690.4	1,020.8	1,268.5	995.2	769.5	764.2	745.6	703.0	725.2	687.7	700.0	755.2	765.4	818.1
1.A.3.a	Domestic Aviation	kt CO <sub>2</sub> e	48.4	45.7	69.6	80.2	65.6	49.5	24.7	15.0	15.4	14.7	15.6	16.8	17.5	16.8
1.A.3.b	Road Transportation	kt CO <sub>2</sub> e	4,789.4	5,892.0	10,374.1	12,562.0	11,907.9	10,996.3	10,747.6	10,375.8	10,606.6	10,855.6	11,330.1	11,764.6	11,517.9	11,677.5
1.A.3.c	Railways	kt CO <sub>2</sub> e	148.9	124.5	137.6	136.6	137.4	136.3	136.5	131.9	131.4	120.5	122.8	125.1	129.1	130.5
1.A.3.d	Domestic navigation	kt CO <sub>2</sub> e	85.8	92.1	152.7	211.2	199.5	200.1	173.7	183.6	179.6	224.8	221.7	266.5	235.3	260.2
1.A.3.e	Other transportation	kt CO <sub>2</sub> e	74.1	125.8	62.7	153.6	150.4	163.4	151.9	139.5	145.6	145.8	137.1	135.1	126.8	139.7
1.A.4.a	Commercial/Institutional	kt CO <sub>2</sub> e	2,244.1	2,101.9	2,364.1	2,428.1	2,290.6	2,308.0	2,094.9	2,098.4	1,919.0	1,752.2	1,799.5	1,854.1	1,977.9	2,108.4
1.A.4.b	Residential	kt CO <sub>2</sub> e	7,523.7	6,452.0	6,462.6	7,271.6	7,467.0	7,800.9	6,609.7	6,232.3	6,395.4	5,745.6	6,041.3	6,046.5	5,740.9	6,197.2
1.A.4.c	Agriculture/Forestry/Fishing	kt CO <sub>2</sub> e	818.5	1,166.7	1,023.0	1,098.6	893.6	829.7	785.0	757.8	674.3	608.6	580.1	600.5	631.1	680.3
1.B.1.a	Coal mining and handling	kt CO <sub>2</sub> e	55.6	33.3	27.0	23.5	21.7	21.2	20.9	20.5	20.1	19.8	19.5	19.2	18.9	18.6
1.B.2.a	Oil	kt CO <sub>2</sub> e	0.2	0.3	0.4	0.4	0.3	0.3	0.3	0.4	0.3	0.3	0.4	0.4	0.4	0.4
1.B.2.b	Natural gas	kt CO <sub>2</sub> e	48.7	59.3	53.3	47.0	58.5	65.4	58.4	57.2	55.7	51.7	52.7	53.9	59.6	61.4
<b>Total Energy</b>			<b>31,022.1</b>	<b>33,824.9</b>	<b>42,485.8</b>	<b>45,711.7</b>	<b>40,798.4</b>	<b>40,427.9</b>	<b>36,925.9</b>	<b>36,998.8</b>	<b>35,816.8</b>	<b>35,114.7</b>	<b>36,665.9</b>	<b>37,998.1</b>	<b>36,840.0</b>	<b>36,582.9</b>

**Table 3.10(b) Absolute and Relative % change in the Energy Sector (1990-2018)**

Absolute change		Unit	1990	1995	2000	2005	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
1.A.1.a	Public Electricity and Heat Production	kt CO <sub>2</sub> e	-	-	-	-	-	-	0.0	0.0	0.0	-0.0	-0.0	-0.0	-0.1	1.7
1.A.1.b	Petroleum Refining	kt CO <sub>2</sub> e	-	-	-	-0.0	-0.0	0.0	0.1	0.1	0.0	-0.0	0.0	-0.0	0.0	0.0
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries	kt CO <sub>2</sub> e	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.A.2.a	Iron and Steel	kt CO <sub>2</sub> e	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.A.2.b	Non-Ferrous Metals	kt CO <sub>2</sub> e	-	-23.6	-90.6	-18.2	73.1	50.5	-128.9	-245.9	-102.1	-142.9	-133.9	-120.2	-88.5	-33.3
1.A.2.c	Chemicals	kt CO <sub>2</sub> e	-	-12.7	-25.6	-3.0	83.5	115.1	123.9	145.2	98.8	110.9	118.1	109.9	121.3	124.3
1.A.2.d	Pulp, Paper and Print	kt CO <sub>2</sub> e	-	-5.0	-6.6	-13.1	-7.1	-7.2	-8.2	-2.9	-3.9	-3.9	-5.1	-4.2	-3.8	-3.9
1.A.2.e	Food Processing, Beverages and Tobacco	kt CO <sub>2</sub> e	-	-40.6	-82.7	-230.0	-149.2	-56.6	9.8	113.2	76.4	110.6	89.1	128.0	166.9	168.9
1.A.2.f	Non-metallic minerals	kt CO <sub>2</sub> e	-	-16.9	-28.1	-145.9	-117.9	-142.2	-139.2	-144.8	-136.3	-78.1	-67.5	-69.3	-87.3	-91.7
1.A.2.g	Other	kt CO <sub>2</sub> e	136.1	82.6	71.0	11.6	-234.0	-271.6	-309.9	-284.3	-251.6	-140.3	-209.1	-218.0	-211.6	-220.7
1.A.3.a	Domestic Aviation	kt CO <sub>2</sub> e	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0
1.A.3.b	Road Transportation	kt CO <sub>2</sub> e	2.6	0.8	6.3	4.9	2.3	1.8	2.7	2.2	3.9	4.5	6.3	8.1	10.3	11.9
1.A.3.c	Railways	kt CO <sub>2</sub> e	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.A.3.d	Domestic navigation	kt CO <sub>2</sub> e	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.A.3.e	Other transportation	kt CO <sub>2</sub> e	-0.7	-0.6	-0.6	-0.6	-1.7	-2.1	-1.5	-0.9	-0.5	-0.1	0.0	0.3	0.2	0.4
1.A.4.a	Commercial/Institutional	kt CO <sub>2</sub> e	-134.0	-96.7	-421.2	-531.6	-694.7	-613.3	-484.6	-419.4	-196.9	-127.9	-82.2	-140.0	-315.4	-356.0
1.A.4.b	Residential	kt CO <sub>2</sub> e	-2.4	113.0	584.1	931.0	1,046.5	971.1	980.3	869.9	573.6	398.3	439.2	443.3	688.0	845.7
1.A.4.c	Agriculture/Forestry/Fishing	kt CO <sub>2</sub> e	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.B.1.a	Coal mining and handling	kt CO <sub>2</sub> e	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.B.2.a	Oil	kt CO <sub>2</sub> e	-	-	-	-	-	-	-	-	-	-	0.0	-	-	-
1.B.2.b	Natural gas	kt CO <sub>2</sub> e	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
<b>Total Energy</b>		<b>kt CO<sub>2</sub>e</b>	<b>1.6</b>	<b>0.2</b>	<b>6.0</b>	<b>5.2</b>	<b>0.9</b>	<b>45.5</b>	<b>44.6</b>	<b>32.6</b>	<b>61.5</b>	<b>130.9</b>	<b>154.9</b>	<b>137.7</b>	<b>280.0</b>	<b>447.2</b>
Relative change																
1.A.1.a	Public Electricity and Heat Production	%	-	-	-	-	-	-	0.0%	0.0%	0.0%	-0.0%	-0.0%	-0.0%	-0.0%	0.0%
1.A.1.b	Petroleum Refining	%	-	-	-	-0.0%	-0.0%	0.0%	0.0%	0.0%	0.0%	-0.0%	0.0%	-0.0%	0.0%	0.0%
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	%	-	-2.0%	-6.3%	-1.6%	6.0%	3.3%	-8.7%	-16.6%	-7.1%	-9.9%	-9.3%	-8.6%	-6.3%	-2.4%
1.A.2.c	Chemicals	%	-	-3.6%	-5.3%	-0.7%	29.6%	42.3%	49.1%	59.1%	38.1%	43.5%	44.8%	39.8%	44.4%	42.5%
1.A.2.d	Pulp, Paper and Print	%	-	-8.0%	-6.5%	-26.0%	-30.6%	-34.0%	-45.6%	-17.7%	-24.8%	-26.6%	-33.6%	-25.8%	-23.4%	-22.7%
1.A.2.e	Food Processing, Beverages and Tobacco	%	-	-3.5%	-5.1%	-17.7%	-13.8%	-5.8%	1.2%	14.1%	8.8%	13.8%	10.4%	14.9%	19.2%	18.8%
1.A.2.f	Non-metallic minerals	%	0.0%	-3.4%	-3.9%	-7.6%	-10.7%	-15.5%	-16.7%	-15.6%	-14.6%	-7.0%	-5.7%	-5.7%	-7.1%	-7.0%
1.A.2.g	Other	%	19.7%	8.1%	5.6%	1.2%	-30.4%	-35.5%	-41.6%	-40.4%	-34.7%	-20.4%	-29.9%	-28.9%	-27.6%	-27.0%
1.A.3.a	Domestic Aviation	%	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0%
1.A.3.b	Road Transportation	%	0.1%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.1%	0.1%
1.A.3.c	Railways	%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.A.3.d	Domestic navigation	%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.A.3.e	Other transportation	%	-1.0%	-0.5%	-1.0%	-0.4%	-1.1%	-1.3%	-1.0%	-0.6%	-0.4%	-0.1%	0.0%	0.2%	0.2%	0.3%
1.A.4.a	Commercial/Institutional	%	-6.0%	-4.6%	-17.8%	-21.9%	-30.3%	-26.6%	-23.1%	-20.0%	-10.3%	-7.3%	-4.6%	-7.6%	-15.9%	-16.9%
1.A.4.b	Residential	%	-0.0%	1.8%	9.0%	12.8%	14.0%	12.4%	14.8%	14.0%	9.0%	6.9%	7.3%	7.3%	12.0%	13.6%
1.A.4.c	Agriculture/Forestry/Fishing	%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.B.1.a	Coal mining and handling	%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.B.2.a	Oil	%	-	-	-	-	-	-	-	-	-	-	0.8%	-	-	-
1.B.2.b	Natural gas	%	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%
<b>Total Energy</b>		<b>%</b>	<b>0.0%</b>	<b>0.0%</b>	<b>0.0%</b>	<b>0.0%</b>	<b>0.0%</b>	<b>0.1%</b>	<b>0.1%</b>	<b>0.1%</b>	<b>0.2%</b>	<b>0.4%</b>	<b>0.4%</b>	<b>0.4%</b>	<b>0.8%</b>	<b>1.2%</b>

## 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<sub>2</sub> or adipic acid production in the case of N<sub>2</sub>O, 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<sub>2</sub> 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<sub>6</sub> and NF<sub>3</sub> (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 6.1 per cent and 5.3 per cent of total national emissions (including indirect CO<sub>2</sub>, without *LULUCF*) in 1990 and 2019, respectively. This sector accounted for 100 per cent of fluorinated gas emissions (HFCs, PFCs, SF<sub>6</sub> and NF<sub>3</sub>), 6.0 per cent of CO<sub>2</sub> emissions and 0.6 per cent of N<sub>2</sub>O emissions in 2019.

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<sub>2</sub> 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<sub>2</sub> emissions. Indirect CO<sub>2</sub> 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<sub>6</sub> and NF<sub>3</sub>. 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<sub>6</sub> and N<sub>2</sub>O. The sources of SF<sub>6</sub> 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<sub>2</sub>O 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<sub>2</sub> 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<sub>2</sub>O 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<sub>6</sub>** 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<sub>3</sub>** 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<sub>6</sub> and NF<sub>3</sub> 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 and 2019 compared to 2017. 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<sub>2</sub> 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<sub>2</sub> 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<sup>3</sup> (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.

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<sup>3</sup> <https://www.seai.ie/data-and-insights/seai-statistics/key-publications/national-energy-balance/>

**Table 4.1 Level 3 Source Methodology for IPPU**

<b>2. Industrial Processes and Product Use</b>	<b>CO<sub>2</sub></b>	<b>CH<sub>4</sub></b>	<b>N<sub>2</sub>O</b>	<b>HFCs</b>	<b>PFCs</b>	<b>SF<sub>6</sub></b>	<b>NF<sub>3</sub></b>
<b>A. Mineral industry</b>							
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>B. Chemical industry</b>							
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
<b>C. Metal industry</b>							
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
<b>D. Non-energy products from fuels and solvent use</b>							
1. Lubricant use	T1, NA	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
<b>E. Electronics industry</b>							
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
<b>F. Product uses as substitutes for ODS</b>							
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
<b>G. Other product manufacture and use</b>							
1. Electrical equipment	NA	NA	NA	NA	NA	T3	NA
2. SF <sub>6</sub> and PFCs from other product use	NA	NA	NA	NA	NA	T1	NA
3. N <sub>2</sub> O from product uses	NA	NA	T1	NA	NA	NA	NA
4. Other	T2	NA	NA	NA	NA	NA	NA
<b>H. Other</b>							
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 1990-2019**

IPCC	Description	Gas	Unit	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
2.A.1	Cement Production	CO <sub>2</sub>	kt CO <sub>2</sub> e	884.00	879.00	1700.90	2357.06	1105.11	966.27	1177.02	1111.75	1461.12	1652.01	1793.52	1839.61	1916.04	1892.60
2.A.2	Lime Production	CO <sub>2</sub>	kt CO <sub>2</sub> e	214.08	187.51	190.43	183.48	192.41	199.06	214.39	189.64	188.98	177.35	173.90	198.94	177.28	163.65
2.A.3	Glass Production	CO <sub>2</sub>	kt CO <sub>2</sub> e	13.33	11.97	10.71	0.48	NO									
2.A.4.a	Other- Ceramics	CO <sub>2</sub>	kt CO <sub>2</sub> e	5.23	5.64	6.66	7.53	0.42	0.83	0.03	0.03	NO	0.50	0.78	0.85	0.95	1.06
2.A.4.b	Other- Soda Ash Use	CO <sub>2</sub>	kt CO <sub>2</sub> e	0.10	0.07	0.07	0.08	0.07	0.07	0.09	0.06	0.07	0.06	0.04	0.07	0.10	0.07
2.A.4.d	Other- Limestone use	CO <sub>2</sub>	kt CO <sub>2</sub> e	NO	NO	NO	4.17	1.03	1.04	0.44	0.21	0.28	0.45	0.16	0.39	0.19	0.29
2.B.1	Ammonia Production	CO <sub>2</sub>	kt CO <sub>2</sub> e	990.23	973.44	882.30	NO										
2.B.2	Nitric Acid Production	N <sub>2</sub> O	kt CO <sub>2</sub> e	995.32	781.00	781.00	NO										
2.C.1	Iron and Steel Production	CO <sub>2</sub>	kt CO <sub>2</sub> e	26.08	24.80	28.80	NO										
2.D.1	Lubricant Use	CO <sub>2</sub>	kt CO <sub>2</sub> e	35.97	11.78	70.08	59.54	16.82	18.73	18.28	19.08	19.84	20.35	20.09	22.22	21.50	20.99
2.D.2	Paraffin Wax Use	CO <sub>2</sub>	kt CO <sub>2</sub> e	6.26	8.59	15.73	35.28	21.84	21.54	20.10	22.68	23.11	24.49	23.71	25.09	23.65	25.45
2.D.3	Solvent use	Indirect CO <sub>2</sub>	kt CO <sub>2</sub> e	51.40	52.40	47.54	50.81	43.07	42.48	41.09	40.30	41.95	40.65	40.84	41.02	43.05	41.69
2.D.3	Urea Used as a Catalyst	CO <sub>2</sub>	kt CO <sub>2</sub> e	NO	NO	NO	NO	5.30	5.82	5.91	6.57	7.16	8.82	11.17	11.98	13.18	13.48
2.E.1	Integrated Circuit or Semiconductor	HFCs, PFCs, SF <sub>6</sub> , NF <sub>3</sub>	kt CO <sub>2</sub> e	1.17	145.33	491.70	310.12	68.19	41.13	31.55	34.63	20.27	46.84	57.04	67.08	77.72	92.85
2.F.1	Refrigeration and Air Conditioning	HFCs	kt CO <sub>2</sub> e	NO	4.98	122.97	694.10	891.32	923.58	917.18	951.52	1040.42	1018.65	1093.77	1010.71	700.07	671.60
2.F.2	Foam Blowing Agents	HFCs	kt CO <sub>2</sub> e	NO													
2.F.3	Fire Protection	HFCs	kt CO <sub>2</sub> e	NO	NO	7.33	14.30	32.36	32.38	32.39	32.41	32.42	32.44	32.45	32.47	32.48	32.49
2.F.4	Aerosols	HFCs	kt CO <sub>2</sub> e	NO	37.94	124.54	144.32	120.26	125.20	122.58	119.00	116.59	114.57	114.97	112.96	107.97	109.07
2.G.1	Electrical Equipment	SF <sub>6</sub>	kt CO <sub>2</sub> e	20.52	25.08	7.43	22.44	12.33	20.70	16.22	18.60	19.15	19.70	19.06	19.87	16.13	7.23
2.G.2	SF <sub>6</sub> and PFCs from Other Product Uses	SF <sub>6</sub>	kt CO <sub>2</sub> e	12.90	12.99	14.69	11.78	3.35	2.64	2.79	2.94	3.09	3.24	3.24	3.24	3.23	3.24
2.G.3.a	N <sub>2</sub> O from product uses	N <sub>2</sub> O	kt CO <sub>2</sub> e	31.34	32.20	33.88	36.96	40.72	40.90	40.99	41.06	41.21	41.44	42.57	42.77	42.98	44.00
2.G.4	Other Solvent and product use	Indirect CO <sub>2</sub>	kt CO <sub>2</sub> e	0.07	0.08	0.09	0.07	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.02	0.04
2.H.2	Food and beverages industry	Indirect CO <sub>2</sub>	kt CO <sub>2</sub> e	21.16	22.63	21.45	30.11	40.04	40.22	45.73	49.41	42.09	44.75	47.33	59.04	59.44	64.39
<b>Total</b>	<b>IPPU</b>		<b>kt CO<sub>2</sub>e</b>	<b>3309.16</b>	<b>3217.41</b>	<b>4558.31</b>	<b>3962.62</b>	<b>2594.70</b>	<b>2482.63</b>	<b>2686.83</b>	<b>2639.93</b>	<b>3057.79</b>	<b>3246.34</b>	<b>3474.68</b>	<b>3488.35</b>	<b>3235.98</b>	<b>3184.18</b>

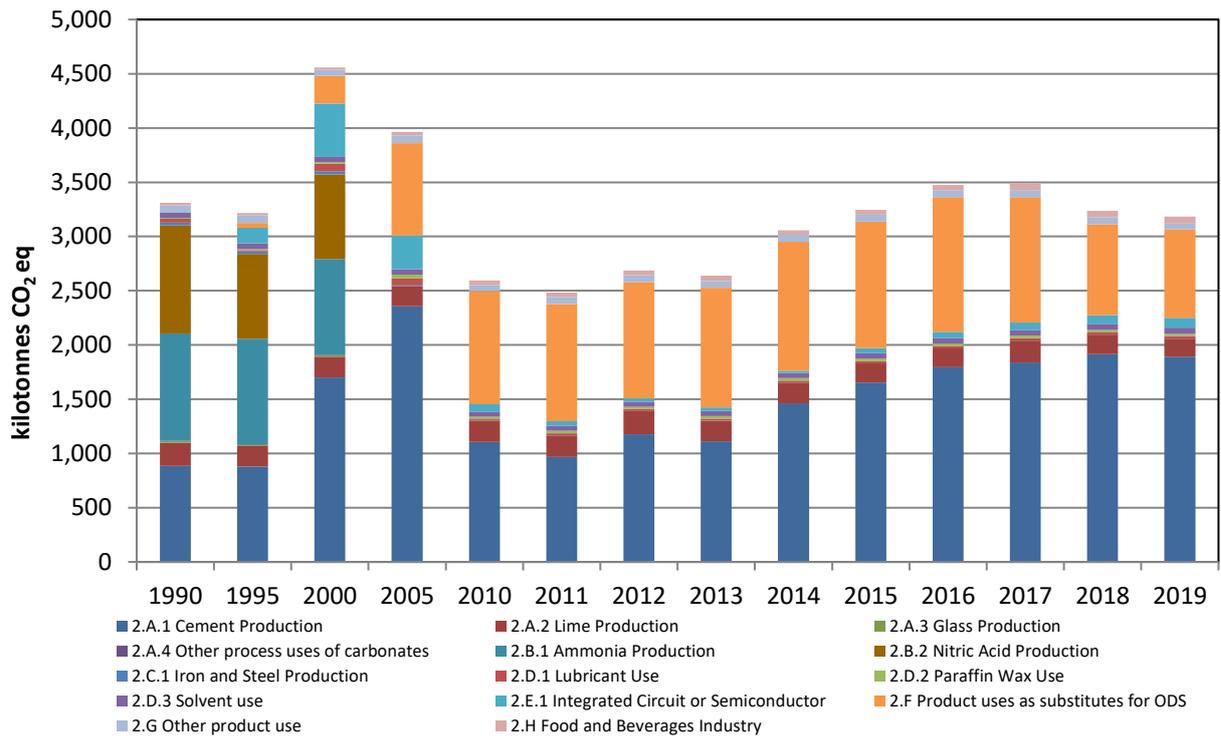


Figure 4.1 Total Emissions from IPPU by Category, 1990-2019

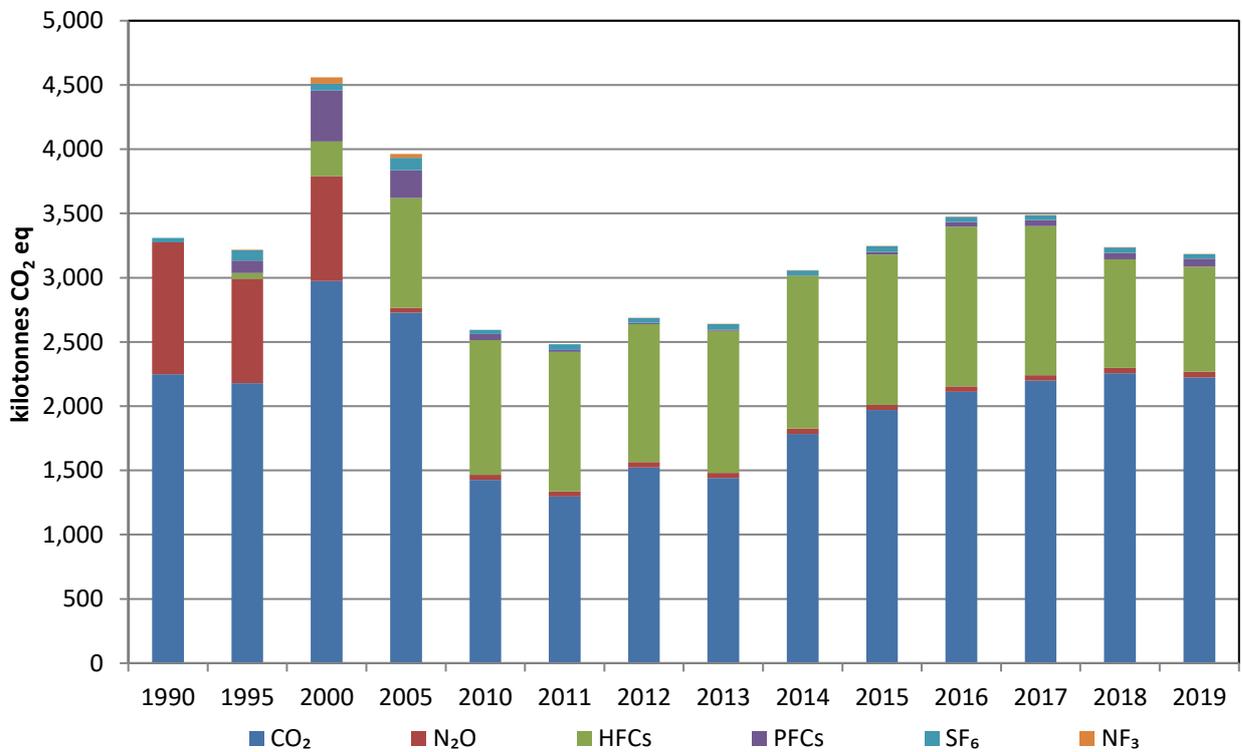


Figure 4.2 Total Emissions from IPPU by Gas, 1990-2019

## 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<sub>2</sub> is produced during the production of clinker. Clinker is produced when limestone, mainly calcium carbonate (CaCO<sub>3</sub>) and small amounts of magnesium carbonate (MgCO<sub>3</sub>), undergo calcination at high temperature to produce lime (Calcium oxide (CaO) and Magnesium oxide (MgO) and CO<sub>2</sub>. 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<sub>2</sub> are usually calculated from the amount of clinker produced and the stoichiometric ratio of CO<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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 2019. Plant specific CO<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> emissions for cement production overall may therefore be considered consistent for the period 1990-2019.

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%.

#### 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<sub>2</sub>. Dolomite and dolomitic (high magnesium) limestone may also be processed at high temperature to obtain dolomitic lime with a loss of CO<sub>2</sub>. Quicklime is then further treated by the addition of water, a process called slaking, to produce slaked lime (Ca(OH)<sub>2</sub> and Ca(OH)<sub>2</sub>.Mg(OH)<sub>2</sub>), 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. 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<sub>2</sub> estimates for lime production in 2005-2019 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<sub>2</sub> 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<sub>2</sub> emissions in Industrial Processes and Product Use.

The implied emission factor for aggregated lime production was 0.76 t CO<sub>2</sub>/t lime in 2019. 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 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 ( $\text{SiO}_2$ ), soda ( $\text{Na}_2\text{O}$ ), and lime ( $\text{CaO}$ ), with small amounts of alumina ( $\text{Al}_2\text{O}_3$ ), 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<sub>2</sub> 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<sub>2</sub>/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<sub>2</sub> 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<sub>2</sub>/t Na<sub>2</sub>CO<sub>3</sub> and 0.267 t CO<sub>2</sub>/t K<sub>2</sub>CO<sub>3</sub>, 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<sub>2</sub> 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<sub>3</sub>), dolomite (CaMg (CO<sub>3</sub>)<sub>2</sub>) and other carbonates (e.g., MgCO<sub>3</sub> and FeCO<sub>3</sub>) 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<sub>2</sub>CO<sub>3</sub>) 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<sub>2</sub> emissions reported under this category refer to those emissions associated with:

- Limestone (CaCO<sub>3</sub>) 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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub>/t limestone between 2001 and 2019. The stoichiometric ratio of CO<sub>2</sub> to CaCO<sub>3</sub> 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<sub>2</sub> 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<sub>2</sub> for all years from 1990-2004 were calculated using an emission factor of 0.41 t CO<sub>2</sub>/t soda ash, indicated by the average 2005-2008 ETS data. This approach has allowed a full 1990-2019 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 2019 there is one plant producing bricks and ceramics in Ireland with an emission of 1.06 kt CO<sub>2</sub>. 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 2015-2019, 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 0.027 to 0.053 tonne CO<sub>2</sub>/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.

#### 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<sub>2</sub> 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 are 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 1990-2019 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<sub>3</sub>) 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

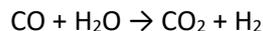
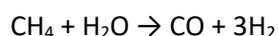
air through liquid air distillation or an oxidative process where air is burnt and the residual nitrogen is recovered. Ammonia is the basis of all nitrogen fertilisers and is normally manufactured by synthesis of nitrogen (N<sub>2</sub>) and hydrogen (H<sub>2</sub>), with natural gas (CH<sub>4</sub>) 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<sub>2</sub> as a by-product.

Urea was one of the main end products of the NH<sub>3</sub> plant, which was formed when the NH<sub>3</sub> produced and the CO<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub>/TJ, the value for indigenous natural gas, which equates to 2.3 tonne CO<sub>2</sub>/tonne natural gas. The CO<sub>2</sub> 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<sub>2</sub> production using CH<sub>4</sub> in the ammonia industry. Anhydrous ammonia produced by catalytic steam reforming of natural gas (mostly CH<sub>4</sub>) involves the following reactions with carbon dioxide produced as a by-product:

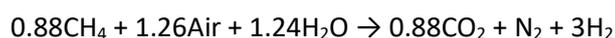
##### Primary steam reforming:



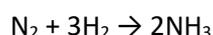
##### Secondary air reforming:



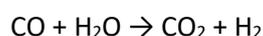
##### Overall reaction:



##### Ammonia synthesis:



##### Secondary reformer process gas shift conversion:



#### 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 ( $\text{HNO}_3$ ), nitrous oxide ( $\text{N}_2\text{O}$ ) is generated as an unintended by-product of the high temperature catalytic oxidation of ammonia ( $\text{NH}_3$ ).

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  $\text{N}_2\text{O}$  emitted during the production process.

Four units at this plant produced 338,000 tonnes of nitric acid in 1990 with associated  $\text{N}_2\text{O}$  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 1990-2019. 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 1990-2019. 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 1990-2019. 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 1990-2019. 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 1990-2019. 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 1990-2019. 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 1990-2019. 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 1990-2019. 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<sub>2</sub> emissions for this category was estimated using the emission factor provided in table 4.5 of the 2006 IPCC guidelines, 0.08 t CO<sub>2</sub>/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 1990-2019. 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 1990-2019. 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 1990-2019. 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 1990-2019. 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 1990-2019. 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 1990-2019. 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<sub>2</sub> 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<sub>2</sub> 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 1990-2019. The carbon content of lubricants value is 20.0 tonne carbon/TJ. Emissions of CO<sub>2</sub> estimated for this category are presented in Table 4.2.

#### Equation 5.2 Lubricants – Tier 1 Method

$$\text{CO}_2 \text{ Emissions} = \text{LC} \bullet \text{CC}_{\text{Lubricant}} \bullet \text{ODU}_{\text{Lubricant}} \bullet 44 / 12$$

Where:

CO<sub>2</sub> Emissions = CO<sub>2</sub> emissions from lubricants, tonne CO<sub>2</sub>

LC = total lubricant consumption, TJ

CC<sub>Lubricant</sub> = carbon content of lubricants (default), tonne C/TJ

ODU<sub>Lubricant</sub> = ODU factor (based on default composition of oil and grease), fraction

44/12 = mass ratio of CO<sub>2</sub>/C

#### 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 were no recalculations in this source category.

#### 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<sub>2</sub> 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<sub>2</sub> 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 1990-2019. The carbon content of paraffin wax value is 20.0 tonne carbon/TJ. Emissions of CO<sub>2</sub> estimated for this category are presented in Table 4.2. CO<sub>2</sub> emissions estimated for this category are presented in Table 4.2.

#### Equation 5.5 Waxes – Tier 2 Method

$$\text{CO}_2 \text{ Emissions} = \sum_i (\text{PW}_i \bullet \text{CC}_i \bullet \text{ODU}_i) \bullet 44 / 12$$

Where:

CO<sub>2</sub> Emissions = CO<sub>2</sub> emissions from waxes, tonne CO<sub>2</sub>

PW<sub>i</sub> = consumption of wax type i (candle wax and residual wax), TJ

CC<sub>i</sub> = carbon content of wax type i, tonne C/TJ

ODU<sub>i</sub> = ODU factor for wax type i, fraction

44/12 = mass ratio of CO<sub>2</sub>/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

A recalculation occurred in 2014, 2017 and 2018 due to a revision in the activity data for candles by the national statistics provider. These revised figures were submitted as part of the ESD review in June 2020.

#### 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<sub>2</sub> 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<sub>2</sub> emissions can be found in Chapter 9 of this report. Estimates of indirect CO<sub>2</sub> emissions are derived from NMVOCs by assuming that 60 per cent of the mass of NMVOCs is converted to CO<sub>2</sub>.

#### 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 no significant recalculations in this source category.

#### 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<sub>x</sub> emissions. The urea solution then releases small amounts of CO<sub>2</sub> and of NH<sub>3</sub> to make a reaction with NO<sub>x</sub> to break it down

into N<sub>2</sub> and H<sub>2</sub>O. However, this small amount of CO<sub>2</sub> from this process causes an additional amount of CO<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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 a share of 76 per cent vehicles having SCR technologies of the eligible categories were applied in the model. The estimated CO<sub>2</sub> 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<sub>2</sub> was estimated from a model using parameters based on assumptions, a 30 percent uncertainty was considered for activity data. As the emissions factor is based on the carbon content, a comparatively lower uncertainty of 5 percent 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 for HDVs; including buses and coaches, from 2006-2018 and in Passenger cars and LDVs for 2015-2018. 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<sub>6</sub> and NF<sub>3</sub> 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<sub>6</sub> and NF<sub>3</sub> 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 2018 due to increased manufacturing operations in the semiconductor industry. NF<sub>3</sub> emission levels were highest in the period 2000-2007 and have been negligible from 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<sub>6</sub> and NF<sub>3</sub> in their plants over the full time series 1990-2019.

#### 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<sub>6</sub> 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.

#### 4.6.1.5 Category-specific Recalculations

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

#### 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 1990-2019. 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 1990-2019. 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 1990-2019. 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 1990-2019. This category is reported as Not Occurring (NO).

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

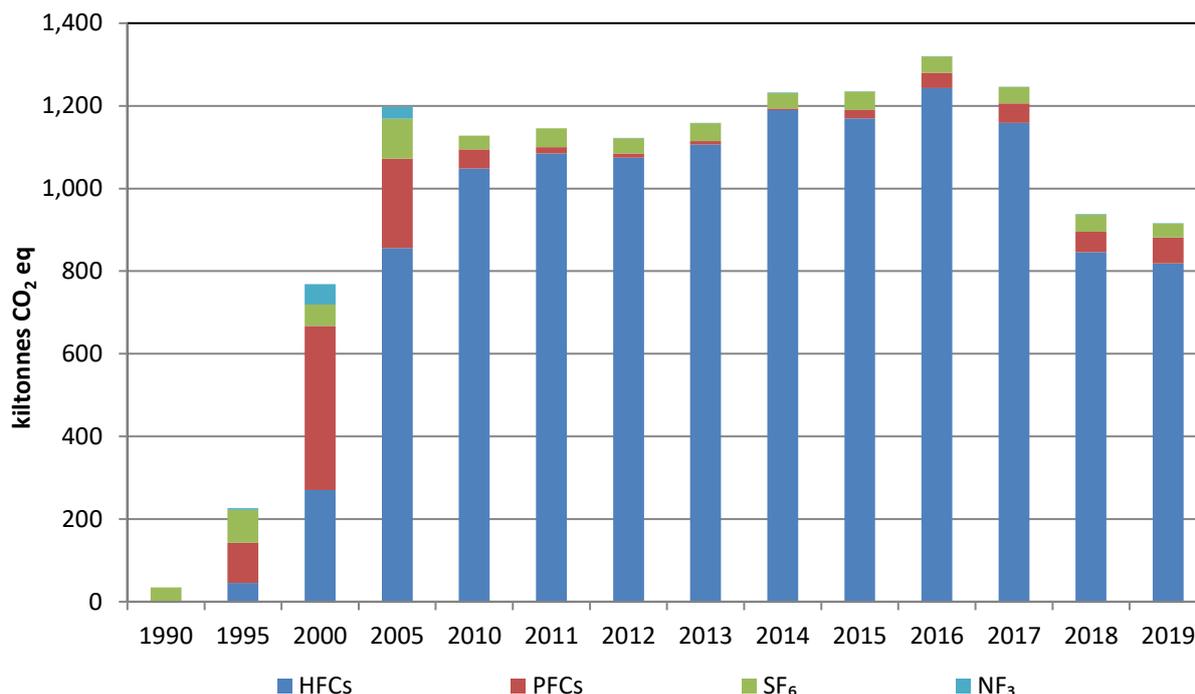
The compilation of emission estimates for fluorinated gases presents major challenges for inventory agencies because they emanate from diverse sources that are entirely different to those traditionally covered by atmospheric emissions inventories. In addition, the use of many of the substances concerned 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, SF6 and NF3 from IPPU 1990-2019 (kt CO2 eq)

IPCC Source Category	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
2.F.1 Refrigeration and Air-Conditioning	NO	0.72	75.43	571.76	667.71	692.49	696.59	730.50	814.21	789.31	857.28	777.73	479.87	480.05
2.F.1 Mobile Air Conditioning	NO	4.25	47.54	122.34	223.62	231.09	220.59	221.03	226.21	229.34	236.49	232.98	220.20	191.55
2.F.2 Foams	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2.F.3 Fire-extinguishers	NO	NO	7.33	14.30	32.36	32.38	32.39	32.41	32.42	32.44	32.45	32.47	32.48	32.49
2.F.4 Aerosols	NO	37.94	88.24	99.22	70.12	74.45	72.31	69.50	66.76	64.14	62.85	60.29	54.17	55.46
2.F.4 Metered Dose Inhalers	NO	NO	36.29	45.10	50.13	50.75	50.27	49.50	49.83	50.43	52.12	52.67	53.80	53.61
2.E.1 Semiconductor manufacture	0.59	2.31	15.13	2.81	4.19	3.11	2.80	3.39	0.58	3.83	1.73	2.52	4.99	5.31
<b>HFCs</b>	<b>0.59</b>	<b>45.23</b>	<b>269.97</b>	<b>855.54</b>	<b>1,048.14</b>	<b>1,084.27</b>	<b>1,074.95</b>	<b>1,106.32</b>	<b>1,190.00</b>	<b>1,169.49</b>	<b>1,242.93</b>	<b>1,158.65</b>	<b>845.51</b>	<b>818.47</b>
2.E.1 Semiconductor manufacture	0.12	97.61	397.76	216.39	46.58	15.88	9.56	8.32	3.56	20.50	37.36	47.20	49.86	63.05
<b>PFCs</b>	<b>0.12</b>	<b>97.61</b>	<b>397.76</b>	<b>216.39</b>	<b>46.58</b>	<b>15.88</b>	<b>9.56</b>	<b>8.32</b>	<b>3.56</b>	<b>20.50</b>	<b>37.36</b>	<b>47.20</b>	<b>49.86</b>	<b>63.05</b>
2.E.1 Semiconductor manufacture	0.46	41.04	29.64	62.54	17.41	22.15	18.41	22.01	15.17	21.55	16.99	16.10	21.55	23.10
2.G.1 Electrical equipment	20.52	25.08	7.43	22.44	12.33	20.70	16.22	18.60	19.15	19.70	19.06	19.87	16.13	7.23
2.G.2 Other - window soundproofing	0.52	0.61	0.41	0.58	1.33	1.48	1.63	1.78	1.94	2.09	2.08	2.08	2.08	2.08
2.G.2 Other - medical applications	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76
2.G.2 Other - sporting goods	NO	NO	1.89	10.45	1.26	0.39	0.39	0.39	0.39	0.39	0.40	0.40	0.40	0.40
2.G.2 Other - gas-air tracers	11.63	11.63	11.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<b>SF<sub>6</sub></b>	<b>33.88</b>	<b>79.11</b>	<b>51.76</b>	<b>96.76</b>	<b>33.09</b>	<b>45.48</b>	<b>37.41</b>	<b>43.55</b>	<b>37.41</b>	<b>44.49</b>	<b>39.29</b>	<b>39.21</b>	<b>40.92</b>	<b>33.57</b>
2.E.1 Semiconductor manufacture	NO	4.37	49.17	28.38	NO	NO	0.78	0.90	0.96	0.96	0.96	1.26	1.32	1.38
<b>NF<sub>3</sub></b>	<b>NO</b>	<b>4.37</b>	<b>49.17</b>	<b>28.38</b>	<b>NO</b>	<b>NO</b>	<b>0.78</b>	<b>0.90</b>	<b>0.96</b>	<b>0.96</b>	<b>0.96</b>	<b>1.26</b>	<b>1.32</b>	<b>1.38</b>
<b>HFC, PFC, SF<sub>6</sub> and NF<sub>3</sub></b>	<b>34.59</b>	<b>226.33</b>	<b>768.66</b>	<b>1,197.06</b>	<b>1,127.81</b>	<b>1,145.63</b>	<b>1,122.70</b>	<b>1,159.10</b>	<b>1,231.93</b>	<b>1,235.44</b>	<b>1,320.54</b>	<b>1,246.32</b>	<b>937.61</b>	<b>916.47</b>



*Figure 4.3 Emissions of HFC, PFC, SF<sub>6</sub> and NF<sub>3</sub>, 1990-2019*

## 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 (2019) and the trend assessment (1990-2019). 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 and 2019 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 show a 38 per cent decrease in emissions in 2018 (480.70 kt CO<sub>2</sub>eq) compared to 2017 (777.73 kt CO<sub>2</sub>eq). 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<sub>2</sub>eq of 38 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% in CO<sub>2</sub> equivalent between 2018 and 2015, whereas the drop measured in volume was only 25%. This shows a clear shift in the supply towards lower GWP HFCs and other alternatives.

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<sub>2</sub> 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 2014-2019.

#### 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<sub>6</sub> 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 correction to the assumed recovery factor for Mobile Air conditioning in cars was made as information was received that recovery is not occurring for End of life vehicles in Ireland. This resulted in increased disposal emissions between 2-10 per cent for HFCs for years 2006-2018. As a result of EPA surveys performed in 2020 described in the methodology section above, the percentage of cars with low GWP gases was increased for the years 2015-2018. This has resulted in a decrease in emissions from 3-20 per cent for years 2015-2018.

Updates to 2017 and 2018 activity data occurred in this submission as updated imports data to Ireland was received. This has resulted in a recalculation to HFC data in 2F1 Refrigeration and AC of -9.6 per cent in 2017 and -26.2 per cent in 2018. The data received indicates a 38 per cent drop in emissions in 2F1 refrigeration and AC in 2018 (479.87 kt CO<sub>2</sub>eq) compared to 2017 (777.73 kt CO<sub>2</sub>eq).

The reason is an overall decrease in the amount of F gases imported to Ireland of -27 percent as well as a clear shift in the supply towards lower GWP HFCs. A significant decrease was noted in the import of gases R404A (GWP 3922), R410A (GWP 2088) and R134a (GWP 1430) in recent years.

All recalculations are presented in table 4.4.

#### 4.7.1.6 Category-specific Planned Improvements

There are no planned improvements for this category.

## 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<sub>6</sub> 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.

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).

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<sub>6</sub> 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.

#### 4.7.4.5 Category-specific Recalculations

There was a recalculation in subcategory Other-Aerosols 2.F.4.b. due to the update of UK population proxy data used to calculate Irelands emissions. This population data was downloaded from ONS and linked to Aerosols and Other Sporting goods. A minor recalculation of 0.1-0.2 per cent is seen in Aerosols and Other sporting goods as a result. 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<sub>6</sub> 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<sub>2</sub>O 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<sub>6</sub> 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<sub>6</sub> is used in equipment across all voltage ranges on both the Distribution and Transmission systems owned by ESB Networks.

Electrical equipment containing SF<sub>6</sub> is imported into Ireland and at time of purchase, is added to the SF<sub>6</sub> installed inventory database. Quantities of SF<sub>6</sub> 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<sub>6</sub> for safe transport to Ireland. Once installed on site the remaining amount of SF<sub>6</sub> 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<sub>6</sub> 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<sub>6</sub>. The inventory estimates assume that the usage of SF<sub>6</sub> 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<sub>6</sub> emissions from their equipment maintenance operations to the inventory agency on a yearly basis. The volume of SF<sub>6</sub> used for maintenance is calculated using the following methodology:

- Maintenance orders for SF<sub>6</sub> top ups are tracked using ESB Network's Enterprise Asset Management system. These are compared against SF<sub>6</sub> related plant outages from both Distribution & 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<sub>6</sub> 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<sub>6</sub> and PFCs from Other Product Uses (2.G.2)

#### 4.8.2.1 Category Description

Emissions of SF<sub>6</sub> are included in this category from the following activities:

- **Soundproof windows 2.G.2.c** – SF<sub>6</sub> 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<sub>6</sub> 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<sub>6</sub> 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<sub>6</sub> 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<sub>6</sub> 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 life-time 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<sub>6</sub> 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<sub>6</sub> 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<sub>6</sub> upon disposal of sporting goods, as the market share of such products is assumed to be similar to that in the UK.

Use of SF<sub>6</sub> 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<sub>6</sub> 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<sub>6</sub> 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<sub>6</sub>/day from 60 capsules (1/animal) for 105 days; whole-crop wheat experiment – emission rate of 3.14 mg SF<sub>6</sub>/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<sub>6</sub> 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<sub>6</sub> 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

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

#### 4.8.2.6 Category-specific Planned Improvements

There are no planned improvements for this category.

### 4.8.3 N<sub>2</sub>O from Product Use (2.G.3)

#### 4.8.3.1 Category Description

Evaporative/fugitive emissions of nitrous oxide (N<sub>2</sub>O) 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<sub>2</sub>O 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.

#### 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<sub>2</sub>O 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<sub>2</sub>O 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<sub>2</sub>O 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<sub>2</sub>O from Product Use are provided in Annex 2. The emission time series for 1990–2019 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 are no 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<sub>2</sub> 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<sub>2</sub> emissions can be found in Chapter 9 of this report. Estimates of indirect CO<sub>2</sub> emissions are derived from NMVOCs by assuming that 60 per cent of the mass of NMVOCs is converted to CO<sub>2</sub>.

#### 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<sub>2</sub> 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<sub>2</sub> emissions can be found in Chapter 9 of this report. Estimates of indirect CO<sub>2</sub> emissions are derived from NMVOCs by assuming that 60 per cent of the mass of NMVOCs is converted to CO<sub>2</sub>.

#### 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 was a minor recalculation for years 1993-2018 due to an update to activity data relating to animal feedstock production from the national statistics office.

#### 4.9.1.5 Category-specific Planned Improvements

There are no planned improvements for this category.

Table 4.4(a) Recalculations Previous and current emission estimates in the IPPU Sector (1990-2018)

2020 Submission		Gases	Units	1990	1995	2000	2005	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
2.A.1	Cement Production	CO <sub>2</sub>	kt CO <sub>2</sub> eq	884.00	879.00	1,700.90	2,357.06	1,326.78	1,105.11	966.27	1,177.02	1,111.75	1,461.12	1,652.01	1,793.52	1,839.61	1,916.04
2.A.2	Lime Production	CO <sub>2</sub>	kt CO <sub>2</sub> eq	214.08	187.51	190.43	183.48	156.40	192.41	199.06	214.39	189.64	188.98	177.35	173.90	198.94	177.28
2.A.3	Glass Production	CO <sub>2</sub>	kt CO <sub>2</sub> eq	13.33	11.97	10.71	0.48	0.02	NO								
2.A.4	Other Process Uses of Carbonates	CO <sub>2</sub>	kt CO <sub>2</sub> eq	5.32	5.71	6.73	11.78	2.13	1.52	1.94	0.56	0.31	0.35	1.00	0.98	1.31	1.23
2.B.1	Ammonia Production	CO <sub>2</sub>	kt CO <sub>2</sub> eq	990.23	973.44	882.30	NO										
2.B.2	Nitric Acid Production	N <sub>2</sub> O	kt CO <sub>2</sub> eq	995.32	781.00	781.00	NO										
2.C.1	Iron and Steel Production	CO <sub>2</sub>	kt CO <sub>2</sub> eq	26.08	24.80	28.80	NO										
2.D.1	Lubricant Use	CO <sub>2</sub>	kt CO <sub>2</sub> eq	35.97	11.78	70.08	59.54	22.39	16.82	18.73	18.28	19.08	19.84	20.35	20.09	22.22	21.81
2.D.2	Paraffin Wax Use	CO <sub>2</sub>	kt CO <sub>2</sub> eq	6.26	8.60	15.73	35.27	24.04	21.82	21.54	20.10	22.68	20.45	24.49	23.71	56.90	46.51
2.D.3	Other Solvent Use	Indirect CO <sub>2</sub>	kt CO <sub>2</sub> eq	51.40	52.25	47.39	49.95	47.86	42.75	42.26	40.26	40.38	41.72	39.99	40.24	40.43	40.84
2.D.3	Urea as Catalyst	CO <sub>2</sub>	kt CO <sub>2</sub> eq	0.00	0.00	0.00	0.00	2.83	2.65	2.83	2.86	4.08	4.53	5.83	7.73	8.71	9.89
	Integrated Circuit or	HFCs, PFCs,															
2.E.1	Semiconductor	SF <sub>6</sub> , NF <sub>3</sub>	kt CO <sub>2</sub> eq	1.17	145.33	491.70	310.12	107.30	68.19	41.13	31.55	34.63	20.27	46.84	57.04	67.08	77.72
2.F.1	Refrigeration and Air Conditioning	HFCs	kt CO <sub>2</sub> eq	0.00	4.98	122.97	699.36	865.09	876.86	905.70	902.76	937.17	1,025.31	1,008.67	1,090.19	1,118.19	948.52
2.F.3	Fire Protection	HFCs	kt CO <sub>2</sub> eq	NO	NO	7.33	14.30	19.63	32.36	32.38	32.39	32.41	32.42	32.44	32.45	32.47	32.48
2.F.4	Aerosols	HFCs	kt CO <sub>2</sub> eq	0.00	38.01	124.90	144.66	130.61	120.82	125.85	122.58	119.00	116.59	114.57	114.97	112.97	114.38
2.G.1	Electrical Equipment	SF <sub>6</sub>	kt CO <sub>2</sub> eq	20.52	25.08	7.43	22.44	13.34	12.33	20.70	16.22	18.60	19.15	19.70	19.06	19.87	16.13
	SF <sub>6</sub> and PFCs from Other Product																
2.G.2	Uses	SF <sub>6</sub>	kt CO <sub>2</sub> eq	12.90	12.99	14.69	11.81	5.87	3.35	2.64	2.79	2.94	3.09	3.24	3.24	3.24	3.23
2.G.3	N <sub>2</sub> O from Product Uses	N <sub>2</sub> O	kt CO <sub>2</sub> eq	31.34	32.20	33.88	36.96	40.53	40.72	40.90	40.99	41.06	41.21	41.44	42.57	42.77	42.98
2.G.4	Other Solvent and product use	Indirect CO <sub>2</sub>	kt CO <sub>2</sub> eq	0.07	0.08	0.09	0.07	0.06	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.02
2.H.2	Food and beverages industry	Indirect CO <sub>2</sub>	kt CO <sub>2</sub> eq	21.16	22.63	21.45	30.11	34.42	40.04	40.22	45.73	49.41	42.09	44.75	47.33	59.04	59.44
<b>Total IPPU (including Indirect CO<sub>2</sub>)</b>			<b>kt CO<sub>2</sub>eq</b>	<b>3,309.16</b>	<b>3,217.34</b>	<b>4,558.52</b>	<b>3,967.37</b>	<b>2,799.28</b>	<b>2,577.80</b>	<b>2,462.21</b>	<b>2,668.53</b>	<b>2,623.17</b>	<b>3,037.16</b>	<b>3,232.72</b>	<b>3,467.07</b>	<b>3,623.78</b>	<b>3,508.50</b>
<b>2021 Submission</b>																	
2.A.1	Cement Production	CO <sub>2</sub>	kt CO <sub>2</sub> eq	884.00	879.00	1,700.90	2,357.06	1,326.78	1,105.11	966.27	1,177.02	1,111.75	1,461.12	1,652.01	1,793.52	1,839.61	1,916.04
2.A.2	Lime Production	CO <sub>2</sub>	kt CO <sub>2</sub> eq	214.08	187.51	190.43	183.48	156.40	192.41	199.06	214.39	189.64	188.98	177.35	173.90	198.94	177.28
2.A.3	Glass Production	CO <sub>2</sub>	kt CO <sub>2</sub> eq	13.33	11.97	10.71	0.48	0.02	NO								
2.A.4	Other Process Uses of Carbonates	CO <sub>2</sub>	kt CO <sub>2</sub> eq	5.32	5.71	6.73	11.78	2.13	1.52	1.94	0.56	0.31	0.35	1.00	0.98	1.31	1.23
2.B.1	Ammonia Production	CO <sub>2</sub>	kt CO <sub>2</sub> eq	990.23	973.44	882.30	NO										
2.B.2	Nitric Acid Production	N <sub>2</sub> O	kt CO <sub>2</sub> eq	995.32	781.00	781.00	NO										
2.C.1	Iron and Steel Production	CO <sub>2</sub>	kt CO <sub>2</sub> eq	26.08	24.80	28.80	NO										
2.D.1	Lubricant Use	CO <sub>2</sub>	kt CO <sub>2</sub> eq	35.97	11.78	70.08	59.54	22.39	16.82	18.73	18.28	19.08	19.84	20.35	20.09	22.22	21.50
2.D.2	Paraffin Wax Use	CO <sub>2</sub>	kt CO <sub>2</sub> eq	6.26	8.59	15.73	35.28	24.04	21.84	21.54	20.10	22.68	23.11	24.49	23.71	25.09	23.65
2.D.3	Other Solvent Use	Indirect CO <sub>2</sub>	kt CO <sub>2</sub> eq	51.40	52.40	47.54	50.81	48.09	43.07	42.48	41.09	40.30	41.95	40.65	40.84	41.02	43.05
2.D.3	Urea as Catalyst	CO <sub>2</sub>	kt CO <sub>2</sub> eq	0.00	0.00	0.00	0.00	5.16	5.30	5.82	5.91	6.57	7.16	8.82	11.17	11.98	13.18
	Integrated Circuit or	HFCs, PFCs,															
2.E.1	Semiconductor	SF <sub>6</sub> , NF <sub>3</sub>	kt CO <sub>2</sub> eq	1.17	145.33	491.70	310.12	107.30	68.19	41.13	31.55	34.63	20.27	46.84	57.04	67.08	77.72
2.F.1	Refrigeration and Air Conditioning	HFCs	kt CO <sub>2</sub> eq	0.00	4.98	122.97	694.10	875.14	891.32	923.58	917.18	951.52	1,040.42	1,018.65	1,093.77	1,010.71	700.07
2.F.3	Fire Protection	HFCs	kt CO <sub>2</sub> eq	NO	NO	7.33	14.30	19.63	32.36	32.38	32.39	32.41	32.42	32.44	32.45	32.47	32.48
2.F.4	Aerosols	HFCs	kt CO <sub>2</sub> eq	NO	37.94	124.54	144.32	130.00	120.26	125.20	122.58	119.00	116.59	114.57	114.97	112.96	107.97
2.G.1	Electrical Equipment	SF <sub>6</sub>	kt CO <sub>2</sub> eq	20.52	25.08	7.43	22.44	13.34	12.33	20.70	16.22	18.60	19.15	19.70	19.06	19.87	16.13
	SF <sub>6</sub> and PFCs from Other Product																
2.G.2	Uses	SF <sub>6</sub>	kt CO <sub>2</sub> eq	12.90	12.99	14.69	11.78	5.87	3.35	2.64	2.79	2.94	3.09	3.24	3.24	3.24	3.23
2.G.3	N <sub>2</sub> O from Product Uses	N <sub>2</sub> O	kt CO <sub>2</sub> eq	31.34	32.20	33.88	36.96	40.53	40.72	40.90	40.99	41.06	41.21	41.44	42.57	42.77	42.98
2.G.4	Other Solvent and product use	Indirect CO <sub>2</sub>	kt CO <sub>2</sub> eq	0.07	0.08	0.09	0.07	0.06	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.02
2.H.2	Food and beverages industry	Indirect CO <sub>2</sub>	kt CO <sub>2</sub> eq	21.16	22.63	21.45	30.11	34.42	40.04	40.22	45.73	49.41	42.09	44.75	47.33	59.04	59.44
<b>Total IPPU (including Indirect CO<sub>2</sub>)</b>			<b>kt CO<sub>2</sub>eq</b>	<b>3,309.16</b>	<b>3,217.41</b>	<b>4,558.31</b>	<b>3,962.62</b>	<b>2,811.28</b>	<b>2,594.70</b>	<b>2,482.63</b>	<b>2,686.83</b>	<b>2,639.93</b>	<b>3,057.79</b>	<b>3,246.34</b>	<b>3,474.68</b>	<b>3,488.35</b>	<b>3,235.98</b>

**Table 4.4(b) Absolute and relative recalculations in the IPPU Sector (1990-2018)**

Absolute change		Gases	Units	1990	1995	2000	2005	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
2.A.1	Cement Production	CO <sub>2</sub>	kt CO <sub>2</sub> eq	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.A.2	Lime Production	CO <sub>2</sub>	kt CO <sub>2</sub> eq	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.A.3	Glass Production	CO <sub>2</sub>	kt CO <sub>2</sub> eq	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.A.4	Other Process Uses of Carbonates	CO <sub>2</sub>	kt CO <sub>2</sub> eq	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.B.1	Ammonia Production	CO <sub>2</sub>	kt CO <sub>2</sub> eq	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.B.2	Nitric Acid Production	N <sub>2</sub> O	kt CO <sub>2</sub> eq	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.C.1	Iron and Steel Production	CO <sub>2</sub>	kt CO <sub>2</sub> eq	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.D.1	Lubricant Use	CO <sub>2</sub>	kt CO <sub>2</sub> eq	-	-	-	-	-	-	-	-	-	-	-	-	-	-0.31
2.D.2	Paraffin Wax Use	CO <sub>2</sub>	kt CO <sub>2</sub> eq	-	-0.01	-	0.01	-	0.02	-	-	-	2.66	-	-	-31.80	-22.86
2.D.3	Other Solvent Use	Indirect CO <sub>2</sub>	kt CO <sub>2</sub> eq	-	0.15	0.15	0.86	0.23	0.32	0.21	0.83	-0.08	0.22	0.66	0.60	0.59	2.21
2.D.3	Urea as Catalyst	CO <sub>2</sub>	kt CO <sub>2</sub> eq	-	-	-	-	2.33	2.65	2.99	3.05	2.49	2.64	2.98	3.44	3.26	3.30
		HFCs, PFCs, SF <sub>6</sub> ,															
2.E.1	Integrated Circuit or Semiconductor	NF <sub>3</sub>	kt CO <sub>2</sub> eq	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.F.1	Refrigeration and Air Conditioning	HFCs	kt CO <sub>2</sub> eq	-	-	-	-5.26	10.05	14.47	17.88	14.42	14.35	15.10	9.98	3.58	-107.48	-248.44
2.F.3	Fire Protection	HFCs	kt CO <sub>2</sub> eq	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.F.4	Aerosols	HFCs	kt CO <sub>2</sub> eq	-	-0.06	-0.37	-0.34	-0.61	-0.56	-0.65	0.00	-	-	-	0.00	-0.01	-6.41
2.G.1	Electrical Equipment	SF <sub>6</sub>	kt CO <sub>2</sub> eq	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SF <sub>6</sub> and PFCs from Other Product																
2.G.2	Uses	SF <sub>6</sub>	kt CO <sub>2</sub> eq	-	-	-0.00	-0.03	0.00	-0.00	-0.00	0.00	-	-	-	0.00	-0.00	0.00
2.G.3	N <sub>2</sub> O from Product Uses	N <sub>2</sub> O	kt CO <sub>2</sub> eq	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.G.4	Other Solvent and product use	Indirect CO <sub>2</sub>	kt CO <sub>2</sub> eq	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.H.2	Food and beverages industry	Indirect CO <sub>2</sub>	kt CO <sub>2</sub> eq	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	<b>Total IPPU (including Indirect CO<sub>2</sub>)</b>		<b>kt CO<sub>2</sub>eq</b>	<b>-</b>	<b>0.08</b>	<b>-0.22</b>	<b>-4.76</b>	<b>12.00</b>	<b>16.90</b>	<b>20.43</b>	<b>18.30</b>	<b>16.77</b>	<b>20.62</b>	<b>13.63</b>	<b>7.62</b>	<b>-135.44</b>	<b>-272.52</b>
	<b>Relative change</b>																
2.A.1	Cement Production	CO <sub>2</sub>	%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.A.2	Lime Production	CO <sub>2</sub>	%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.A.3	Glass Production	CO <sub>2</sub>	%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.A.4	Other Process Uses of Carbonates	CO <sub>2</sub>	%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.B.1	Ammonia Production	CO <sub>2</sub>	%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.B.2	Nitric Acid Production	N <sub>2</sub> O	%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.C.1	Iron and Steel Production	CO <sub>2</sub>	%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.D.1	Lubricant Use	CO <sub>2</sub>	%	-	-	-	-	-	-	-	-	-	-	-	-	-	-1.4%
2.D.2	Paraffin Wax Use	CO <sub>2</sub>	%	-	-0.1%	-	0.0%	-	0.1%	-	-	-	13.0%	-	-	-55.9%	-49.2%
2.D.3	Other Solvent Use	Indirect CO <sub>2</sub>	%	-	0.3%	0.3%	1.7%	0.5%	0.8%	0.5%	2.1%	-0.2%	0.5%	1.7%	1.5%	1.5%	5.4%
2.D.3	Urea as Catalyst	CO <sub>2</sub>	%	-	-	-	-	82.5%	100.0%	105.6%	106.8%	61.1%	58.3%	51.2%	44.5%	37.5%	33.3%
		HFCs, PFCs, SF <sub>6</sub> ,															
2.E.1	Integrated Circuit or Semiconductor	NF <sub>3</sub>	%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.F.1	Refrigeration and Air Conditioning	HFCs	%	-	-	-	-0.8%	1.2%	1.7%	2.0%	1.6%	1.5%	1.5%	1.0%	0.3%	-9.6%	-26.2%
2.F.3	Fire Protection	HFCs	%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.F.4	Aerosols	HFCs	%	-	-0.2%	-0.3%	-0.2%	-0.5%	-0.5%	-0.5%	0.0%	-	-	-	0.0%	-0.0%	-5.6%
2.G.1	Electrical Equipment	SF <sub>6</sub>	%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SF <sub>6</sub> and PFCs from Other Product																
2.G.2	Uses	SF <sub>6</sub>	%	-	-	-0.0%	-0.2%	0.0%	-0.0%	-0.1%	0.0%	-	-	-	0.0%	-0.0%	0.0%
2.G.3	N <sub>2</sub> O from Product Uses	N <sub>2</sub> O	%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.G.4	Other Solvent and product use	Indirect CO <sub>2</sub>	%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.H.2	Food and beverages industry	Indirect CO <sub>2</sub>	%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	<b>Total IPPU (including Indirect CO<sub>2</sub>)</b>		<b>%</b>	<b>-</b>	<b>0.0%</b>	<b>-0.0%</b>	<b>-0.1%</b>	<b>0.4%</b>	<b>0.7%</b>	<b>0.8%</b>	<b>0.7%</b>	<b>0.6%</b>	<b>0.7%</b>	<b>0.4%</b>	<b>0.2%</b>	<b>-3.7%</b>	<b>-7.8%</b>

# 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 nine 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<sub>4</sub>), Dairy Cattle** (Level)
- **3.B.1.1 Manure Management (CH<sub>4</sub>), Cattle** (Level)
- **3.B.1.3 Manure Management (CH<sub>4</sub>) Swine** (Level)
- **3.D.1 Direct Soil Emissions** (Level and Trend)
- **3.D.2 Indirect Soil Emissions** (Level)
- **3.G.1 Liming** (Level)

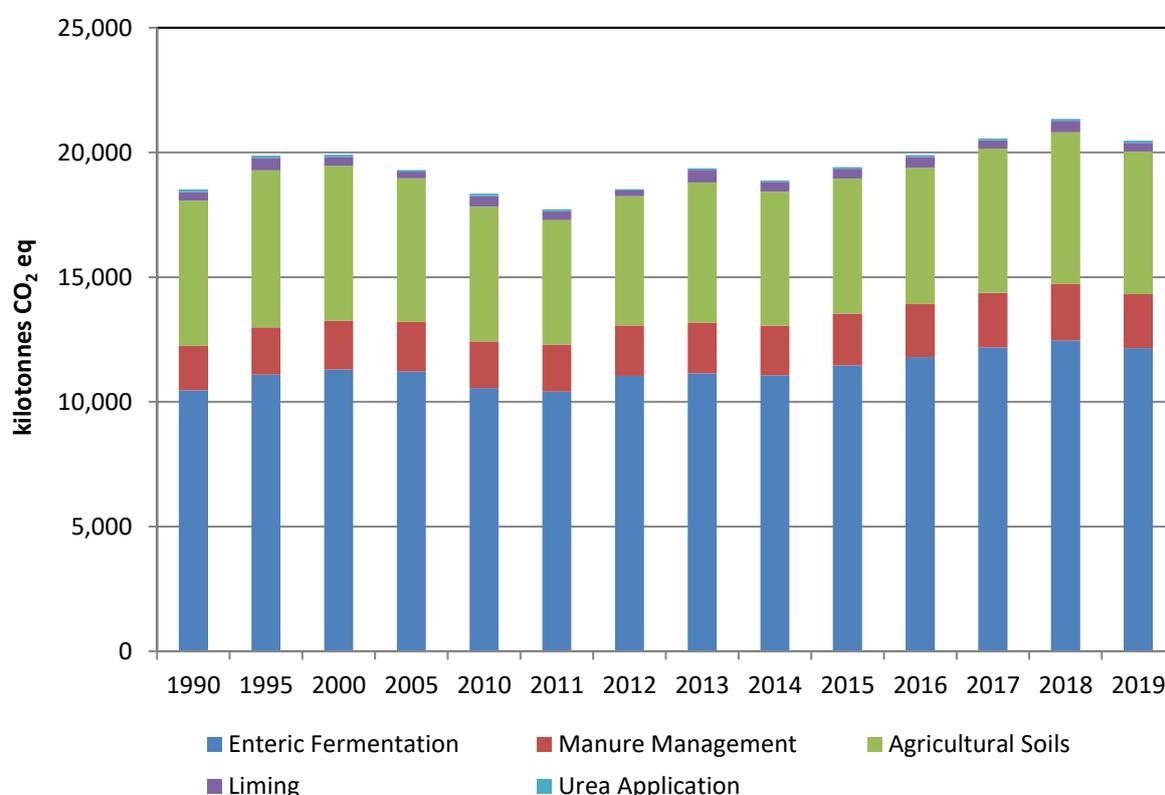
Other categories present in this sector include:

- **3.A.3 Enteric Fermentation, Swine**
- **3.A.4 Enteric Fermentation, Other Livestock**
- **3.B.1.2 Manure Management (CH<sub>4</sub>), Sheep**
- **3.B.1.4 Manure Management (CH<sub>4</sub>), Other Livestock**
- **3.B.2.1 Manure Management (N<sub>2</sub>O), Cattle**
- **3.B.2.2 Manure Management (N<sub>2</sub>O), Sheep**
- **3.B.2.3 Manure Management (N<sub>2</sub>O), Swine**
- **3.B.2.4 Manure Management (N<sub>2</sub>O), Other Livestock**
- **3.B.2.5 Manure Management (N<sub>2</sub>O), Indirect N<sub>2</sub>O Emissions**
- **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 have decreased by 3.5 per cent between 1990-2019.
- **Nitrous Oxide** emissions originate from 3.B Manure Management and 3.D Agricultural Soils.
- **Methane** emissions originate from 3.A Enteric Fermentation and 3.B Manure Management. Methane is the most significant GHG in agriculture, contributing 67.0 per cent of agricultural emissions in 2019.

The 2021 submission shows total GHG emissions of 20,479.7 kt CO<sub>2</sub> equivalent in the *Agriculture* sector in 2019, of which 3.A Enteric Fermentation accounts for 59.3 per cent 3.D Agricultural Soils 27.9 per cent, 3.B Manure Management 10.6 per cent, 3.G Liming 1.7 per cent, and 3.H Urea Application 0.4 per cent. The latest estimates show that emissions in the *Agriculture* sector have increased by 10.6 per cent from 1990 to 2019 mainly due to a 16.1 per cent increase in CH<sub>4</sub> emissions from 3.A Enteric Fermentation and a 22.1 per cent increase in emissions (kt CO<sub>2</sub>eq) from 3.B Manure Management.



*Figure 5.1 Total Emissions from Agriculture by Sector, 1990-2019*

### 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. The majority 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<sub>4</sub> and N<sub>2</sub>O. 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*

<b>3. Agriculture</b>	<b>CO<sub>2</sub></b>	<b>CH<sub>4</sub></b>	<b>N<sub>2</sub>O</b>
<b>A. Enteric Fermentation</b>			
1. Cattle*	NA	T2*	NA
2. Sheep*	NA	T1*	NA
3. Swine	NA	T1	NA
4. Other Livestock	NA	T1	NA
<b>B. Manure Management</b>			
1. Cattle*	NA	T2*	T1
2. Sheep	NA	T1	T2
3. Swine*	NA	T1	T2
4. Other Livestock	NA	T1	T2
5. Indirect N <sub>2</sub> O emissions*	NA	NA	T2*
<b>C. Rice Cultivation</b>	NO	NO	NO
<b>D. Agricultural Soils</b>			
1. Direct N <sub>2</sub> O from Managed Soils*	NA	NA	T1*
2. Indirect N <sub>2</sub> O from Managed Soils*	NA	NA	T1*
<b>E. Prescribed Burning of Savannas</b>	NO	NO	NO
<b>F. Field Burning of Agricultural Residues</b>	NO	NA	NA
<b>G. Liming*</b>	T1*	NO	NO
<b>H. Urea Application</b>	T1	NO	NO
<b>I. Other Carbon-containing fertilisers</b>	NA	NO	NO
<b>J. Other</b>	NO	NO	NO

\* Key Category

Table 5.2 Emissions from Agriculture 1990-2019

	Gas	Unit	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	
<b>3.A.1</b>	<b>Cattle</b>	CH <sub>4</sub>	kt CO <sub>2</sub> eq	9210.5	9796.5	10084.7	10214.0	9812.8	9664.2	10241.9	10348.6	10271.8	10684.4	11006.7	11353.6	11650.7	11345.5
<b>3.A.2</b>	<b>Sheep</b>	CH <sub>4</sub>	kt CO <sub>2</sub> eq	1176.3	1195.2	1114.4	904.7	637.3	650.6	695.1	696.4	694.2	683.1	685.4	732.9	718.5	710.7
<b>3.A.3</b>	<b>Swine</b>	CH <sub>4</sub>	kt CO <sub>2</sub> eq	41.4	52.0	56.9	55.2	51.1	51.8	51.3	50.0	50.7	50.1	52.2	53.5	53.5	54.0
<b>3.A.4</b>	<b>Other livestock</b>	CH <sub>4</sub>	kt CO <sub>2</sub> eq	37.9	42.3	39.8	43.4	53.5	52.7	54.8	49.6	47.0	46.0	45.6	42.5	42.0	41.0
<b>3.B.1</b>	<b>Cattle</b>	CH <sub>4</sub>	kt CO <sub>2</sub> eq	920.9	954.4	960.2	984.9	969.9	963.3	1046.8	1053.2	1034.3	1089.7	1124.5	1157.2	1188.5	1140.6
<b>3.B.1</b>	<b>Cattle</b>	N <sub>2</sub> O	kt CO <sub>2</sub> eq	257.6	282.8	295.6	315.9	292.1	287.4	325.1	321.6	297.0	316.3	325.0	337.3	360.4	328.2
<b>3.B.2</b>	<b>Sheep</b>	CH <sub>4</sub>	kt CO <sub>2</sub> eq	99.2	103.7	98.4	79.8	54.0	55.3	60.1	60.9	62.0	60.2	59.8	64.6	63.4	62.5
<b>3.B.2</b>	<b>Sheep</b>	N <sub>2</sub> O	kt CO <sub>2</sub> eq	22.7	23.1	23.1	19.8	14.4	14.6	15.3	15.2	15.0	14.8	14.9	15.9	15.5	15.3
<b>3.B.3</b>	<b>Swine</b>	CH <sub>4</sub>	kt CO <sub>2</sub> eq	206.5	258.6	291.6	284.5	249.1	257.4	253.0	253.6	256.7	250.6	259.6	261.4	264.4	266.4
<b>3.B.3</b>	<b>Swine</b>	N <sub>2</sub> O	kt CO <sub>2</sub> eq	10.1	12.5	13.6	13.2	12.1	12.2	12.0	11.8	12.0	11.8	12.3	12.5	12.5	12.6
<b>3.B.4</b>	<b>Other livestock</b>	CH <sub>4</sub>	kt CO <sub>2</sub> eq	61.6	50.2	54.7	64.1	69.3	69.7	81.1	85.3	87.6	95.5	96.4	99.1	102.0	102.8
<b>3.B.4</b>	<b>Other livestock</b>	N <sub>2</sub> O	kt CO <sub>2</sub> eq	11.2	10.6	10.5	11.4	12.8	12.8	13.6	12.9	12.9	12.9	12.8	12.2	12.1	11.9
<b>3.B.5</b>	<b>Indirect N<sub>2</sub>O emissions</b>	N <sub>2</sub> O	kt CO <sub>2</sub> eq	187.4	201.4	207.0	213.2	199.6	197.8	215.8	215.1	206.7	215.8	222.9	230.3	242.0	229.0
<b>3.D.1</b>	<b>Direct N<sub>2</sub>O Emissions from Managed Soils</b>	N <sub>2</sub> O	kt CO <sub>2</sub> eq	5264.6	5715.8	5613.4	5208.2	4861.4	4502.4	4674.5	5080.4	4860.3	4876.0	4910.8	5194.3	5461.4	5150.9
<b>3.D.2</b>	<b>Indirect N<sub>2</sub>O Emissions from Managed Soils</b>	N <sub>2</sub> O	kt CO <sub>2</sub> eq	555.9	589.5	593.5	553.0	534.3	495.3	511.1	538.8	522.3	538.1	558.3	583.5	614.6	572.4
<b>3.G.1</b>	<b>Limestone CaCO<sub>3</sub></b>	CO <sub>2</sub>	kt	355.0	494.6	366.4	266.7	427.9	360.7	229.4	515.7	391.1	401.1	433.6	332.7	461.1	343.9
<b>3.H</b>	<b>Urea Application</b>	CO <sub>2</sub>	kt	96.7	86.3	91.8	60.8	98.2	70.3	46.4	47.1	54.5	64.3	79.1	84.0	88.8	92.0
<b>3</b>	<b>Total Agriculture</b>		kt CO <sub>2</sub> eq	<b>18515.4</b>	<b>19869.2</b>	<b>19915.9</b>	<b>19292.8</b>	<b>18349.9</b>	<b>17718.5</b>	<b>18527.2</b>	<b>19356.0</b>	<b>18876.0</b>	<b>19410.9</b>	<b>19899.8</b>	<b>20567.8</b>	<b>21351.2</b>	<b>20479.7</b>

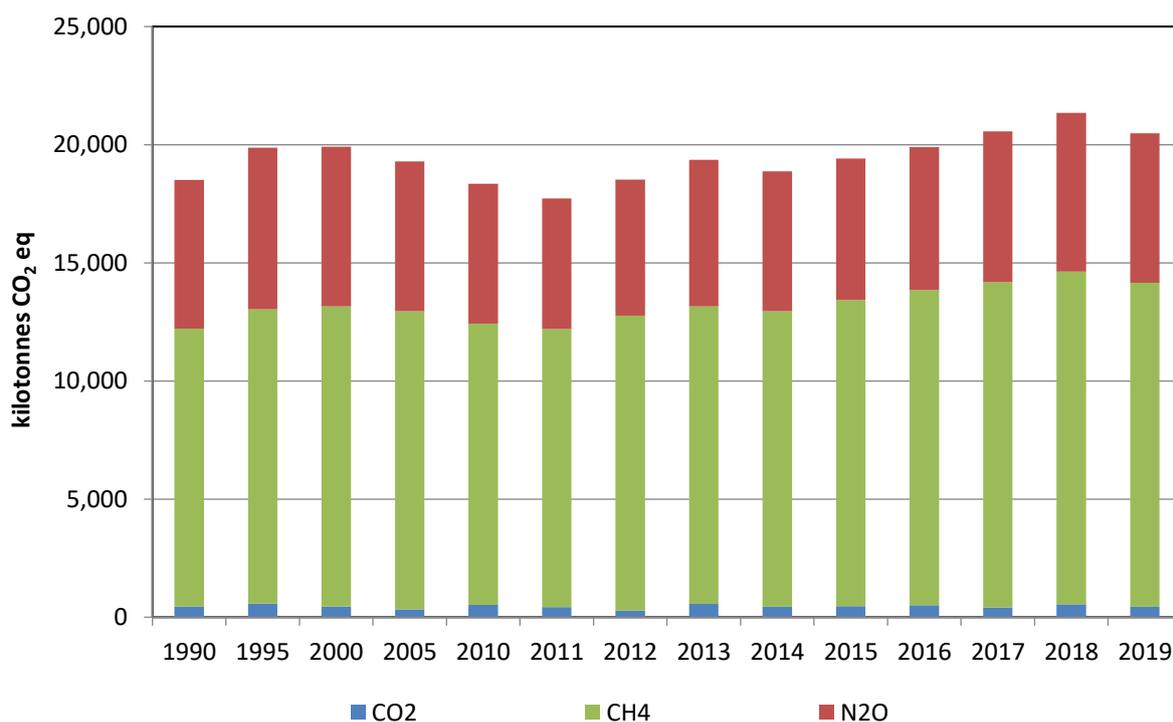


Figure 5.2 Total Emissions from Agriculture by Gas, 1990-2019

## 5.2 Emissions from livestock (3.1)

The two IPCC Level 2 emission source categories under 3.1 *Livestock* in 2019 are 3.A *Enteric Fermentation* and 3.B *Manure Management*. Total emissions from these activities amounted to 14,320.5 kt CO<sub>2</sub>eq in 2019.

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. (2020), Teagasc National Farm Survey - A report on bovine manure management, application and storage practices in Ireland
- DAFM (2020), 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<sub>3</sub> emissions as outlined in the EMEPA/EEA Emission Inventory Guidebook (EMEP/EEA, 2013, 2016 and 2019), 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 2019 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 12,151.2 kt CO<sub>2</sub>eq in 2019.

#### 5.2.1.1 Enteric Fermentation, Cattle (3.A.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<sub>4</sub> in Ireland.

##### 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 2019 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<sub>4</sub> 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; 2005; 2006; 2007; 2008, 2009, 2010) and the Department of Agriculture Food and the Marine (DAFM, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020). 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<sup>4</sup>.

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 bodyweight 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<sub>l</sub>). 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:

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<sup>4</sup> 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.

Maintenance  $NE_i$  requirements (MJ) =  $9.96 + (0.6 \times LW/100)$ , 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);

$NE_i$  (MJ) required per kg milk =  $0.376 \times \text{fat content} + 0.209 \times \text{protein content} + 0.948$ ;

Pregnancy: mean of 12.1 MJ  $NE_i$  /day for the last 3 months of pregnancy;

Live-weight change: each kg live-weight lost contributed 24.9 MJ  $NE_i$  to energy requirements, while each kg of live-weight gained required 32 MJ  $NE_i$ .

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).

A constant methane conversion rate of 0.065 of gross energy intake is applied when the diet consists of grazed grass and 3 kg or less of concentrate supplement per day. This is based on a large New Zealand database of measurements for grazing animals on similar production systems to those in Ireland. A methane output of 21.6 g/kg DM is used for pasture diets with a grass GE content of 18.45 MJ/kg, which is equivalent to 6.5 per cent of Gross Energy (Harry Clark, AgResearch New Zealand Personal Communication, O'Mara, 2006). 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, 2020), grazing period (O'Mara, 2006; Hyde et al., 2008; Buckley et al, 2020) 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, 2020). 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<sub>mg</sub>.

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 weaning 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 0.065 of gross energy intake was applied 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<sub>4</sub> Enteric Fermentation Emission Factors for cattle 1990 to 2019*

	Enteric Fermentation (kg/head/year)													
	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
<b>Dairy cows</b>	101.38	104.46	107.54	112.58	114.46	115.06	112.88	113.72	113.68	116.73	115.83	118.62	119.88	121.56
<b>Suckler cows</b>	75.36	75.33	75.29	76.35	73.09	74.04	75.42	72.88	73.33	74.20	73.81	73.83	73.46	73.65
<b>Male cattle &lt; 1 year</b>	25.53	28.00	30.47	32.62	33.43	33.66	37.14	36.64	33.84	35.64	35.38	36.08	39.11	35.53
<b>Male cattle 1 - 2 years</b>	58.67	60.16	61.66	60.70	61.99	59.92	60.25	59.48	59.92	60.47	58.75	59.32	60.09	58.34
<b>Male cattle &gt; 2 years</b>	33.81	34.22	34.63	38.76	41.30	39.45	38.98	38.94	37.39	37.80	36.43	34.50	35.90	37.63
<b>Female cattle &lt; 1 year</b>	24.01	26.46	28.91	30.61	31.77	31.36	34.54	33.98	31.40	33.15	32.57	33.19	36.01	32.57
<b>Female cattle 1 - 2 years</b>	42.70	43.90	45.10	49.58	51.09	50.04	51.70	51.43	51.61	52.09	51.64	52.12	53.26	52.09
<b>Female cattle &gt; 2 years</b>	23.06	23.06	23.06	23.03	22.63	22.52	22.32	22.24	22.08	21.55	21.29	21.14	21.07	21.01
<b>Bulls for breeding</b>	72.45	78.69	84.92	89.45	92.61	91.03	98.90	97.33	91.03	94.97	93.39	94.97	102.04	93.39
<b>Dairy in-calf heifers</b>	46.88	49.42	51.96	53.80	54.91	54.13	57.29	56.65	54.13	55.55	54.92	55.55	58.39	54.92
<b>Beef in-calf heifers</b>	50.29	52.88	55.47	57.35	58.46	57.66	60.83	60.20	57.66	59.08	58.45	59.08	61.93	58.45

## Uncertainties and Time-series Consistency

The uncertainties applicable to *Enteric Fermentation* are provided in Annex 2. The emission time series for agriculture 1990–2019 is consistent. Key activity data such as disaggregated animal numbers are available for all years and are used in a consistent manner.

## 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.

## Category-specific Recalculations

The EPA funded a review of methane emission models from cattle, originally developed in 2006. This review was undertaken by Teagasc (Ireland's national agriculture and food development authority) and published in 2019 (O'Brien and Shalloo, 2019). The updated model was used in the 2019 inventory and to re-calculate all previous years in the time series to obtain a more accurate estimate of emissions from livestock. In addition, updated data on crude protein content in concentrate feeds and trends over time was obtained from a survey conducted by DAFM (Department of Agriculture, Food & Marine) in 2019 (previous data source was from a survey in 2003). Together these resulted in a 1.24 per cent increase in emissions from 3.A *Enteric fermentation* on average across time series (Table 5.8).

## Category-specific Planned Improvements

The inventory agency has in this submission incorporated the results of study (O'Brien and Shalloo, 2019) aimed at reviewing the Tier 2 methodology used for the estimation of CH<sub>4</sub> 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.

### 5.2.1.2 Enteric Fermentation, All Other Livestock (3.A.2-3.A.4)

#### 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<sub>4</sub> 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.

#### 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<sub>4</sub> conversion rate ( $Y_m$ ) of 4.5 per cent as per Table 10.13 of the 2006 IPCC guidelines. For swine the default emission factor of 1.5 kg CH<sub>4</sub> per head (Table 10.10 of 2006 IPCC guidelines) per year is adjusted for each subcategory of swine on the basis of a default swine weight (in the 2006 IPCC guidelines) of 82 kg and the known average weight of each subcategory of swine in Ireland. 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.

### Uncertainties and Time-series Consistency

The uncertainties applicable to *Enteric Fermentation* are provided in Annex 2. The emission time series for agriculture 1990–2019 is consistent. Key activity data such as disaggregated animal numbers are available for all years and are used in a consistent manner.

### 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.

### Category-specific Recalculations

Recalculations from all other livestock (3.A.2 – 3.A.4) are confined to updated activity data for sheep (3.A.2) for 2017, leading to a 0.9 per cent increase in emissions from sheep for 2017.

### Category-specific Planned Improvements

The inventory agency continues to investigate the applicability of developing Tier 2 estimates of CH<sub>4</sub> 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.

## 5.3 Emissions from Manure Management (3.B)

The IPCC Level 3 emission source categories relevant under *3.B Manure Management* in 2019 are *3.B.1 Cattle*, *3.B.2 Sheep*, *3.B.3 Swine*, *3.B.4 Other Livestock*, and *3.B.5 Indirect N<sub>2</sub>O Emissions*. Total emissions of CH<sub>4</sub> and N<sub>2</sub>O from these activities amounted to 2,169.3 kt CO<sub>2</sub>eq in 2019.

### 5.3.1 Manure Management, Cattle (3.B.1)

#### 5.3.1.1 Category Description

This category describes how to estimate CH<sub>4</sub> 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<sub>4</sub> 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<sub>4</sub>. 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<sub>4</sub> is produced.

The decomposition of the organic material in cattle manures is both a level and trend key category of CH<sub>4</sub> emissions in Ireland.

This category also includes N<sub>2</sub>O produced, directly and indirectly, during the storage and treatment of manure before it is applied to land. The N<sub>2</sub>O 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<sub>2</sub>O Emissions from Managed Soils*'.

Direct N<sub>2</sub>O emissions occur via combined nitrification and denitrification of nitrogen contained in the manure. The emission of N<sub>2</sub>O 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<sub>3</sub>) and nitrogen oxides (NO<sub>x</sub>). 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.

#### 5.3.1.2 Methodological Issues

Manure management practice surveys (Hyde et al., 2008; Buckley et al., 2020) provide detailed data on manure management practices to support the adoption of a higher tier method. The manure management surveys are carried 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, 2020) 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., 2020) 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<sub>4</sub> emission factors for manure management. The results 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<sub>0</sub>) of manure, the allocation to manure management systems based on the manure management surveys

(Hyde et al., 2008; Buckley et al., 2020) and the corresponding values of MCF (methane conversion factor) given for the cool climate ( $\leq 10^{\circ}\text{C}$ ) zone in Table 10.17 of the 2006 IPCC guidelines. Ireland uses the values of  $0.24 \text{ m}^3 \text{ CH}_4/\text{kg VS}$  and  $0.18 \text{ m}^3 \text{ CH}_4/\text{kg VS}$  for dairy cows and other cattle, respectively as outlined in Table 10A-4 and Table 10A-5 of the 2006 IPCC guidelines.

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 2017, and in this submission (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 2016 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  $\text{CH}_4$  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., 2020) 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  $\text{CH}_4$  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 2019 EMEP/EEA Inventory Guidebook (EMEP/EEA, 2019).

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<sub>2</sub>O emissions from managed agricultural soils (Section 5.5.1). In 2019 the bulk of cattle manures in housing were managed in pit storage systems (94.8 per cent and 84.3 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<sub>2</sub>O-N/N excreted for pit storage and 0.01 kg N<sub>2</sub>O-N/N excreted for deep bedding manure management systems are used for cattle manures. The emission factor presented in the 2006 IPCC guidelines, Table 11.3 of 0.10 kg N<sub>2</sub>O-N (kg NH<sub>3</sub>-N + NO<sub>x</sub>-N volatilised) is used to estimate indirect N<sub>2</sub>O emissions from manure management.

*Table 5.5 Tier 2 CH<sub>4</sub> Manure Management Emission Factors for cattle 1990 to 2019*

	Manure Management (kg/head/year)													
	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Dairy cows	11.21	11.19	11.17	11.32	11.26	11.30	11.08	11.06	11.08	11.20	11.08	11.18	11.17	11.30
Suckler cows	6.53	6.34	6.14	6.35	6.65	6.89	7.14	7.04	7.19	7.44	7.43	7.51	7.48	7.51
Male cattle < 1 year	3.69	3.93	4.18	4.40	4.79	4.69	5.20	5.13	4.71	4.97	4.94	5.05	5.47	4.96
Male cattle 1 - 2 years	6.17	6.20	6.24	6.16	6.49	6.23	6.24	6.17	6.28	6.38	6.12	6.20	6.34	6.10
Male cattle > 2 years	1.00	1.03	1.06	1.43	1.69	1.55	1.54	1.54	1.38	1.45	1.32	1.18	1.34	1.49
Female cattle < 1 year	3.56	3.80	4.05	4.25	4.48	4.45	4.90	4.81	4.46	4.72	4.64	4.76	5.15	4.66
Female cattle 1 - 2 years	3.98	4.08	4.17	4.39	5.04	4.86	5.14	5.15	5.26	5.29	5.21	5.32	5.48	5.32
Female cattle > 2 years	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.25	0.25	0.25	0.24	0.24	0.24	0.24
Bulls for breeding	7.63	8.31	9.00	9.53	9.98	9.76	10.90	10.67	9.76	10.33	10.10	10.33	11.35	10.10
Dairy in-calf heifers	3.49	3.77	4.04	4.25	4.43	4.34	4.79	4.70	4.34	4.56	4.47	4.56	4.98	4.47
Beef in-calf heifers	4.18	4.43	4.69	4.89	5.07	4.98	5.44	5.34	4.98	5.20	5.11	5.20	5.62	5.11

### 5.3.1.3 Uncertainties and Time-series Consistency

The uncertainties applicable to *Manure Management* are provided in Annex 2. The emission time series for agriculture 1990–2019 is consistent. Key activity data such as disaggregated animal numbers are available for all years and are used in a consistent manner.

### 5.3.1.4 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.

### 5.3.1.5 Category-specific Recalculations

Category-specific recalculations for 3.B were incorporated due to updated activity data and revised Tier 2 methodology used for the estimation of CH<sub>4</sub> emissions from enteric fermentation and manure management in cattle (O'Brien and Shalloo, 2019). Manure management data has been updated to reflect current practices based on the National Farm Survey which is undertaken by Teagasc. Previous knowledge in this space was based on a survey undertaken in 2003, which was not fully reflective of current practice. These resulted in a 4.12% increase in average emissions for 3.B across the time series (Table 5.8).

### 5.3.1.6 Category-specific Planned Improvements

The inventory agency has in this submission incorporated the results of study (O'Brien and Shalloo, 2019) aimed at reviewing the Tier 2 methodology used for the estimation of CH<sub>4</sub> 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.

## 5.3.2 Manure Management, All Other Livestock (3.B.2-3.B.4)

### 5.3.2.1 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**.

### 5.3.2.2 Methodological Issues

The Tier 1 approach in the 2006 IPCC Guidelines is used to estimate CH<sub>4</sub> 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<sub>0</sub> and VS from Table 10A.9 of 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<sub>0</sub> values used for swine are those presented in Tables 10A.7 and 10A.8 and MCF values from Table 10.17.

The Tier 2 approach in the 2006 IPCC Guidelines is used to estimate N<sub>2</sub>O 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 2019, 89.9 per cent of sheep manure is on pasture with the remainder in deep bedding system. All swine manure is in pit storage systems whereas for the other livestock categories combined (deer, goats, horses, mules and asses, poultry and fur animals) only 3.9 per cent of manures is on pasture.

The remainder of animal manures produced in-house are in different MMS as outlined with CH<sub>4</sub> emission factors for manure management in Annex 3.3.

The emission factors given by the 2006 IPCC guidelines, Table 10.21, 0.002 kg N<sub>2</sub>O-N/N excreted for pit storage and 0.01 kg N<sub>2</sub>O-N/N excreted for deep bedding, 0.005 kg N<sub>2</sub>O-N/N excreted for liquid system, 0.005 kg N<sub>2</sub>O-N/N excreted for solid storage and dry lot, 0.001 kg N<sub>2</sub>O-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 0.10 kg N<sub>2</sub>O-N (kg NH<sub>3</sub>-N + NO<sub>x</sub>-N volatilised) is used to estimate indirect N<sub>2</sub>O emissions from manure management.

### 5.3.2.3 Uncertainties and Time-series Consistency

The uncertainties applicable to *Manure Management* are provided in Annex 2. The emission time series for agriculture 1990–2019 is consistent. Key activity data such as disaggregated animal numbers are available for all years and are used in a consistent manner.

### 5.3.2.4 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.

### 5.3.2.5 Category-specific Recalculations

There are minor recalculations for the years 2015 to 2018 for 3.B.1.4 and 3.B.2.4 as a result of revised activity data for the national poultry flock. There are also minor recalculations for sheep as a result of updated activity data for 2018, leading to a 0.05 per cent decrease in CH<sub>4</sub> emissions from sheep for 2018 and a 0.2 per cent decrease in N<sub>2</sub>O emissions.

### 5.3.2.6 Category-specific Planned Improvements

The inventory agency continues to investigate the applicability of developing Tier 2 estimates of CH<sub>4</sub> 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.

## 5.4 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).

## 5.5 Emissions from Agricultural Soils (3.D)

The IPCC Level 3 emission source categories relevant under *3.D Agricultural Soils* in 2019 are *3.D.1 Direct N<sub>2</sub>O Emissions from Managed Soils* and *3.D.2 Indirect N<sub>2</sub>O Emissions from Managed Soils*. Total emissions from these activities amounted to 5,723.3 kt CO<sub>2</sub>eq in 2019.

The emissions of N<sub>2</sub>O 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<sub>3</sub> and NO<sub>x</sub> from managed soils and the subsequent

redeposition of these gases and their products  $\text{NH}_4^+$  and  $\text{NO}_3^-$  to soils and waters; and (ii) after leaching and runoff of N, mainly as  $\text{NO}_3^-$ , from managed soils.

## 5.5.1 Direct $\text{N}_2\text{O}$ Emissions from Managed Soils (3.D.1)

### 5.5.1.1 Category Description

*Direct  $\text{N}_2\text{O}$  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, cultivation of organic soils and mineralisation/immobilization associated with loss/gain of soil organic matter.**

The following N sources are included in the methodology for estimating direct  $\text{N}_2\text{O}$  emissions from managed soils:

- synthetic N fertilisers ( $F_{\text{SN}}$ );
- organic N applied as fertiliser ( $F_{\text{ON}}$ ) (both animal manures and sewage sludge);
- urine and dung N deposited on pasture, range and paddock by grazing animals ( $F_{\text{PRP}}$ );
- N in crop residues (above-ground and below-ground), including from N-fixing crops and from forages during pasture renewal ( $F_{\text{CR}}$ );
- N mineralisation associated with loss of soil organic matter resulting from change of land use or management of mineral soils ( $F_{\text{SOM}}$ ); and
- drainage/management of organic soils (i.e., Histosols)( $F_{\text{OS}}$ ).

### 5.5.1.2 Methodological Issues

The Tier 1 approach in the 2006 IPCC Guidelines is used for *Direct  $\text{N}_2\text{O}$  Emissions from Managed Soils*.

The estimates of direct  $\text{N}_2\text{O}$  emissions from agricultural soils take into account the nitrogen inputs from all of these sources. The overarching equation used for estimating *Direct  $\text{N}_2\text{O}$  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:

$$N_2O_{\text{Direct}} - N = N_2O - N_{N \text{ inputs}} + N_2O - N_{\text{OS}} + N_2O - N_{\text{PRP}}$$

Where:

$$N_2O - N_{N \text{ inputs}} = [(F_{\text{SN}} + F_{\text{ON}} + F_{\text{CR}} + F_{\text{SOM}}) \times EF_1]$$

$$N_2O - N_{\text{OS}} = [(F_{\text{OS,G,Temp,NP}}) \times EF_2]$$

$$N_2O - N_{\text{PRP}} = [(F_{\text{PRP, CPP}} \times EF_{3\text{PRP, CPP}}) + (F_{\text{PRP, SO}} \times EF_{3\text{PRP, SO}})]$$

Where:

$F_{\text{SN}}$  = annual amount of synthetic fertiliser N applied to soils,  $\text{kg N yr}^{-1}$

$F_{\text{ON}}$  = annual amount of animal manure ( $F_{\text{AM}}$ ) and sewage sludge ( $F_{\text{SEW}}$ ) applied to soils  $\text{kg N yr}^{-1}$

$F_{CR}$  = annual amount of N in crop residues returned to soils, kg N yr<sup>-1</sup>

$F_{SOM}$  = 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<sup>-1</sup>

$F_{PRP}$  = annual amount of urine and dung N deposited by grazing animals, kg N yr<sup>-1</sup> (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<sub>2</sub>O emissions from N inputs, kg N<sub>2</sub>O–N (kg N input)<sup>-1</sup>

$EF_2$  = emission factor for N<sub>2</sub>O emissions from drained/managed organic soils, kg N<sub>2</sub>O–N ha<sup>-1</sup> yr<sup>-1</sup>

$EF_{3PRP}$  = emission factor for N<sub>2</sub>O emissions from urine and dung N deposited on pasture, range and paddock by grazing animals, kg N<sub>2</sub>O–N (kg N input)<sup>-1</sup>; (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<sub>2</sub>O–N/kg N applied, respectively for CAN, urea and urea + n-butyl thiophosphoric triamide. The implied emission factor for  $EF_1$  is on average 24 percent (0.0124 kg N<sub>2</sub>O–N/kg N) higher than the default value (0.010 kg N<sub>2</sub>O–N/kg N) presented in 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<sub>2</sub>O emissions from Managed Soils (3.D.2)* the quantity of these fertilisers which are volatilised as NH<sub>3</sub> and NO<sub>x</sub> 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 0.5 per cent of the organic nitrogen input to agricultural soils in 2019. 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 1990-2019.

In 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 0.02 kg N<sub>2</sub>O–N/N kg ( $EF_{3PRP, CPP}$ ), and emissions from sheep and other livestock (horses, mules, goats and deer), which utilize the emission factor of 0.01 kg N<sub>2</sub>O–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 ( $F_{PRPcattle-dung}$ ) and urine ( $F_{PRPcattle-urine}$ ). 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 56 per cent lower than the

default value (0.02 kg N<sub>2</sub>O-N/ kg N) presented in the 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 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, 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<sub>2</sub>O 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 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 and EF<sub>2</sub> from Table 2.5 of the 2013 IPCC Wetland Supplement for nutrient poor grasslands.

**Table 5.6 Information related to Direct N<sub>2</sub>O Emissions from Managed Soils (3.D.1)**

Parameter	Emission Factor	Emission Factor Reference
EF <sub>1CAN</sub>	0.0140 kg N <sub>2</sub> O-N/kg N	Harty et al. (2016) and Roche et al (2016).
EF <sub>1Urea</sub>	0.0025 kg N <sub>2</sub> O-N/kg N	Harty et al. (2016)
EF <sub>1Urea+NBPT</sub>	0.0040 kg N <sub>2</sub> O-N/kg N	Harty et al. (2016)
EF <sub>2</sub>	4.3 kg N <sub>2</sub> O-N/ha	Table 11.1, Volume 4, Chapter 11 of the 2006 IPCC Guidelines & Table 2.5, 2013 IPCC Wetland Supplement
EF <sub>3PRP, CPP</sub>	0.02 kg N <sub>2</sub> O-N/kg N	Table 11.1, Volume 4, Chapter 11 of the 2006 IPCC Guidelines
EF <sub>3cattle-dung</sub>	0.0031 kg N <sub>2</sub> O-N/kg N	Krol et al. (2016)
EF <sub>3cattle - urine</sub>	0.012 kg N <sub>2</sub> O-N/kg N	Krol et al. (2016)
EF <sub>3PRP, SO</sub>	0.01kg N <sub>2</sub> O-N/kg N	Table 11.1, Volume 4, Chapter 11 of the 2006 IPCC Guidelines

### 5.5.1.3 Uncertainties and Time-series Consistency

The uncertainties applicable to *Direct N<sub>2</sub>O Emissions from Managed Soils* are provided in Annex 2. The emission time series for agriculture 1990–2019 is consistent. Key activity data such as fertiliser use statistics are available for all years and are used in a consistent manner.

### 5.5.1.4 Category-specific QA/QC and verification

Standard QA/QC procedures have been applied to *Direct N<sub>2</sub>O Emissions from Managed Soils*. Details of Ireland’s QA/QC process can be found in Chapter 1 of this report.

### 5.5.1.5 Category-specific Recalculations

Category-specific recalculations due to updated activity data and revised Tier 2 methodology used for the estimation of emissions from enteric fermentation and manure management in cattle (O’Brien

and Shalloo, 2019) resulted in recalculated CH<sub>4</sub> and NH<sub>3</sub> emissions estimates across all years in the time series. In addition, minor revisions to emission factors used in NARSES model for other livestock (Misselbrook et al, 2020) have also been taken on board. As a result of this, estimates of N inputs to managed soils increased, leading to a concomitant rise in N<sub>2</sub>O emissions (direct and indirect). These resulted in average increases in annual emissions of 0.84 per cent in 3.D *Agricultural soils*. Revised estimates of emissions and removals for 4.B *Croplands* and 4.C *Grasslands* which are used as the activity data for Direct N<sub>2</sub>O Emissions from managed soils (3.D.1.5) also contributed to the increase (0.6 per cent) in emissions in 3.D.1 *Direct N<sub>2</sub>O Emissions From Managed Soils* on average.

#### 5.5.1.6 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<sub>2</sub>O 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<sub>2</sub>O from soils. Notwithstanding the above Ireland has integrated country specific research results into emission calculation 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<sub>2</sub>O emissions from soil. An emission factor for N<sub>2</sub>O 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<sub>2</sub>O 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<sub>2</sub>O emissions to identify mitigation measures, with an initial focus on the effect of soil phosphorus on N<sub>2</sub>O emissions. Additionally, a Global Research Alliance funded project investigating mitigation measures associated with dairy cow urine on N<sub>2</sub>O emissions commenced in 2019. Finally, the effect of multispecies grasslands for reducing N<sub>2</sub>O emissions, enhancing carbon sequestration and stabilising yields is also due to be investigated.

### 5.5.2 Indirect N<sub>2</sub>O Emissions from Managed Soils (3.D.2)

#### 5.5.2.1 Category Description

*Indirect N<sub>2</sub>O 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<sub>3</sub> and NO<sub>x</sub> from managed soils and the subsequent redeposition of these gases and their products NH<sub>4</sub><sup>+</sup> and NO<sub>3</sub><sup>-</sup> to soils and waters; and (ii) after leaching and runoff of N, mainly as NO<sub>3</sub><sup>-</sup>, from managed soils.

#### 5.5.2.2 Methodological Issues

The Tier 1 approach in the 2006 IPCC Guidelines is used for *Indirect N<sub>2</sub>O Emissions from Managed Soils*.

The IPCC methodology for indirect emissions is based on a simple approach that allocates emissions of N<sub>2</sub>O due to nitrogen deposition resulting from NH<sub>3</sub> and NO<sub>x</sub> emissions in agriculture and from nitrogen leaching to the country that generated the source nitrogen. The contributions from NH<sub>3</sub> and NO<sub>x</sub> 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<sub>2</sub>O<sub>(ATD)</sub>) arise due to the volatilisation of nitrogen applied to soils in synthetic fertilisers and animal manures. The proportions of these fertilisers that are volatilised are Fra<sub>C<sub>GAS</sub>F</sub> and Fra<sub>C<sub>GAS</sub>M</sub> respectively. The volatilisation rates for Ireland are determined in an elaborate NH<sub>3</sub> inventory for agriculture (Duffy et al, 2019). It is assumed that nitrogen lost as NO<sub>x</sub> is negligible in comparison to NH<sub>3</sub>. Fra<sub>C<sub>GAS</sub>M</sub> is split into Fra<sub>C<sub>GAS</sub>M1</sub> and Fra<sub>C<sub>GAS</sub>M2</sub> with Fra<sub>C<sub>GAS</sub>M1</sub> referring to NH<sub>3</sub>-N losses from animal manures in housing, storage and landspreading and Fra<sub>C<sub>GAS</sub>M2</sub> being the proportion of nitrogen from sewage sludge applied to soils that is volatilised as NH<sub>3</sub>. These values are presented in Table 5.7. Equation 11.9 in Volume 4, Chapter 11 of the 2006 IPCC Guidelines which is used to estimate the emissions:

$$N_2O_{(ATD)} - N = [(F_{SN} \times \text{Fra}_{C_{GAS}F}) + ((F_{AM} + F_{PRP}) \times \text{Fra}_{C_{GAS}M1}) + (F_{SEW} \times \text{Fra}_{C_{GAS}M2})] \times EF_4$$

Where:

N<sub>2</sub>O<sub>(ATD)</sub>-N = annual amount of N<sub>2</sub>O-N produced from atmospheric deposition of N volatilised from managed soils, kg N<sub>2</sub>O-N yr<sup>-1</sup>

Fra<sub>C<sub>GAS</sub>F</sub> = fraction of synthetic fertiliser N that volatilises as NH<sub>3</sub> and NO<sub>x</sub>, kg N volatilised (kg of N applied)<sup>-1</sup>

Fra<sub>C<sub>GAS</sub>M1</sub> = fraction of applied animal manure N (F<sub>AM</sub>) and of urine and dung N deposited by grazing animals (F<sub>PRP</sub>) that volatilises as NH<sub>3</sub> and NO<sub>x</sub>, kg N volatilised (kg of N applied or deposited)<sup>-1</sup>

Fra<sub>C<sub>GAS</sub>M2</sub> = fraction of applied sewage sludge N (F<sub>SEW</sub>) that volatilises as NH<sub>3</sub> and NO<sub>x</sub>, kg N volatilised (kg of N applied or deposited)<sup>-1</sup>

EF<sub>4</sub> = emission factor for N<sub>2</sub>O emissions from atmospheric deposition of N on soils and water surfaces, [0.01 kg N-N<sub>2</sub>O (kg NH<sub>3</sub>-N + NO<sub>x</sub>-N volatilised)<sup>-1</sup>]

Conversion of N<sub>2</sub>O<sub>(ATD)</sub>-N emissions to N<sub>2</sub>O 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 2006 IPCC Guidelines:

$$N_2O_{(L)} - N = (F_{SN} + F_{ON} + F_{CR} + F_{SOM} + F_{PRP}) \times \text{Fra}_{LEACH-(H)} \times EF_5$$

Where:

N<sub>2</sub>O<sub>(L)</sub>-N = annual amount of N<sub>2</sub>O-N produced from leaching and runoff of N additions to managed soils in regions where leaching/runoff occurs, kg N<sub>2</sub>O-N yr<sup>-1</sup>

$F_{\text{LEACH-(H)}}$  = 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)<sup>-1</sup>

$EF_5$  = emission factor for N<sub>2</sub>O emissions from N leaching and runoff, 0.0075 kg N<sub>2</sub>O–N (kg N leached and runoff)<sup>-1</sup>

$F_{\text{SN}}$ ,  $F_{\text{ON}}$ ,  $F_{\text{CR}}$ ,  $F_{\text{SOM}}$  and  $F_{\text{PRP}}$  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%. The value of 0.1 is thus considered to be a more realistic estimate of  $F_{\text{LEACH-(H)}}$  for Irish conditions than the default value of 0.3 and it is used in this submission.

**Table 5.7 Information related to Indirect N<sub>2</sub>O Emissions from Managed Soils (3.D.2)**

Parameter	Emission Factor	Emission Factor Reference
$F_{\text{C}_{\text{GASF}}}$	0.025	Calculated value for 2019
$F_{\text{C}_{\text{GASM1}}}$	0.095	Calculated value for 2019
$F_{\text{C}_{\text{GASM2}}}$	0.13	Table 3.1 & Annex 1.1 Chapter 3D of the 2016 EMEP/EEA Emission Inventory Guidebook
$F_{\text{LEACH-(H)}}$	0.1	OSPAR Convention (NEUT, 1999); Ryan et al., 2006; Del Prado et al., 2006 and Richards et al., 2009

### 5.5.2.3 Uncertainties and Time-series Consistency

The uncertainties applicable to *Indirect N<sub>2</sub>O Emissions from Managed Soils* are provided in Annex 2. The emission time series for agriculture 1990–2019 is consistent.

### 5.5.2.4 Category-specific QA/QC and verification

Standard QA/QC procedures have been applied to *Indirect N<sub>2</sub>O Emissions from Managed Soils*. Details of Ireland’s QA/QC process can be found in Chapter 1 of this report.

### 5.5.2.5 Category-specific Recalculations

Category-specific recalculations due to updated activity data and revised Tier 2 methodology used for the estimation of emissions from enteric fermentation and manure management in cattle (O’Brien and Shalloo, 2019) resulted in recalculated CH<sub>4</sub> and NH<sub>3</sub> emissions estimates for cattle. In addition, minor revisions to emission factors used in NARSES model for other livestock (Misselbrook et al, 2020) have also been taken on board. As a result of this, estimates of N inputs to managed soils increased, leading to a concomitant rise in N<sub>2</sub>O emissions (direct and indirect). Revised estimates of emissions and removals for *4.B Croplands* which are used as the activity data to estimate emissions from *3.D.2.2 Nitrogen Leaching and Run-off* also contributed to increase in emissions of N<sub>2</sub>O from this category across the timeseries.

### 5.5.2.6 Category-specific Planned Improvements

There are no planned improvements for this category.

## 5.6 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).

## 5.7 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<sup>5</sup>. This category is reported as Not Occurring (NO).

## 5.8 Emissions from Liming (3.G)

### 5.8.1 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) in Ireland. In Ireland, emissions from liming only occur from **Limestone CaCO<sub>3</sub>**, with no activities identified for **Dolomite CaMg(CO<sub>3</sub>)<sub>2</sub>** which is reported as Not Occurring (NO). Total emissions from *Liming* amounted to 343.9 kt CO<sub>2</sub>eq in 2019.

### 5.8.2 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. 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.

### 5.8.3 Uncertainties and Time-series Consistency

The uncertainties applicable to *Liming* are provided in Annex 2. The emission time series for agriculture 1990–2019 is consistent. Key activity data are available for all years and are used in a consistent manner.

### 5.8.4 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.

### 5.8.5 Category-specific Recalculations

Updated activity data from the Department of Agriculture, Food & Marine on total lime applied resulted in a minor recalculation (0.8% increase) for this category in 2018. All values for other years in the time series remain unchanged.

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<sup>5</sup> <http://www.agriculture.gov.ie/farmerschemespayments/crosscompliance/>

### 5.8.6 Category-specific Planned Improvements

There are no planned improvements for this category.

## 5.9 Emissions from Urea Application (3.H)

### 5.9.1 Category Description

Adding urea to soils during fertilisation leads to a loss of CO<sub>2</sub> that was fixed in the industrial production process. Total emissions from these activities amounted to 92.0 kt CO<sub>2</sub>eq in 2019.

### 5.9.2 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.

### 5.9.3 Uncertainties and Time-series Consistency

The uncertainties applicable to *Urea Application* are provided in Annex 2. The emission time series for agriculture 1990–2019 is consistent. Key activity data such as fertiliser use statistics are available for all years and are used in a consistent manner.

### 5.9.4 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.

### 5.9.5 Category-specific Recalculations

No recalculations have been undertaken in this category in this submission.

### 5.9.6 Category-specific Planned Improvements

There are no planned improvements for this category.

## 5.10 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).

## 5.11 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 1990-2018**

			1990	1995	2000	2005	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
<b>Estimates in 2020 Submission (kt)</b>																
3.A	Enteric Fermentation	CH <sub>4</sub>	454.28	459.20	450.43	433.73	415.07	406.22	401.81	415.17	421.31	426.24	435.21	448.48	461.51	461.73
3.B	Manure Management	CH <sub>4</sub>	56.24	56.69	55.76	54.12	50.79	50.07	50.08	52.09	52.70	53.18	54.15	55.90	57.01	57.08
3.B	Manure Management	N <sub>2</sub> O	1.67	1.74	1.75	1.77	1.70	1.64	1.62	1.71	1.73	1.71	1.74	1.81	1.84	1.82
3.D.1	Direct em. from Managed Soils	N <sub>2</sub> O	17.83	19.17	18.67	17.26	15.32	16.20	15.05	15.49	16.90	16.34	16.27	16.40	17.24	17.86
3.D.2	Indirect em. From Managed Soils	N <sub>2</sub> O	1.87	1.96	1.94	1.79	1.69	1.73	1.61	1.62	1.72	1.70	1.73	1.80	1.87	1.92
3.G	Liming	CO <sub>2</sub>	355.04	494.60	366.38	266.73	307.32	427.93	360.68	229.40	515.69	391.07	401.15	433.60	332.75	457.45
3.H	Urea Application	CO <sub>2</sub>	96.68	86.27	91.84	60.81	89.02	98.24	70.27	46.35	47.09	54.55	64.27	79.11	83.99	88.76
3	Total Carbon dioxide	CO <sub>2</sub>	451.71	580.86	458.23	327.55	396.34	526.18	430.94	275.75	562.78	445.62	465.41	512.71	416.74	546.21
3	Total Methane	CH <sub>4</sub>	510.52	515.89	506.19	487.84	465.86	456.29	451.89	467.26	474.01	479.42	489.36	504.38	518.52	518.80
3	Total Nitrous oxide	N <sub>2</sub> O	21.38	22.87	22.36	20.83	18.71	19.57	18.28	18.83	20.35	19.76	19.74	20.01	20.95	21.60
3	Total (CO <sub>2</sub> eq)	CO <sub>2</sub> eq	<b>19,584.98</b>	<b>20,292.81</b>	<b>19,777.21</b>	<b>18,731.03</b>	<b>17,617.15</b>	<b>17,765.62</b>	<b>17,176.34</b>	<b>17,568.04</b>	<b>18,477.16</b>	<b>18,318.42</b>	<b>18,581.00</b>	<b>19,084.68</b>	<b>19,621.92</b>	<b>19,953.07</b>
<b>Recalculated Estimates in 2021 Submission (kt)</b>																
3.A	Enteric Fermentation	CH <sub>4</sub>	418.64	443.44	451.83	448.69	431.57	422.19	416.77	441.72	445.78	442.55	458.55	471.60	487.30	498.59
3.B	Manure Management	CH <sub>4</sub>	51.53	54.67	56.20	56.53	54.39	53.70	53.83	57.64	58.12	57.63	59.84	61.61	63.30	64.73
3.B	Manure Management	N <sub>2</sub> O	1.64	1.78	1.85	1.92	1.85	1.78	1.76	1.95	1.93	1.82	1.92	1.97	2.04	2.16
3.D.1	Direct em. from Managed Soils	N <sub>2</sub> O	17.67	19.18	18.84	17.48	15.46	16.31	15.11	15.69	17.05	16.31	16.36	16.48	17.43	18.33
3.D.2	Indirect em. From Managed Soils	N <sub>2</sub> O	1.87	1.98	1.99	1.86	1.75	1.79	1.66	1.71	1.81	1.75	1.81	1.87	1.96	2.06
3.G	Liming	CO <sub>2</sub>	355.04	494.60	366.38	266.73	307.32	427.93	360.68	229.40	515.69	391.07	401.15	433.60	332.75	461.06
3.H	Urea Application	CO <sub>2</sub>	96.68	86.27	91.84	60.81	89.02	98.24	70.27	46.35	47.09	54.55	64.27	79.11	83.99	88.76
3	Total Carbon dioxide	CO <sub>2</sub>	451.71	580.86	458.23	327.55	396.34	526.18	430.94	275.75	562.78	445.62	465.41	512.70	416.74	549.82
3	Total Methane	CH <sub>4</sub>	470.17	498.11	508.03	505.22	485.96	475.88	470.60	499.36	503.90	500.17	518.39	533.21	550.60	563.32
3	Total Nitrous oxide	N <sub>2</sub> O	21.17	22.94	22.67	21.26	19.06	19.89	18.53	19.35	20.79	19.89	20.09	20.32	21.43	22.54
3	Total (CO <sub>2</sub> eq)	CO <sub>2</sub> eq	<b>18,515.41</b>	<b>19,869.20</b>	<b>19,915.89</b>	<b>19,292.84</b>	<b>18,224.16</b>	<b>18,349.93</b>	<b>17,718.49</b>	<b>18,527.16</b>	<b>19,356.01</b>	<b>18,876.04</b>	<b>19,410.89</b>	<b>19,899.82</b>	<b>20,567.80</b>	<b>21,351.15</b>

Percentage Change in Total Emissions due to Recalculations																
3.A	Enteric Fermentation	CH <sub>4</sub>	-7.84%	-3.43%	0.31%	3.45%	3.97%	3.93%	3.72%	6.40%	5.81%	3.83%	5.36%	5.15%	5.59%	7.98%
3.B	Manure Management	CH <sub>4</sub>	-8.39%	-3.56%	0.80%	4.46%	7.09%	7.24%	7.48%	10.65%	10.29%	8.35%	10.51%	10.22%	11.03%	13.41%
3.B	Manure Management	N <sub>2</sub> O	-1.91%	2.01%	5.29%	8.46%	9.19%	8.85%	8.40%	13.97%	12.01%	6.46%	10.24%	8.97%	11.15%	18.35%
3.D.1	Direct em. from Managed Soils	N <sub>2</sub> O	-0.92%	0.07%	0.90%	1.24%	0.93%	0.70%	0.41%	1.26%	0.87%	-0.18%	0.58%	0.47%	1.08%	2.60%
3.D.2	Indirect em. From Managed Soils	N <sub>2</sub> O	-0.46%	1.08%	2.60%	3.52%	3.11%	3.38%	3.19%	5.67%	5.00%	2.88%	4.51%	4.35%	4.95%	7.63%
3.G	Liming	CO <sub>2</sub>	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%	0.79%
3.H	Urea Application	CO <sub>2</sub>	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 <sub>2</sub>	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%	0.66%
3	Total Methane	CH <sub>4</sub>	-7.90%	-3.45%	0.36%	3.56%	4.31%	4.30%	4.14%	6.87%	6.31%	4.33%	5.93%	5.72%	6.19%	8.58%
3	Total Nitrous oxide	N <sub>2</sub> O	-0.95%	0.31%	1.39%	2.05%	1.87%	1.62%	1.36%	2.79%	2.17%	0.66%	1.77%	1.58%	2.31%	4.38%
3	Total (CO <sub>2</sub> eq)	CO <sub>2</sub> eq	<b>-5.46%</b>	<b>-2.09%</b>	<b>0.70%</b>	<b>3.00%</b>	<b>3.45%</b>	<b>3.29%</b>	<b>3.16%</b>	<b>5.46%</b>	<b>4.76%</b>	<b>3.04%</b>	<b>4.47%</b>	<b>4.27%</b>	<b>4.82%</b>	<b>7.01%</b>

# 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 use before 1990, and 2): lands converted from other land uses since 1990. Defined in this way, the second sub-category enables tracking of land between the principal fixed categories using 1990 as a base year. The approach ensures consistency and comparability of activities reported under the UNFCCC (herein referred to Convention reporting) and those reported under the Kyoto Protocol. 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<sub>2</sub> 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 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<sub>2</sub>O and CH<sub>4</sub> 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<sub>2</sub>O and CH<sub>4</sub> are reported for biomass burning (and CO<sub>2</sub> 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 1990-2019 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 1990-2019. 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 Office of Environmental Sustainability (OES) of the EPA (see section 1.3 of this report). All other emissions and removals estimates were 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 <sub>2</sub>			CH <sub>4</sub>	N <sub>2</sub> O
	Biomass	DOM	Soils		
<b>A. Forest Land</b>					
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>B. Cropland</b>					
1. Cropland remaining Cropland	All	NO	All	NA	IE
2. Land converted to Cropland	NO	NO	NO	NA	NO
<b>C. Grassland</b>					
1. Grassland remaining Grassland	NO	NO	All, NO*	NO	All, IE
2. Land converted to Grassland	All	All	All	All	Part, IE
<b>D. Wetlands</b>					
1. Wetlands remaining Wetlands	All	NO	All	NO	IE
2. Land converted to Wetlands	All	All	All	All	All
<b>E. Settlements</b>					
1. Settlements remaining Settlements	NO	NO	NA	NO	IE, NE
2. Land converted to Settlements	All	All	All	All	Part, IE
<b>F. Other Land</b>					
1. Other Land remaining Other Land	NO	NO	NO*	NO	NO
2. Land converted to Other Land	All	All	All	All	All
<b>G. Harvested wood products</b>			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 from deforested lands

The 1990-2019 inventory for LULUCF follows the same general approach and methodologies as those used for the 2020 submission for the 1990-2018 inventory, and ensures transparent and consistent reporting of activities and land use transition under the Convention and under the Kyoto Protocol. In particular, it should be noted that, within the 2013 submission, there was a major reappraisal of the transition of areas remaining in a land use category and those lands converted to other land uses. Previous CRF tables 4.A to 4.F reported land use transition based on a 20-year transition. The current approach reports all land areas converted to another land use after the 1st of January 1990, and lands not subject to land use change before the 1st January 1990. For example,

forest land remaining forests (4.A) includes all forest areas remaining forest before 1990 and lands converted to forests after 1990. This now ensures consistent and transparent comparison of areas reported under Convention reporting and those elected under KP LULUCF.

The estimates of emissions and removals from LULUCF over the period 1990-2019 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

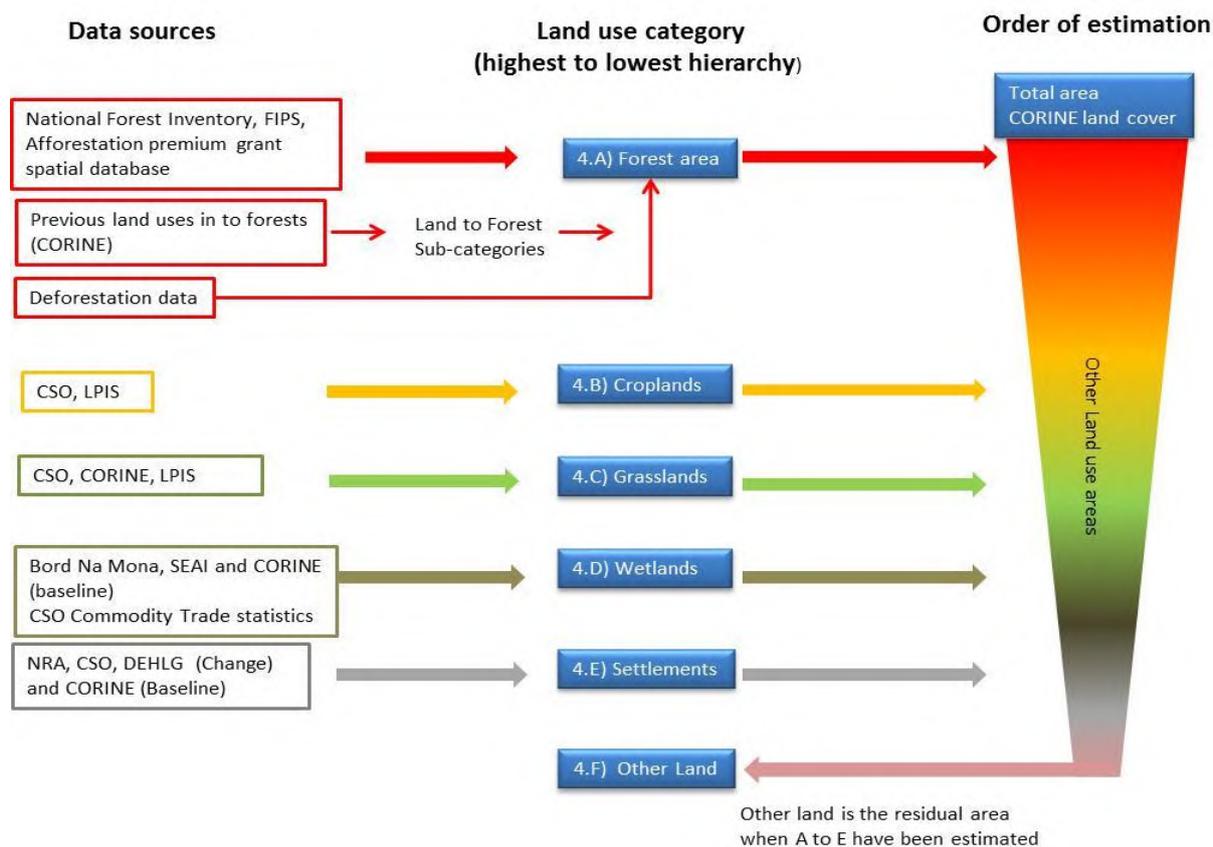
Table 6.3 summarises the definitions and coverage of the IPCC land-use categories in the LULUCF sector as they relate to Ireland along with the data sources that are used for estimating the respective areas remaining in the categories before 1990, the areas converted to the categories since 1990 and their associated greenhouse gas emissions and removals. The IPCC Wetlands category has been sub divided into natural 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. As previously mentioned, the relationship between areas afforested since 1990 (KP Article 3.3 sub-category AR) are now fully consistent with Convention area in lands converted to forest land since 1990.

### 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 hierarchical 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 and 2017 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 of areas of drainage of 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.

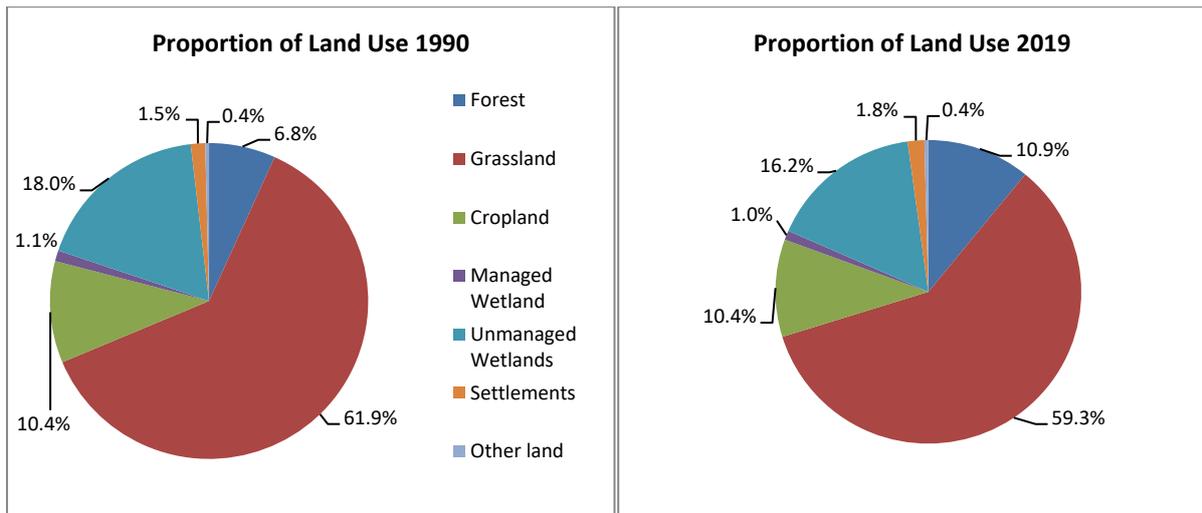


**Figure 6.1 Methodologies and hierarchy of determining land use areas and transitions**

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 2019. Grassland is the dominant land-use category in all years, accounting for 61.0 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 11.0 per cent and Settlements at 1.5 per cent. Other Land is the residual land use at 0.7 per cent. The major land-use changes since 1990 have been the conversion of Grassland and Wetland to Forest Land. In 2019, Grassland accounted for 59.3 per cent of land area, Wetland 17.2 per cent, Forest Land 10.9 per cent, Cropland at 10.4 per cent, with Settlement and Other Land accounting for 1.8 per cent and 0.4 per cent, respectively.



*Figure 6.2 Overview of land use change between 1990 and 2019*

Table 6.2 Emissions<sup>a</sup> and Removals<sup>a</sup> from Land Use Land-Use Change and Forestry 1990-2019 (kt CO<sub>2</sub> eq)

LULUCF	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
<b>4A Forestland</b>	<b>-3711.06</b>	<b>-2741.58</b>	<b>-1968.79</b>	<b>-2984.55</b>	<b>-3690.38</b>	<b>-3751.87</b>	<b>-4495.05</b>	<b>-5289.60</b>	<b>-4070.37</b>	<b>-4851.13</b>	<b>-4218.79</b>	<b>-3601.16</b>	<b>-3964.54</b>	<b>-4433.69</b>
A. Forest Land CO <sub>2</sub>	-3862.42	-2933.25	-2174.70	-3205.78	-3962.27	-4027.58	-4734.28	-5537.74	-4317.81	-5098.20	-4464.13	-3898.27	-4227.47	-4687.71
A. Forest Land CH <sub>4</sub>	58.51	72.69	70.07	68.87	102.49	104.32	68.59	76.82	75.67	72.74	69.70	115.54	81.81	71.91
A. Forest Land N <sub>2</sub> O	92.86	118.97	135.84	152.36	169.40	171.39	170.64	171.32	171.77	174.32	175.63	181.57	181.12	182.12
<b>4B Cropland</b>	<b>20.31</b>	<b>88.85</b>	<b>74.24</b>	<b>102.56</b>	<b>-74.38</b>	<b>44.85</b>	<b>101.60</b>	<b>39.26</b>	<b>1.69</b>	<b>-9.46</b>	<b>-42.97</b>	<b>-43.19</b>	<b>-129.26</b>	<b>-110.12</b>
B. Cropland CO <sub>2</sub>	20.24	88.77	74.19	102.45	-74.40	44.85	101.60	39.26	1.69	-9.46	-42.97	-43.19	-129.28	-110.14
B. Cropland CH <sub>4</sub>	0.05	0.06	0.04	0.08	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
B. Cropland N <sub>2</sub> O	0.01	0.02	0.01	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<b>4C Grassland</b>	<b>7249.44</b>	<b>6462.52</b>	<b>6843.84</b>	<b>6745.65</b>	<b>6933.90</b>	<b>6906.33</b>	<b>7048.82</b>	<b>7429.17</b>	<b>6930.43</b>	<b>6923.36</b>	<b>6949.24</b>	<b>6966.58</b>	<b>7022.16</b>	<b>7013.96</b>
C. Grassland CO <sub>2</sub>	6964.36	6205.08	6592.77	6485.74	6546.24	6573.70	6714.74	7070.05	6543.25	6573.53	6616.56	6596.15	6683.19	6684.10
C. Grassland CH <sub>4</sub>	269.63	233.39	242.75	244.59	308.07	251.58	242.18	250.36	275.46	244.23	243.47	280.03	257.27	253.37
C. Grassland N <sub>2</sub> O	15.46	24.05	8.32	15.32	79.59	81.05	91.89	108.77	111.73	105.61	89.21	90.40	81.71	76.50
<b>4D Wetlands</b>	<b>1897.80</b>	<b>2417.66</b>	<b>1791.95</b>	<b>2789.34</b>	<b>3514.81</b>	<b>2839.38</b>	<b>2081.36</b>	<b>2861.60</b>	<b>3653.36</b>	<b>4046.53</b>	<b>2899.73</b>	<b>3802.35</b>	<b>2461.99</b>	<b>2331.54</b>
D. Wetlands CO <sub>2</sub>	1735.30	2228.47	1643.34	2613.77	3151.83	2668.93	2006.16	2709.89	3333.27	3898.39	2788.66	3450.97	2315.74	2212.32
D. Wetlands CH <sub>4</sub>	131.42	151.97	120.65	140.78	284.99	137.21	64.17	124.52	254.24	123.50	95.46	279.76	121.20	99.93
D. Wetlands N <sub>2</sub> O	31.08	37.23	27.96	34.80	77.99	33.24	11.02	27.18	65.86	24.63	15.61	71.62	25.04	19.30
<b>4E Settlements</b>	<b>86.75</b>	<b>119.37</b>	<b>212.10</b>	<b>391.40</b>	<b>315.10</b>	<b>126.47</b>	<b>322.78</b>	<b>134.08</b>	<b>122.96</b>	<b>138.46</b>	<b>143.84</b>	<b>175.82</b>	<b>169.77</b>	<b>209.84</b>
E. Settlements CO <sub>2</sub>	80.46	109.11	194.13	330.44	229.04	54.02	251.36	61.97	52.83	66.96	72.09	101.29	93.85	129.39
E. Settlements CH <sub>4</sub>	NO													
E. Settlements N <sub>2</sub> O	6.29	10.26	17.97	60.96	86.06	72.44	71.42	72.10	70.13	71.50	71.75	74.53	75.92	80.45
<b>4F Other Land</b>	<b>0.89</b>	<b>23.41</b>	<b>54.59</b>	<b>69.44</b>	<b>62.13</b>	<b>62.04</b>	<b>61.96</b>	<b>61.88</b>	<b>61.88</b>	<b>59.23</b>	<b>56.68</b>	<b>54.12</b>	<b>51.57</b>	<b>49.02</b>
F. Other Land CO <sub>2</sub>	0.81	20.74	40.80	45.80	11.09	11.08	11.07	11.06	11.06	10.79	10.52	10.25	9.98	9.71
F. Other Land CH <sub>4</sub>	NO													
F. Other Land N <sub>2</sub> O	0.08	2.66	13.78	23.64	51.04	50.96	50.89	50.81	50.81	48.45	46.16	43.87	41.59	39.31
<b>4G Harvested Wood Products</b>	<b>-413.04</b>	<b>-679.70</b>	<b>-1123.25</b>	<b>-1129.67</b>	<b>-818.73</b>	<b>-741.72</b>	<b>-668.59</b>	<b>-662.33</b>	<b>-763.17</b>	<b>-728.72</b>	<b>-803.70</b>	<b>-868.83</b>	<b>-825.66</b>	<b>-617.93</b>
G. HWP CO <sub>2</sub>	-413.04	-679.70	-1123.25	-1129.67	-818.73	-741.72	-668.59	-662.33	-763.17	-728.72	-803.70	-868.83	-825.66	-617.93
G. HWP CH <sub>4</sub>	NO													
G. HWP N <sub>2</sub> O	NO													
<b>Total LULUCF kt CO<sub>2</sub> eq</b>	<b>5131.08</b>	<b>5690.53</b>	<b>5884.67</b>	<b>5984.18</b>	<b>6242.44</b>	<b>5485.46</b>	<b>4452.86</b>	<b>4574.05</b>	<b>5936.78</b>	<b>5578.28</b>	<b>4984.03</b>	<b>6485.68</b>	<b>4786.03</b>	<b>4442.62</b>

<sup>a</sup> 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 2019 (ha)	Percentage change 1990-2019	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	776,650	+61.4%	National Forest Inventory (NFI) 2006, 2012 and 2017 FIPS (Forest Inventory and Planning System) 1995 COILLTE database Forest Service Premiums database CORINE Land Cover General Soil Map Deforestation statistics	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.	739,969	738,673	-1.2%	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.	4,402,202	4,216,174	-4.2%	CSO, CORINE Land Cover, NFI LPIS (Land Parcels Information System) Indicative Soil Map for Ireland	Forest land, Settlement	Forest land
Unmanaged Wetlands	Natural unexploited wetlands	1,278,983	1,155,434	-9.7%	CORINE Land Cover, NFI Indicative Soil Map for Ireland	Managed Wetland, Forest land	Forest land
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.	78,441	70,020	-10.7%	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	125,279	+20.8%	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	27,377	29,556	+8.0%	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 Canadian Forest Service Carbon Budget Model framework (CFS-CBM, 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 2006 NFI. The first Irish NFI was completed in 2006 with a second NFI inventory was completed in 2012 and a third in 2017. 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 CFS-CBM model (Kurz et al., 2009; section 6.3.3.1 and Annex 3.4.A.5). The CFS-CBM 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 CFS-CBM 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 CFS-CBM model has been used for the recent EU LULUCF Forest Reference Level (FRL) submission in 2018 and 2019. The model has been parameterised for Irish conditions, but detailed uncertainty analysis is yet to be completed. 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 and post 2006 time series does offer the potential of introducing a time series bias or inconsistency. However, this is addressed by re-scaling the historic (FORCARB) time series by interpolation against the CFS-CBM model outputs as indicated in Figure 6.3.1 (also see section 6.3.4.1 and section 6.3.4.1) in line with Chapter 5 Volume 1 of the 2006 IPCC guidelines.

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 CFS-CBM 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 different modelling frameworks FORCARB and CFS-CBM. 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.

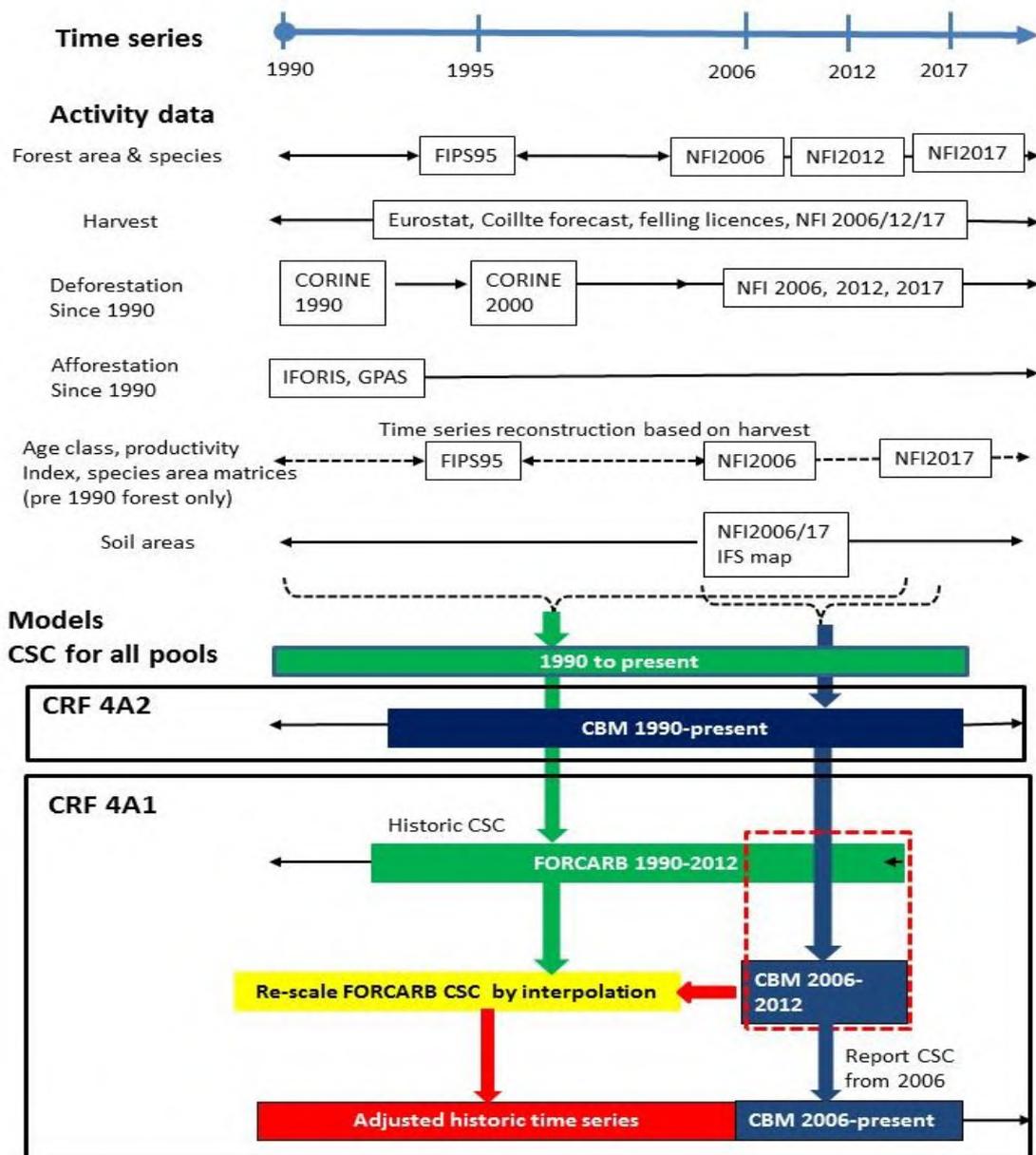


Figure 6.3 Activity data and models used to derive carbon stock changes for forest land

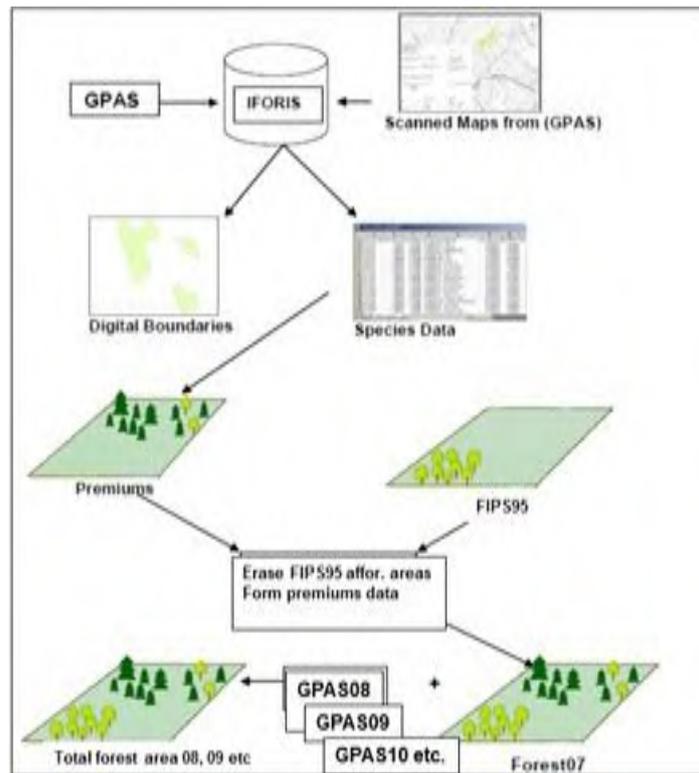
## 6.3.2 Detailed description of activity data

### 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 CFS-CBM 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 CFS-CBM 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. 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 was completed in 2006 using a sampling approach, based on a randomised systematic grid sample design. The second inventory was completed in 2012. The third NFI was completed in 2017. 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 (see chapter 11). 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.

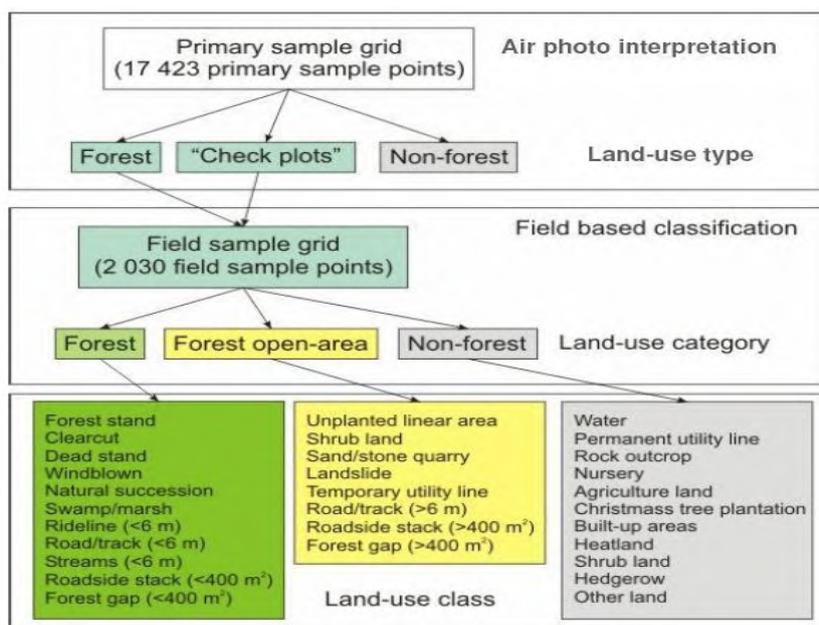
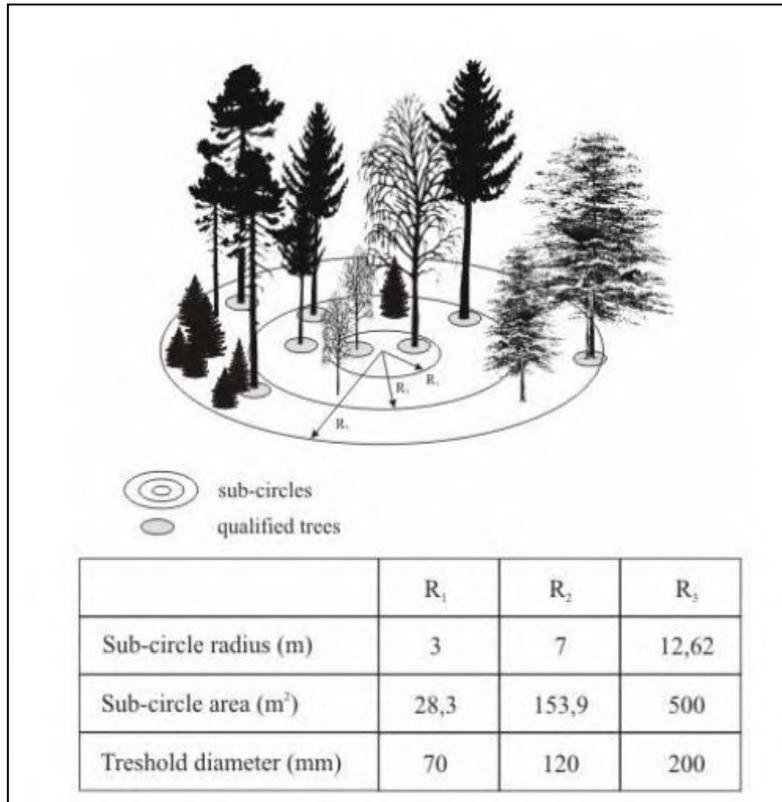


Figure 6.5 Overview of the National Forest Inventory classification system (taken from NFI, 2007a)

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<sup>2</sup> (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 CFS-CBM 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).



*Figure 6.6 The concentric plot design and mapping of individual trees 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 KP 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:

$$\text{New sub-category area (4.809 kha)} = (12/650) \times 260.47 \quad (\text{eq 6.3.1})$$

#### 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 a 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 2019 were compiled using national data submitted to the FAO and EUROSTAT. For the 1990-2019 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 2016

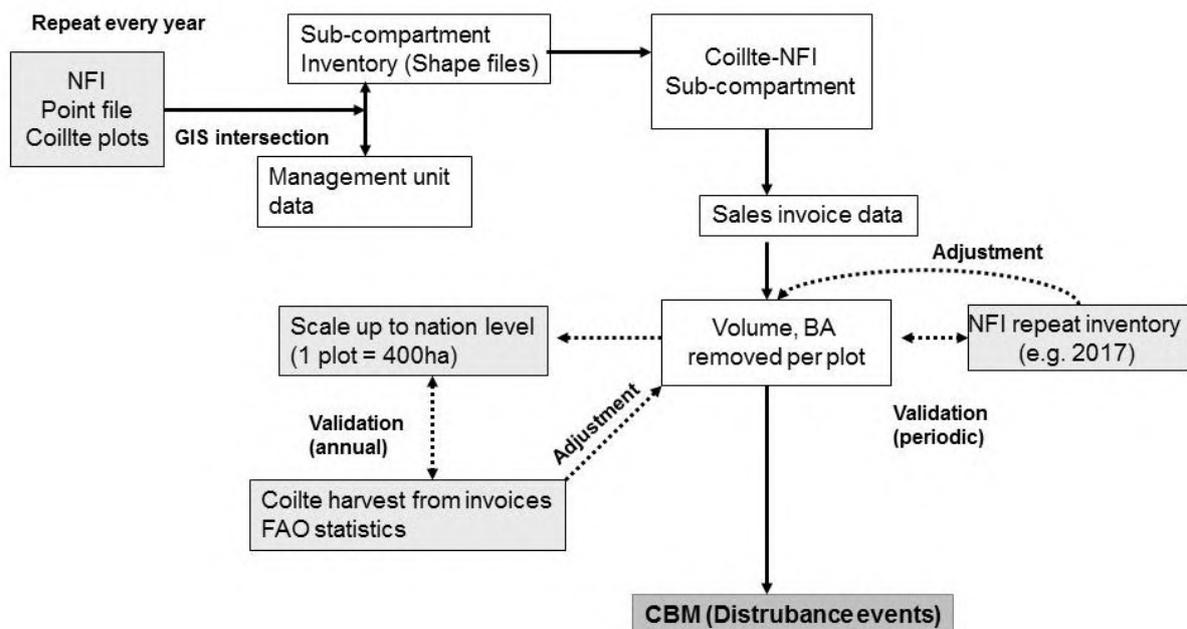
The 2006, 2012 and 2017 NFIs were used to derive harvest data for the periods after 2005. The 2012-2017 inventory cycle was chosen to represent the period up to the end of 2016 as it is the mid-point of the 3rd NFI measurement period. The NFI records individual trees within permanent sample plots (PSP) 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 2006/17 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 CFS-CBM 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).

Harvest from forest land remaining forest land (CRF 4.A.1) increased from ca. 1.8 Mm<sup>3</sup> in 1990 to ca. 2.6 Mm<sup>3</sup> by 2018, reducing to 2.05 Mm<sup>3</sup> in 2019 due to changes in the age class structure and clearfell of more crops at rotation age (Table 6.6). Harvest from lands converted to forest land (i.e. all forests established since 1990, CRF 4.A.2) only occurred from 2007 onwards due to the young age class structure of this category. All harvests occurring on afforested land since 1990 are carried out as first thinning's of more productive conifer crops. The total timber volumes harvested from the areas afforested since 1990 was 0.08 Mm<sup>3</sup> in 2007 increasing to 0.88 Mm<sup>3</sup> by 2014 and subsequently reducing to 0.56 Mm<sup>3</sup> in 2016, and increasing to 1.16 Mm<sup>3</sup> in 2019 (Table 6.13). Harvesting from the Coillte lands (state forest) represented ca. 77 per cent of the total timber harvest (NFI, 2017). Approximately 65 per cent of the afforestation area is privately owned, where thinning's 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 2016

To derive harvest after 2016 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 AIDB database in CFS-CBM model to simulate the harvesting of trees. A final validation is performed in CFS-CBM 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 CFS-CBM model to

simulate the harvesting of trees. A final validation is performed in CFS-CBM model to ensure that the expected and simulated harvest rates are consistent (Figure 6.8).

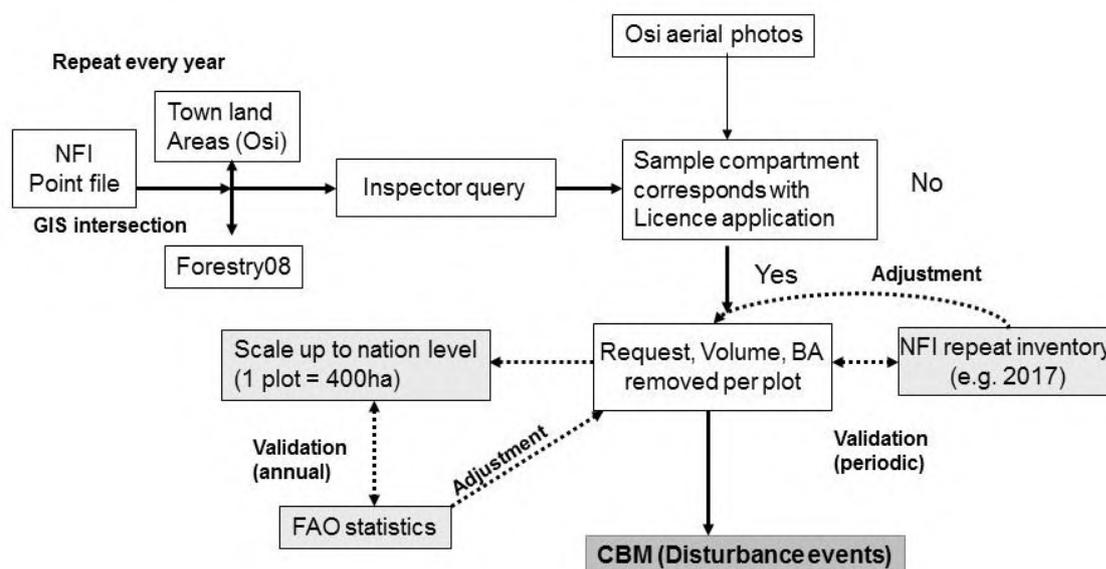


Figure 6.8 Procedure used to derive harvest activity data for private forested areas

## 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 from 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 under estimated 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 a 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 2006-2016 using the NFI

The NFI 2017 and previous NFIs are used to derive deforestation data for the period 2006 to 2016. 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.

#### 4) Deforestation records from 2016 onwards (see Annex 3.4.A.3)

The Forestry Act 2014 legally requires a formal application to the Forest Service to fell trees under either a limited or a general felling license. General felling licences cover forestry activities associated with silvicultural management, such as thinnings or clearfell and replanting. Limited felling licences capture areas and volumes felled and land use transitions for all forest land converted to other land uses. All limited felling licence applications for 2017 and all years thereafter are considered as deforestation and the records provide the basis for estimating emissions for all biomass pools at the time of harvest.

Felling stands younger than 10 years old are not subject to the forestry act felling licence application. However, records were kept because these areas were previously subject to premium payments under the afforestation scheme. Owners in receipt of these payments are obliged to notify the Forest Service if these areas are taken out ('lands taken out') of the premiums payment due to deforestation. A data base of these records has been compiled to capture the land use change and soil categories. The biomass, litter and DOM losses associated with deforestation are based on the NFI, PSP average of all 10 year old forest areas.

The NFI programme will continue to monitor whether clear felled forest land under general licences are 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 2016

Activity data of land afforested since 2016, 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 CFS-CBM 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 first-approximation 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.

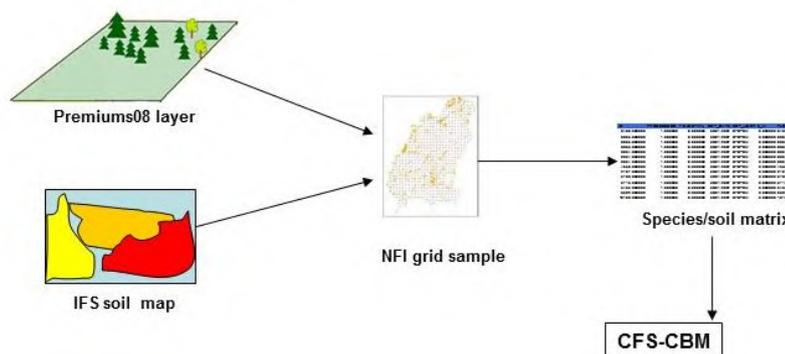


Figure 6.9 Procedure to derive activity data for Afforestation areas after 2016

#### 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 2006-2016

The land use prior to afforestation for 2006-2016 was derived using the 2006 and 2017 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 2006-2017 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 carbon pools

**Table 6.4 Definition of carbon pools used in LULUCF and KP-LULUCF reporting**

LULUCF	KP LULUCF	Definition
Living biomass	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
Dead organic matter	Deadwood	Standing deadwood, dead stumps, roots (min 2 mm) and logs (min 7cm diameter)
	Litter <sup>a</sup>	Needles, leaves and branches up to a diameter of 7cm
Mineral soil	Mineral soil	SOC of less than 20% (reported to max depth of 30cm)
Organic soil	Organic soil	SOC of > 20% and depth > 30cm
Organo-mineral soil	Organo-mineral soil	Mineral soil with a top organic soil of depth < 30cm

<sup>a</sup>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 CFS-CBM

Estimation of carbon stock changes by all forests are estimated using a tier 3 model, CFS-CBM. A detailed description of CBM 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, 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 (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).

*Table 6.5 IPCC and CBM carbon pools*

<b>IPCC Carbon Pools</b>	<b>Pool Names in CBM-CFS3</b>
<b>Living Biomass</b>	
Above-ground biomass	Merchantable stemwood
	Other (sub-merchantable stemwood, tops, branches, stumps, non-merchantable trees)
Below-ground biomass	Foliage
	Coarse roots
	Fine roots
<b>Dead Organic matter (DOM)</b>	
Deadwood	Above-ground fast
	Below-ground fast
	Medium
	Softwood stem snag
	Softwood branch snag
	Hardwood stem snag
	Hardwood branch snag
Litter	Above-ground very fast
	Above-ground slow
<b>Soils</b>	
Soil organic matter	Below-ground very fast
	Below-ground slow
	Black carbon <sup>1</sup>
	Peat <sup>1</sup>

<sup>1</sup> Black carbon and peat are currently not estimated in CBM

CBM 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) (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 (Kurtz et al., 2009). This is the only climate depended relationship used in CBM. The annual mean temperature for all regions in Ireland is set to 7.5 deg C in the AIDB database of the CBM.

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 is 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).

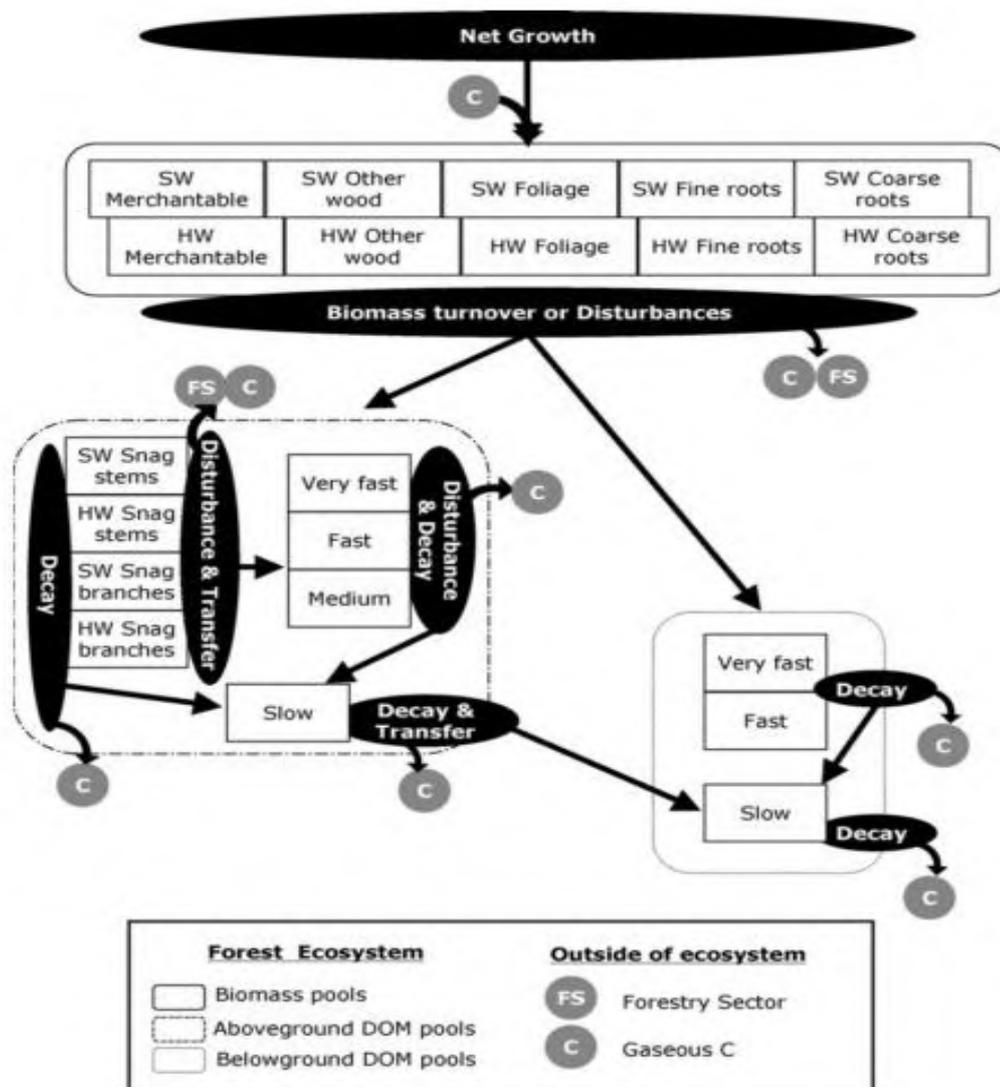


Figure 6.10 A schematic summary of how annual processes and carbon transfer between pools are simulated in the CFS-CBM model\* (taken directly from Kurtz et al., 2009).

\*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 CFS-CBM 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).

#### 6.3.3.2 FORCARB

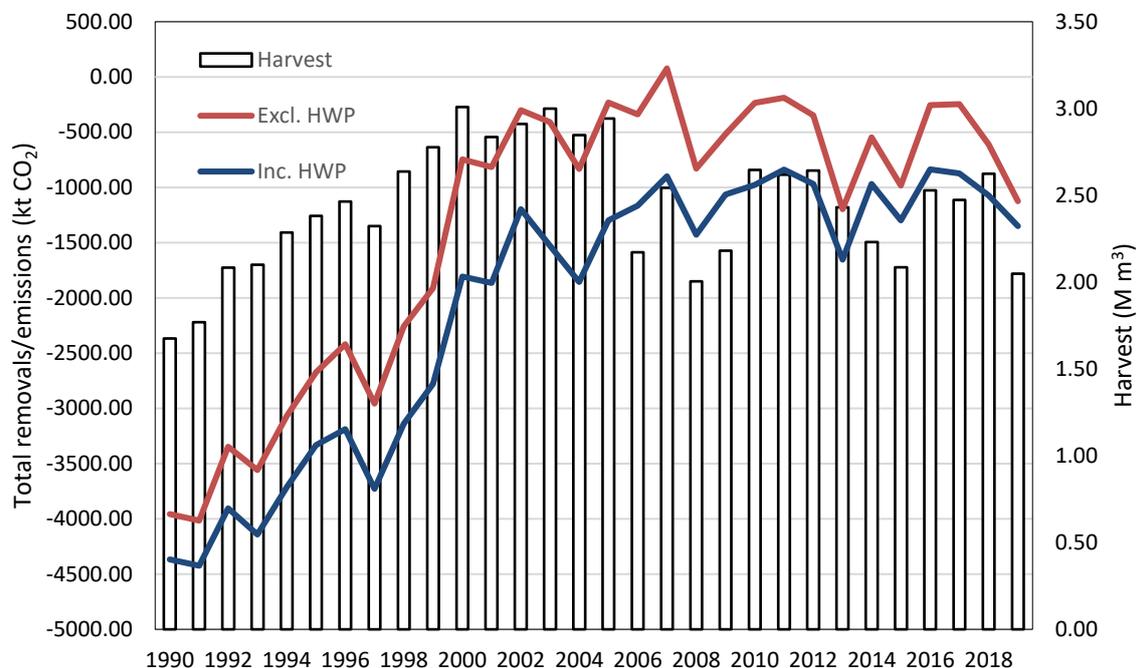
The FORCARB model (described in Annex 3.4.C) was used to calculate carbon stock changes in biomass and DOM pools in forest land remaining forest land for 1990 to 2005. For the time series adjustment of derived C pools, the FORCARB model was run until 2012 and the 1990 to 2006 time series data was re-scaled using the CBM 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 (pre-1990 forests) has decreased from 465.2 kHa in 1990 to 446.0 kHa in 2019 due to deforestation (Table 6.6 and CRF 4A.1). These forest areas are dominated by plantation forestry, predominantly conifer species such as Sitka spruce and lodgepole pine, which make up 58.7 % 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). 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 forest category 4.A.1 and related HWP are driven largely by 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 1.6 Mm<sup>3</sup> in 1990 to over 2.9 Mm<sup>3</sup> by 2005 resulted in a decrease in net removals from 3956 Gg CO<sub>2</sub> per year in 1990 to 232 Gg CO<sub>2</sub> per year in 2005 (Figure 6.11 and Table 6.6). The level of harvest has slightly declined since 2007 due increased harvest in lands converted to forest land and the economic recession in 2008/9. It is also evident that a decline in

biomass gains 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 slightly reversed trends over the period 2006 to 2012 suggests an increase in mean age, which is consistent with a higher proportion of harvest coming from thinned stands (Black et al., 2012).



**Figure 6.11 Time series of carbon stock changes (including and excluding Harvested Wood Products) and annual harvest rates for category 4.A.1.**

### 6.3.4.1 Forest remaining forest land carbon stock changes

Net biomass, dead organic matter, soil C and CO<sub>2</sub> emissions/removals for the time series 1990-2019 for forest land remaining forest land (i.e. all forest established before 1990 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 2019 time series, the CFS CBM model estimates are reported.

**Table 6.6 Time series data for category 4.A.1**

Year	Area (kHa)		CSC (Gg C)						Net CO <sub>2</sub> Gg	Harvests <sup>1</sup> (M m <sup>3</sup> )
	Total	Organic	Living biomass			DOM <sup>2</sup>	Mineral Soils	Organic soils	CO <sub>2</sub> Total	EUROSTAT
			Gain	Loss	Net					
1990	465.26	277.87	3134.81	-1947.80	1187.02	52.21	-8.78	-151.44	-3956.33	1.68
1995	464.84	277.85	3249.29	-2404.55	844.74	43.41	-8.78	-150.62	-2672.07	2.38
2000	462.65	277.62	3298.99	-2897.75	401.24	-40.92	-8.74	-147.97	-746.61	3.01
2005	458.37	276.47	3301.00	-3012.64	288.36	-72.89	-8.65	-143.40	-232.51	2.94
2010	451.17	272.47	3357.88	-3131.49	226.39	-20.24	-6.99	-135.55	-233.26	2.65
2011	449.57	272.07	3363.44	-3157.73	205.71	-14.93	-6.57	-133.24	-186.87	2.62
2012	449.57	272.07	3380.34	-3139.57	240.77	-9.06	-5.79	-131.32	-346.89	2.64
2013	447.97	271.67	3395.95	-2757.51	638.44	-174.90	-7.60	-129.28	-1197.74	2.43
2014	447.97	271.67	3411.44	-3110.54	300.91	-19.67	-5.34	-126.98	-546.06	2.23
2015	447.17	270.87	3427.40	-2945.83	481.57	-84.31	-6.08	-122.81	-984.03	2.08
2016	446.37	270.47	3493.70	-3237.27	256.43	-57.58	-7.22	-122.34	-254.06	2.53
2017	446.24	270.41	3471.51	-3240.46	231.05	-35.49	-6.83	-121.84	-245.28	2.47
2018	446.14	270.41	3485.92	-3199.95	285.97	10.11	-8.37	-121.49	-609.47	2.63
2019	446.05	270.41	3455.06	-2932.39	522.67	-84.91	-9.72	-121.01	-1125.80	2.05

<sup>1</sup> Note: the harvest volumes are calculated as total harvest (FAO/EUROSTAT) minus post-1990 forest harvests minus the deforestation harvest.

<sup>2</sup>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 CFS-CBM modelling framework (Section 6.3.3.1 and Annex 3.4.B). These estimates exclude emissions from historical (1970-1989) afforestation of soils because these are demonstrated not to be significant (see section 6.3.5.1.1)

### 6.3.4.3 Drainage of organic soils

A large proportion of forest land remaining land (FL-FL) 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 2017 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 FL-FL (pre-1990 forests younger than 50 years) and L-FL (post-1990 forest) 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, 2017), since these are not planted or drained and emissions are

assumed to be zero. Forests older than 50 years old are assumed to be in steady state regardless of the soil type (Table 6.7).

On site emissions from peat soils due to drainage given by equation 6.3.2 is based on published data (Byrne and Farrell, 2005), 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 ( $A_i$ ) 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 0.59 t C ha<sup>-1</sup>.yr<sup>-1</sup> for the first 50 years following afforestation and is zero thereafter. 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

$$SD = \frac{\text{depth}(cm)}{30cm} \quad (\text{eq 6.3.4})$$

Ireland uses a country specific emission factor for organic forest soils (Byrne and Farrell, 2005). This is calculated as the mean on site organic soil EF of 0.59 t C ha<sup>-1</sup>.yr<sup>-1</sup> over the first rotation (assumed to be 50 years for peatland forests). Byrne and Farrell (2005) demonstrate that organic soils are not a source following successive rotations. These EFs are based on total soil respiration measurements, which include respiratory inputs from autotrophic respiration and litter decomposition. Therefore, these EFs are considered an overestimate since autotrophic respiration is accounted for in NPP estimates (i.e. below ground biomass growth) and litter decomposition is accounted for in the litter pool. Other studies suggest that autotrophic respiration accounts for up to 40 per cent of total soils respiration (Siaz et al., 2007). There is one national research publication on the partitioning of soil respiration between heterotrophic and autotrophic processes in peatland soils (Jovani-Sancho et al., 2018). However, this study did not estimate partitioning in non-forested peat soils to derive an emission factor specifically related to drainage of organic soils. Therefore, a conservative EF is applied until new research information becomes available. While the EF rate is lower compared to the default rate of 0.68 t C ha<sup>-1</sup> year<sup>-1</sup> for organic soils in cold wet temperate conditions and the region (Table 4.6 in Chapter 4 Volume 4 of the 2006 IPCC guidelines) specific value used in previous submissions of 4 t C ha<sup>-1</sup> year<sup>-1</sup>, the transition period is much longer than the previously used default periods. The accumulated default emission of 29.5 t C ha<sup>-1</sup> over 50 years is now more than 2-fold higher than the previously used methods (i.e. 13.6 t C ha<sup>-1</sup> to Tier 1 and 14 t C ha<sup>-1</sup> for previously used tier 2, Hargreaves et al, 2003, Duffy et al., 2011). A country specific transition period of fifty years is therefore considered appropriate to afforested areas on organic soils (See Byrne and Farrell, 2005). This EF is applied to all first rotation forests going back to 1940 assuming that 60 per cent of afforestation occurred on peat soils before 1990 (Black et al., 2009a). All forest lands planted before 1940 are assumed to be second rotation crops or are older than 50 years by 1990 and organic soils emissions from these forests are deemed to be zero (Byrne and Farrell, 2005).

An additional off-site emission factor of 0.31 t C ha<sup>-1</sup> year<sup>-1</sup> 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 emissions 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 siers for forest land remaining forests (CRF 4.A.1)

Year	Total Area <sup>1</sup>	Mineral	Organic	Open area <sup>2</sup>	Drained productive area		Sites < 50 years old (Drained productive area)		On-site emissions		Off-site DOC emissions		Total
					Organic <sup>3</sup>	Organo-mineral <sup>3</sup>	Organic <sup>4</sup>	Organo-mineral <sup>4</sup>	Organic <sup>5</sup>	Organo-mineral <sup>5</sup>	Organic <sup>6</sup>	Organo-mineral <sup>6</sup>	
					(kHa)				Gg C				Gg CO <sub>2</sub>
1990	465.3	187.4	277.9	41.4	221.5	31.8	107.6	28.8	-63.5	-9.4	-68.7	-9.9	555.3
1995	464.8	187.0	277.8	41.5	221.3	31.8	106.5	28.5	-62.8	-9.3	-68.6	-9.9	552.3
2000	462.7	185.0	277.6	41.3	220.2	31.7	103.0	27.8	-60.8	-9.1	-68.3	-9.8	542.5
2005	458.4	181.9	276.5	42.0	217.7	31.3	97.5	26.6	-57.5	-8.7	-67.5	-9.7	525.8
2010	451.2	178.7	272.5	43.0	213.4	30.7	88.5	23.2	-52.2	-7.7	-66.1	-9.5	497.0
2011	449.6	177.5	272.1	43.2	212.4	30.5	85.6	22.3	-50.5	-7.4	-65.9	-9.5	488.6
2012	449.6	177.5	272.1	43.2	212.4	30.5	82.8	21.4	-48.9	-7.1	-65.9	-9.5	481.5
2013	448.0	176.3	271.7	43.6	212.2	30.5	80.6	21.1	-47.5	-7.0	-65.8	-9.5	475.9
2014	448.0	176.3	271.7	43.6	212.1	30.5	77.6	19.6	-45.8	-6.4	-65.8	-9.5	467.2
2015	447.2	176.3	270.9	43.6	212.0	30.5	71.5	17.9	-42.2	-6.1	-65.7	-9.4	452.4
2016	446.4	175.9	270.5	43.6	212.0	30.5	71.5	17.9	-42.2	-6.1	-65.7	-9.4	452.4
2017	446.2	175.8	270.4	43.6	212.0	30.5	71.5	17.9	-42.2	-6.1	-65.7	-9.4	452.4
2018	446.1	175.7	270.4	43.6	210.4	30.2	69.5	17.3	-41.0	-5.9	-65.2	-9.4	445.5
2019	446.0	175.6	270.4	43.6	210.4	30.2	68.7	17.2	-40.5	-5.9	-65.2	-9.4	443.7

<sup>1</sup>Total area includes open areas

<sup>2</sup>Open area within forest areas (roads, extraction routes, biodiversity etc).

<sup>3</sup>Area of drained organic (org.) and organo-mineral soils based in NFI 2006 to 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).

<sup>4</sup>No emissions from drained organic soils on sites older than 50 years old, (Data source NFI)

<sup>5</sup>On-site emissions are calculated using Eq 6.3.2 and 6.2.3 and areas of productive and drained organic and organo-mineral soils less than 50 years old.

<sup>6</sup>Off-site emissions are calculated using an 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 Wetland Supplement.

#### 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 CFS CBM 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 CFS CBM 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 wild fires;
- 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<sub>2</sub> eq ha<sup>-1</sup> compared to an IEF of 39 t CO<sub>2</sub> eq ha<sup>-1</sup> 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<sup>-1</sup>, equivalent to 149,450 kg biomass d.wt ha<sup>-1</sup>. The average C stock for litter and deadwood is estimated to be 14.1 t C ha<sup>-1</sup>, equivalent to 28,263 kg biomass d.wt ha<sup>-1</sup>. 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<sup>-1</sup>, equivalent to 90,526 kg biomass d.wt ha<sup>-1</sup>. The average C stock for litter and deadwood is estimated to be 6.5 t C ha<sup>-1</sup>, equivalent to 12,959 kg biomass d.wt ha<sup>-1</sup>;
- 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.

#### 6.3.4.5 Direct and indirect emissions of N<sub>2</sub>O from organic and inorganic fertilisers

Ireland does not report separately the emissions of N<sub>2</sub>O 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<sub>2</sub>O and CH<sub>4</sub> from drainage and rewetted organic soils

##### a) N<sub>2</sub>O from drained organic soils

Tier 1 estimates of N<sub>2</sub>O emissions due to the drainage of organic soils in forest lands were first reported in 2009 (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 rich organic and poor organic soils over the time-series, based on planting year, soil type and cultivation 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). Soils were assumed not to be drained if there was no cultivation, no drainage or if pit planting was employed during forest establishment as specified in the NFI database. Some upland previously degraded peatland sites are not drained prior to afforestation. Some of these lands were drained in the 1970s due to the development of a national arterial drainage scheme at the time before they were afforested. In addition, cutaway peats were drained before afforestation occurred. 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<sub>2</sub>O 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<sub>2</sub>O-N ha<sup>-1</sup> yr<sup>-1</sup>) 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<sub>2</sub>O ha<sup>-1</sup> yr<sup>-1</sup>. Therefore, we have adopted to use the default EF for nutrient rich organic soils (2.8 N<sub>2</sub>O-N ha<sup>-1</sup> yr<sup>-1</sup>) and a country specific EF of 0.7 kg N<sub>2</sub>O ha<sup>-1</sup> yr<sup>-1</sup> for nutrient poor organic soils, since this is more reflective of national circumstances (Table 6.9). The decline in N<sub>2</sub>O 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).

Table 6.8 Area statistics and emission profiles over the time series 1990 to 2019 for wild fires in categories 4.A.1 and 4.A.2 and reported in CRF Table 4(V)

	Pre-1990							Post 1990							Total CRF4V							
	Fire area Ha	Prop area burned	Biom&DOM Mg	CO <sub>2</sub> Gg	CH <sub>4</sub>	N <sub>2</sub> O	GgCO <sub>2</sub> eq	Prop area burned	Biom&DOM Mg	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O	GgCO <sub>2</sub> eq	GgCO <sub>2</sub> eq								
																Gg						
1990	389.00	1.00	69130.75	101.39	0.44	2.58E-03	113.22	NO	NO	NO	NO	NO	NO	113.22								
1995	508.00	1.00	90278.72	132.41	0.58	3.37E-03	147.86	NO	NO	NO	NO	NO	NO	147.86								
2000	334.00	1.00	59356.48	87.06	0.38	2.22E-03	97.21	NO	NO	NO	NO	NO	NO	97.21								
2005	200.00	1.00	35542.80	52.13	0.23	1.33E-03	58.21	NO	NO	NO	NO	NO	NO	58.21								
2010	1013.09	0.63	113040.74	165.79	0.72	4.22E-03	185.14	0.37	39014.69	57.22	0.25	1.46E-03	63.90	249.04								
2011	375.55	0.63	42047.05	61.67	0.27	1.57E-03	68.86	0.37	14379.80	21.09	0.09	5.37E-04	23.55	92.42								
2012	95.00	0.63	10636.18	15.60	0.07	3.97E-04	17.42	0.37	3637.50	5.34	0.02	1.36E-04	5.96	23.38								
2013	408.36	0.61	44268.20	64.93	0.28	1.65E-03	72.50	0.39	16480.97	24.17	0.11	6.15E-04	26.99	99.49								
2014	328.47	0.60	34766.62	50.99	0.22	1.30E-03	56.94	0.40	13747.16	20.16	0.09	5.13E-04	22.51	79.46								
2015	184.17	0.59	19340.62	28.37	0.12	7.22E-04	31.68	0.41	7796.27	11.43	0.05	2.91E-04	12.77	44.44								
2016	37.41	0.59	3896079.07	5.71	0.02	1.45E-04	6.38	0.42	1609578.59	2.36	0.01	6.01E-05	2.60	8.98								
2017	1960.00	0.58	202022922.59	296.30	1.29	7.54E-03	330.87	0.42	85190337.15	124.95	0.55	3.18E-03	137.38	468.25								
2018	500.00	0.58	51268491.47	75.19	0.33	1.91E-03	83.97	0.42	21888270.24	32.10	0.14	8.17E-04	35.30	119.27								
2019	57.33	0.57	5851368.49	8.58	0.04	2.18E-04	9.58	0.43	2525476.20	3.70	0.02	9.43E-05	4.07	13.66								

## b) CH<sub>4</sub> from drained land and ditches

Estimation of CH<sub>4</sub> emissions from drained organic soils and forest drain ditches are based on the same activity data used for the determination of N<sub>2</sub>O 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<sub>CH<sub>4</sub>land</sub> (2.5 kg CH<sub>4</sub> ha<sup>-1</sup> yr<sup>-1</sup>, Table 2.3 of the Wetland supplement 2013) and EF<sub>CH<sub>4</sub>ditch</sub> (217 kg CH<sub>4</sub> ha<sup>-1</sup> yr<sup>-1</sup>, Table 2.4 of the Wetland supplement 2013) are used. The fraction of the total areas which is occupied by ditches (Frac<sub>Ditch</sub>) 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<sub>Ditch</sub> of 0.0249. This derived country specific Frac<sub>Ditch</sub> 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<sub>Ditch</sub> of 0.00375.

The decline in CH<sub>4</sub> 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.

### 6.3.4.7 N<sub>2</sub>O emissions from mineral soils as a result of land use change (F<sub>SOM</sub>)

Emissions of N<sub>2</sub>O from mineral soils are based on mineralisation rates due to loss of organic C from mineral soils (Eq 11.8 Chapter 11, Vol 4 of the 2006 IPCC guidelines). We report that management and afforestation of mineral soils results in no significant change in soil organic carbon (see section 6.3.3.1). Therefore, emissions due to mineralisation of forest soil do not occur (NO).

*Table 6.9 The activity data and N<sub>2</sub>O and CH<sub>4</sub> emissions from drainage of forest land remaining forest land*

Year	Area (kHa)				kt N <sub>2</sub> O			kt CH <sub>4</sub>		
	Total Area	Open area	Organic N-poor	Organic N-rich	Organic N-poor	Organic N-rich	Total N <sub>2</sub> O	Drained lands	Ditches	Total CH <sub>4</sub>
1990	465.3	41.4	221.5	31.8	0.16	0.14	0.30	0.62	1.22	1.84
1995	464.8	41.5	221.3	31.8	0.15	0.14	0.29	0.62	1.22	1.84
2000	461.8	41.5	219.7	31.6	0.15	0.14	0.29	0.61	1.21	1.83
2005	458.4	42.0	217.7	31.3	0.15	0.14	0.29	0.61	1.20	1.81
2010	451.2	43.0	213.4	30.7	0.15	0.13	0.28	0.60	1.18	1.77
2011	449.6	43.2	212.4	30.5	0.15	0.13	0.28	0.59	1.17	1.77
2012	449.6	43.2	212.4	30.5	0.15	0.13	0.28	0.59	1.17	1.77
2013	448.0	43.6	211.4	30.4	0.15	0.13	0.28	0.59	1.17	1.76
2014	448.0	43.6	211.4	30.4	0.15	0.13	0.28	0.59	1.17	1.76
2015	447.2	43.6	211.0	30.3	0.15	0.13	0.28	0.59	1.16	1.75
2016	446.4	43.6	210.6	30.3	0.15	0.13	0.28	0.59	1.16	1.75
2017	446.2	43.6	210.5	30.3	0.15	0.13	0.28	0.59	1.16	1.75
2018	446.1	43.6	210.4	30.2	0.15	0.13	0.28	0.59	1.16	1.75
2019	446.0	43.6	210.4	30.2	0.15	0.13	0.28	0.59	1.16	1.75

#### 6.3.4.8 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 for the Convention reporting and Article 3.3 activities described in this chapter 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<sub>2</sub> 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).

$$U_{\text{total}} = \sqrt{U_1^2 + U_2^2 + U_3^2 + U_n^2} \quad (\text{eq 6.3.5})$$

Where:

$U_{\text{total}}$  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):

$$U_{\text{total}} = \frac{\sqrt{(U_1 \times x_1)^2 + (U_2 \times x_2)^2 + (U_n \times x_n)^2}}{|x_1 + x_2 + x_n|} \quad (\text{eq 6.3.6})$$

Where:

$U_{\text{total}}$  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 uncertainty of estimates for forest land remaining forest land was 47.9 per cent in 2019. Emission/removals values closer to zero makes the percentage uncertainty higher when the absolute uncertainty is much lower, when compared to other years.

**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 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	90	Assume same as Tier 1 (Table 2.3,2.3.1 Ch2, 2006 IPCC Guidelines)
F	Fire C stocks	fire	15	95 % confidence interval for biomass stocks (NFI)
G	Areas burned	fire area	50	Expert Judgement, guess
H	N <sub>2</sub> O	N <sub>2</sub> O and CH <sub>4</sub> , area	12.3	Conf. interval of NFI analysis
I	N <sub>2</sub> O EF	N <sub>2</sub> O emissions drained	119	Wetland supplement Table 2.5 and Yamulki et al., 2013
J	CH <sub>4</sub> LAND EF	CH <sub>4</sub> emissions drainage	87.2	Wetland supplement Table 2.4
K	CH <sub>4</sub> DITCH EF	CH <sub>4</sub> 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	15.8	A+B
DOM	DOM	CBM	22.2	B+C+D
SO	Soils	Section 6.3.4.3	100.0	B+E+L
Fires	Fire	Section 6.3.4.4	52.2	F+G
N <sub>2</sub> O	Drainage of soils	2006 IPCC Guidelines	119.6	H+I
CH <sub>4</sub>	Drainage of soils	2006 IPCC Guidelines	153.7	H+J+K

**Table 6.12 Uncertainty analysis for forest land remaining forest land since 1990<sup>6</sup>**

Year	Category	Year emission/reductions (Gg CO2 eq)	Base year emission/reductions (Gg CO2eq)	Combined uncertainty in year (±%)	Contribution to total variance in year (fraction)	Mean trend in year in relation to base-year (% mean trend)
<b>1990</b>	CRF 4A.1	-3956.3	-3956.3	22.2	0.8	na
	CRF 4 (II)	134.0	134.0	78.5	0.1	na
	CRF4(V)	112.4	112.4	59.4	0.1	na
	<b>Total</b>	<b>-3709.9</b>	<b>-3709.9</b>	<b>23.6</b>	<b>1.0</b>	<b>na</b>
<b>2000</b>	CRF 4A.1	-746.6	-3956.3	75.9	0.8	-81.1
	CRF 4 (II)	133.2	134.0	78.5	0.1	-0.6
	CRF4(V)	92.0	112.4	59.4	0.1	-18.1
	<b>Total</b>	<b>-521.3</b>	<b>-3709.9</b>	<b>108.4</b>	<b>1.0</b>	<b>-85.9</b>
<b>2005</b>	CRF 4A.1	-232.5	-3956.3	209.9	0.8	-94.1
	CRF 4 (II)	131.7	131.7	78.5	0.2	0.0
	CRF4(V)	33.5	112.4	59.4	0.0	-70.2
	<b>Total</b>	<b>-67.4</b>	<b>-3712.2</b>	<b>603.1</b>	<b>1.0</b>	<b>-98.2</b>
<b>2010</b>	CRF 4A.1	-233.3	-3956.3	198.6	0.6	-94.1
	CRF 4 (II)	129.1	134.0	78.5	0.1	-3.7
	CRF4(V)	269.7	112.4	59.4	0.2	139.9
	<b>Total</b>	<b>165.5</b>	<b>-3709.9</b>	<b>335.0</b>	<b>1.0</b>	<b>-104.5</b>
<b>2015</b>	CRF 4A.1	-984.0	-3956.3	53.1	0.8	-75.1
	CRF 4 (II)	127.6	134.0	78.5	0.2	-4.8
	CRF4(V)	31.7	112.4	59.4	0.0	-71.8
	<b>Total</b>	<b>-824.7</b>	<b>-3709.9</b>	<b>64.0</b>	<b>1.0</b>	<b>-77.8</b>
<b>2016</b>	CRF 4A.1	-254.1	-3956.3	169.2	0.8	-93.6
	CRF 4 (II)	127.4	134.0	78.5	0.2	-5.0
	CRF4(V)	6.4	112.4	59.4	0.0	-94.3
	<b>Total</b>	<b>-120.3</b>	<b>-3709.9</b>	<b>353.2</b>	<b>1.0</b>	<b>-96.8</b>
<b>2017</b>	CRF 4A.1	-245.3	-3956.3	172.8	0.6	-93.8
	CRF 4 (II)	127.3	134.0	78.5	0.1	-5.0
	CRF4(V)	330.9	112.4	59.4	0.3	194.3
	<b>Total</b>	<b>212.9</b>	<b>-3709.9</b>	<b>226.6</b>	<b>1.0</b>	<b>-105.7</b>
<b>2018</b>	CRF 4A.1	-609.5	-3956.3	74.2	0.8	-84.6
	CRF 4 (II)	127.3	134.0	78.5	0.2	-5.0
	CRF4(V)	84.0	112.4	59.4	0.1	-25.3
	<b>Total</b>	<b>-398.2</b>	<b>-3709.9</b>	<b>117.4</b>	<b>1.0</b>	<b>-89.3</b>
<b>2019</b>	CRF 4A.1	-1125.8	-3956.3	46.6	0.8	-71.5
	CRF 4 (II)	127.3	134.0	78.5	0.2	-5.0
	CRF4(V)	9.6	112.4	59.4	0.0	-91.5
	<b>Total</b>	<b>-988.9</b>	<b>-3709.9</b>	<b>47.9</b>	<b>1.0</b>	<b>-73.3</b>

<sup>6</sup> Note that uncertainties for category 4A(II) and 4A(V) include land in the forest remaining forest land category

### 6.3.4.9 Recalculations for forest land remaining forest land (CRF 4.A.1)

The area of forest fires was adjusted for the years 1990-2013 and for 2018 and 2019 based on new forest fire statistics. This recalculation resulted higher average fire emissions over the entire time series (ca. 17 kt CO<sub>2</sub>eq.) but this was higher in some years (e.g. in an increase emission of 211 kt CO<sub>2</sub> eq. in 2011) and lower emission from forest fires in other years (e.g. -25 kt CO<sub>2</sub> eq. in 2002).

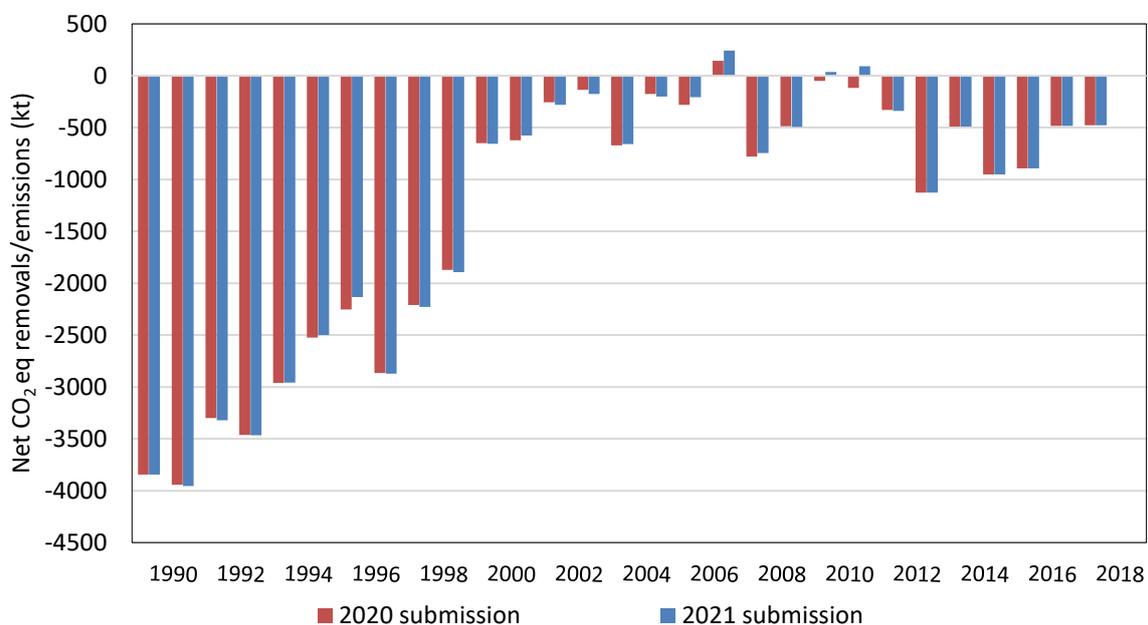


Figure 6.12 Comparison of category 4.A.1 emissions/removals for 2020 and 2021 submissions

### 6.3.5 Land converted to forest land (CRF 4.A.2)

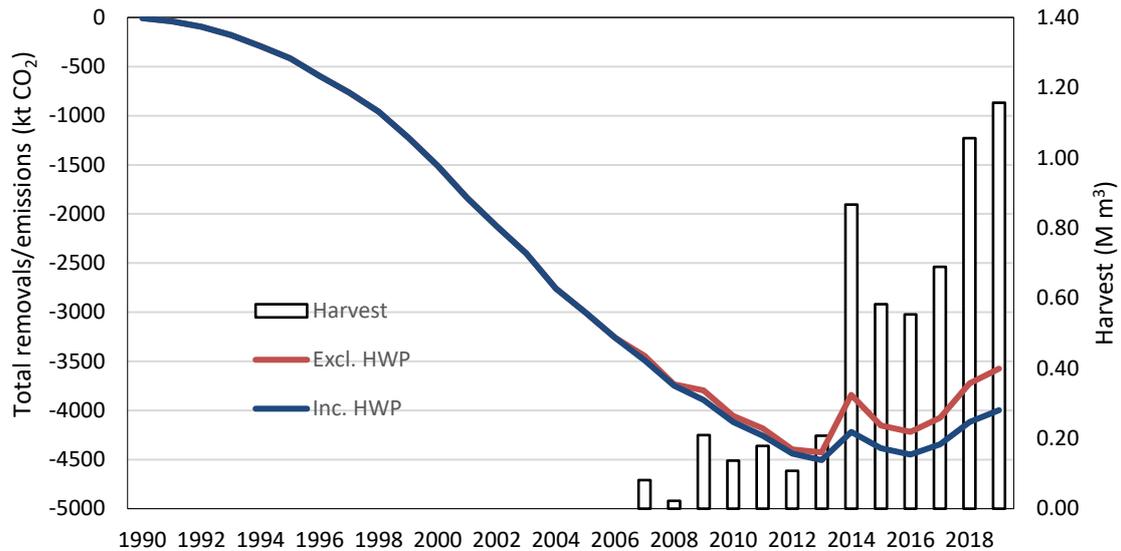
Forest cover has increased from less than 1% in 1900 to over 11% by 2019. Over 330,600 ha has been afforested in Ireland since 1990. The majority of the land afforested has been privately-owned agricultural land. Afforestation continues to be incentivised by the State through establishment grants and 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, but current annual afforestation rates of wetlands have declined by 96% 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 55.9 per cent of afforested land since 1990. The increase in removals by the post 1990 forest (category 4.A.2) is due to an increase in forests area and productivity as new established forests mature. Stabilisation and a subsequent decrease in removals since 2007 onward is due to thinning harvests in productive forests at age 17 years old and older and a reduction in annual afforestation rates (Figure 6.13, and Table 6.13). In 2019, timber harvests from afforested land represents ca 36 percent of the total annual harvest.

Table 6.13 shows the net biomass, dead organic matter, soil C and net CO<sub>2</sub> emissions/removals for the time series 1990-2019 for lands converted to forest land (i.e. all forest established after 1990 reported in category 4.A.2). The CFS CBM model is used to estimate CSCs for the data time series. The methods used and values reported in category 4.A.2 are now fully consistent and comparable with KP emission/removals reported for AR activities, for the years 2008-2019 (see chapter 11)..

Table 6.13 Time series for forest category 4.A.2

Year	Area (kHa)		CSC (Gg C)						Net CO <sub>2</sub> Gg Total	Harvests <sup>1</sup> (M m <sup>3</sup> )	
	Total	Organic	Living biomass			DOM	Mineral Soils	Organic soils		Eurostat	CBM model
			Gain	Loss	Net	Net	Net	Net			
1990	15.82	9.92	10.26	-0.82	9.44	0.47	-0.87	-7.19	-6.77	NO	NO
1995	110.83	65.52	188.57	-38.50	150.07	16.34	-4.47	-48.38	-416.37	NO	NO
2000	184.54	106.88	596.24	-161.23	435.01	55.53	-2.56	-76.02	-1510.52	NO	NO
2005	243.99	141.21	1178.59	-372.05	806.54	110.17	3.92	-101.56	-3003.25	NO	NO
2010	280.41	156.04	1725.62	-700.26	1025.36	186.40	7.44	-112.92	-4056.34	0.14	0.14
2011	287.06	159.07	1819.00	-772.48	1046.51	202.22	8.09	-116.20	-4182.29	0.18	0.18
2012	292.91	161.73	1903.30	-777.85	1125.45	184.42	8.12	-118.68	-4397.45	0.11	0.11
2013	299.17	164.50	1988.47	-894.95	1093.52	224.48	9.07	-119.82	-4426.61	0.21	0.21
2014	304.92	167.69	2068.36	-1281.27	787.09	371.66	11.59	-122.26	-3842.94	0.88	0.87
2015	311.22	171.30	2131.22	-1160.52	970.70	276.85	10.63	-125.27	-4154.01	0.59	0.58
2016	317.72	175.04	2188.24	-1181.04	1007.19	259.98	11.07	-127.84	-4218.14	0.56	0.55
2017	323.15	178.23	2239.32	-1297.70	941.62	289.22	12.10	-131.78	-4074.23	0.70	0.69
2018	327.09	180.54	2291.37	-1511.72	779.64	356.85	14.00	-134.50	-3725.30	1.05	1.06
2019	330.60	182.79	2332.37	-1561.02	771.35	326.01	14.34	-136.92	-3574.20	1.16	1.16

<sup>1</sup> The harvest volumes show a comparison of the EUROSTAT and modelled harvest using FORCARB and the CBM model



**Figure 6.13 Timeseries of carbon stock changes (including and excluding Harvested Wood Products) and annual harvest rate for category 4.A.2.**

### 6.3.5.1 Mineral Soils

Grassland converted to forest land (L-FL since 1990) 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 CFS CBM 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).

#### Demonstration that emissions from historic transitions are not significant

Historic transitions and associated emissions from mineral soils due to afforestation prior to 1990 are not included in the land converted to forest land category (CRF4.A2.). For the forest land remaining forest land category (4A1) CBM does not consider previous C stocks from land use when FL-FL simulations are run. The DOM pool is equilibrated to represent the initial DOM pools before simulations are run. Emissions from mineral soils for L-FL transitions prior to 1990 for the period 1970-1990 have been demonstrated not to be significant and are not reported in accordance with paragraph 37 of 24/CMP19.

- 1) CSCs in mineral soils following afforestation are a net emission only for a maximum 5 to 10 years following afforestation (Table 6.13).
- 2) Based on Table 6.13 the maximum implied emission factor (IEF) over the period 1990 to 2019 is  $0.16 \text{ t C ha}^{-1}$ . This is assumed to be a conservative over estimate and the maximum expected emission because C has not accumulated in this pool due to transfers from biomass turnover, deadwood or litter.
- 3) The area of afforested mineral soils for the period 1970-1989 is estimated to be 40.2 of the total 165.7 hka (Table 6.14). Since emissions only occur in the first 10 years after afforestation the cumulative mineral soil area with emissions would vary from

3.2 kHa to 34.9 kHa over inventory years 1990-2009 (column 3 (mineral soils cumulative area, Table 6.14).

- 4) Using the maximum emission factor of 0.16 t C ha<sup>-1</sup>, the maximum SOC emission from historic transitions are 1.91 to 20.5 kt CO<sub>2</sub> per year (Table 6.14), which is below the threshold of 0.05 % of total national emissions and less than 500 kt CO<sub>2</sub> eq for all years.

**Table 6.14: Estimation of emissions from mineral soils in historic transitions (1970-1989) in the FL-FL category showing that emissions are not significant**

Year	Afforestation	Mineral soils	Year transition	Max emission	National emission (incl LULUCF)	% of total
	kha/yr	cum kha	to FL-FL	Gg CO <sub>2</sub>	Gg CO <sub>2</sub>	
1970	8.09	3.25	1990	1.91	59531.40	0.003
1971	8.39	6.62	1991	3.88	60185.15	0.006
1972	9.38	10.39	1992	6.10	59886.68	0.010
1973	9.70	14.29	1993	8.38	60342.60	0.014
1974	9.33	18.04	1994	10.58	61923.85	0.017
1975	9.18	21.73	1995	12.75	64431.41	0.020
1976	8.56	25.17	1996	14.77	66196.02	0.022
1977	8.33	28.52	1997	16.73	66958.62	0.025
1978	8.25	31.84	1998	18.68	69312.52	0.027
1979	7.72	34.94	1999	20.50	70689.54	0.029
1980	6.19	34.18	2000	20.05	74343.38	0.027
1981	6.37	33.37	2001	19.58	77683.21	0.025
1982	6.51	32.22	2002	18.90	75457.89	0.025
1983	6.03	30.74	2003	18.04	76166.04	0.024
1984	5.67	29.27	2004	17.17	73855.22	0.023
1985	5.39	27.75	2005	16.28	76248.52	0.021
1986	7.25	27.22	2006	15.97	76031.09	0.021
1987	8.61	27.33	2007	16.03	74214.52	0.022
1988	11.71	28.72	2008	16.85	72976.97	0.023
1989	15.13	31.70	2009	18.60	66926.97	0.028

### 6.3.5.2 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 since 1990 (section 6.3.4.3). However, there are no forests older than 50 years-old in the categories reported in 4.A.2, so this was not considered (Table 6.15). 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 6.15 Area (in kha) and emissions from different organic soils types and over the timeseries for land converted to forests (CRF 4.A.2)

Year	Total Area <sup>1</sup>	Mineral	Org.	Open area <sup>2</sup>	Drained productive area		On-site emissions		Off-site DOC emissions		Total
					Org. <sup>3</sup>	Org.-mineral <sup>3</sup>	Org. <sup>4</sup>	Org.-mineral <sup>4</sup>	Org. <sup>6</sup>	Org.-mineral <sup>6</sup>	
				(kHa)			Gg C				Gg CO <sub>2</sub>
1990	15.8	5.9	9.9	1.9	6.6	2.1	-3.9	-0.6	-2.0	-0.7	-26.4
1995	110.8	45.3	65.5	13.2	43.0	16.0	-25.4	-4.7	-13.3	-5.0	-177.4
2000	200.0	83.2	116.8	23.8	72.4	28.9	-42.7	-8.5	-22.4	-9.0	-303.0
2005	244.0	102.8	141.2	29.0	88.6	36.0	-52.3	-10.6	-27.5	-11.2	-372.4
2010	280.4	124.4	156.0	35.6	94.3	47.7	-55.6	-13.3	-29.2	-14.8	-414.1
2011	287.1	128.0	159.1	36.6	96.1	49.1	-56.7	-14.5	-29.8	-15.2	-426.1
2012	292.9	131.2	161.7	37.6	97.8	50.2	-57.7	-15.1	-30.3	-15.6	-435.2
2013	299.2	134.7	164.5	38.6	98.3	50.5	-58.0	-15.7	-30.5	-15.7	-439.3
2014	304.9	137.2	167.7	39.5	101.0	50.5	-59.6	-15.7	-31.3	-15.7	-448.3
2015	311.2	139.9	171.3	40.4	103.1	52.4	-60.8	-16.3	-32.0	-16.3	-459.3
2016	317.7	142.7	175.0	41.4	105.3	53.4	-62.1	-16.5	-32.6	-16.5	-468.8
2017	323.2	144.9	178.2	42.0	108.5	55.0	-64.0	-17.1	-33.6	-17.1	-483.2
2018	327.1	146.6	180.5	42.3	110.7	56.2	-65.3	-17.4	-34.3	-17.4	-493.2
2019	330.6	147.8	182.8	42.7	112.7	57.2	-66.5	-17.7	-34.9	-17.7	-502.0

<sup>1</sup>Total area includes open areas

<sup>2</sup>Open area within forest areas (roads, extraction routes, biodiversity etc).

<sup>3</sup>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).

<sup>4</sup>On-site emissions are calculated using Eq 6.3.23 and 6.2.24 and areas of productive and drained organic and organo-mineral soils.

<sup>5</sup>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.

### 6.3.5.3 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). Fires are only reported from 2008 onwards because 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 wild fires (Table 6.8). Fires on land afforested since 1990 represent 36 per cent to 43 per cent of the total forest area over the period 2008 to 2019 (Table 6.8).

### 6.3.5.4 Emissions of N<sub>2</sub>O from nitrogen fertiliser application

Ireland does not report separately the emissions of N<sub>2</sub>O 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<sub>2</sub>O emissions from nitrogen fertiliser application are reported under agriculture. The notation key IE is therefore used in CRF Table 4(I).

### 6.3.5.5 Emissions of N<sub>2</sub>O and CH<sub>4</sub> from drainage and rewetted organic soils

The methodology for estimating N<sub>2</sub>O and CH<sub>4</sub> emissions from drainage of organic soils are discussed section 6.3.4.6.

#### **a) N<sub>2</sub>O from drained organic soils**

The increase in N<sub>2</sub>O 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 6.16).

#### **b) CH<sub>4</sub> from drained lands and ditches**

The increase in CH<sub>4</sub> 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 6.16 The area, activity data and N<sub>2</sub>O and CH<sub>4</sub> emissions from the drainage of land converted to forest land

Year	Area (kHa)				kt N <sub>2</sub> O			kt CH <sub>4</sub>		
	Total Area	Open area	Organic N-poor	Organic N-rich	Organic N-poor	Organic N-rich	Total N <sub>2</sub> O	Drained lands	Ditches	Total CH <sub>4</sub>
1990	15.8	1.9	6.6	2.1	0.00	0.01	<b>0.01</b>	0.02	0.04	<b>0.06</b>
1995	110.8	13.2	43.0	16.0	0.03	0.07	<b>0.10</b>	0.14	0.25	<b>0.39</b>
2000	184.5	22.0	67.2	25.7	0.05	0.11	<b>0.16</b>	0.23	0.38	<b>0.61</b>
2005	244.0	29.0	88.6	36.0	0.06	0.16	<b>0.22</b>	0.31	0.51	<b>0.81</b>
2010	280.4	35.6	94.3	47.7	0.07	0.21	<b>0.28</b>	0.35	0.55	<b>0.90</b>
2011	287.1	36.6	96.1	49.1	0.07	0.22	<b>0.28</b>	0.36	0.56	<b>0.92</b>
2012	292.9	37.6	97.8	50.2	0.07	0.22	<b>0.29</b>	0.36	0.57	<b>0.93</b>
2013	299.1	38.6	98.3	50.5	0.07	0.22	<b>0.29</b>	0.37	0.57	<b>0.94</b>
2014	305.2	39.5	101.0	50.5	0.07	0.22	<b>0.29</b>	0.37	0.59	<b>0.96</b>
2015	311.1	40.4	103.1	52.4	0.07	0.23	<b>0.30</b>	0.38	0.60	<b>0.98</b>
2016	317.7	41.4	105.3	53.4	0.07	0.23	<b>0.31</b>	0.39	0.61	<b>1.00</b>
2017	323.2	42.0	108.5	55.0	0.08	0.24	<b>0.32</b>	0.40	0.63	<b>1.03</b>
2018	327.1	42.3	110.7	56.2	0.08	0.25	<b>0.32</b>	0.41	0.64	<b>1.05</b>
2019	330.6	42.7	112.7	57.2	0.08	0.25	<b>0.33</b>	0.42	0.66	<b>1.07</b>

### 6.3.5.6 N<sub>2</sub>O emissions from mineral soils as a result of change of management (F<sub>SOM</sub>)

Emissions of N<sub>2</sub>O 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 CFS CBM model does not model SOC. The CFS CBM 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<sub>2</sub>O emissions due to mineralisation of SOC due to land use change are not significant and are reported using the notation key "NO".

#### Justification for not reporting F<sub>SOM</sub>

Benanti et al., (2014) show that total N<sub>2</sub>O emissions from afforested Irish coniferous stands vary from 0-10 kg N<sub>2</sub>O ha<sup>-1</sup> yr<sup>-1</sup>, 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<sub>2</sub>O ha<sup>-1</sup> yr<sup>-1</sup> (Benanti et al., 2014). Based on this information and the following assumptions it is evident that N<sub>2</sub>O emissions from mineralisation of SOC following afforestation is insignificant (see paragraph 37 of 24/CMP19):

- Assuming the abovementioned maximum reported N<sub>2</sub>O emission value of 10 kg N<sub>2</sub>O ha<sup>-1</sup> yr<sup>-1</sup> for conifers (70% of forest area) and 1 kg N<sub>2</sub>O ha<sup>-1</sup> yr<sup>-1</sup> for broadleaves (30% of forest area).
- Less than 1% of all N mineralisation in forest soils comes from SOC turnover (Strange et al., 2000), so it can be assumed that 1% of total N<sub>2</sub>O emissions relate to F<sub>SOM</sub> emissions.
- The area of afforested mineral soils was 147.8 kHa in 2019
- The estimated total F<sub>SOM</sub> N<sub>2</sub>O emissions would be:  

$$(((10*0.7)+(1*0.3))*0.01*147819*298)/1000000 = 3.22 \text{ kt CO}_2 \text{ eq per year in 2019}$$
- The total national emission for 2019 is 59,777.6 kt CO<sub>2</sub> eq
- Therefore, we demonstrate that these emissions are less than 500 kt CO<sub>2</sub> and they are less than 0.05 percent of the total national emissions in 2019.

#### 6.3.5.7 CO<sub>2</sub> emissions from urea application to soils

All fertiliser application related emissions, including CO<sub>2</sub> emissions from urea application are reported under 3. *Agriculture* because these are based on national sales data (IE).

#### 6.3.5.8 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 6.17).

Table 6.17 shows that the uncertainty of estimates for land converted to forest land was 269.8 per cent in 1990, decreasing to 21 per cent by 2019. This is because the net emission reduction in 1990 was close to zero, which makes the percentage uncertainty higher when the absolute uncertainty is much lower, when compared to other years. The same issue arises when trend uncertainty compared to a base year is analysed. Hence the use of a base year, where absolute values are zero, or where values are very small, and expressing these as a percentage does not truly reflect the absolute uncertainty.

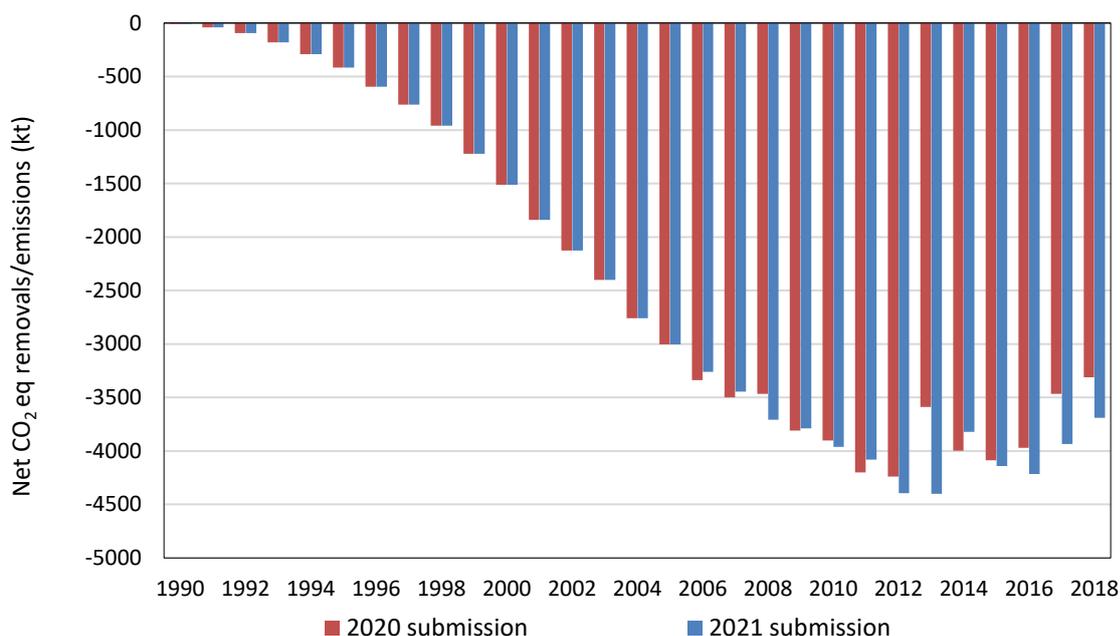
Table 6.17 Uncertainty analysis for lands converted to forest land as reported in category 4.A.2

Year	Category	Year emission/reductions (Gg CO2 eq)	Base year emission/reductions (Gg CO2eq)	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	-6.8	-6.8	269.8	0.7	na
	CRF 4(II)	8.7	8.7	88.4	0.3	na
	CRF4(V)	0.0	0.0	52.2	0.0	na
	<b>Total</b>	1.9	1.9	269.8	1.0	na
2000	CRF 4A.2	-1510.5	-6.8	24.9	0.8	22218.2
	CRF 4(II)	92.9	8.7	90.6	0.2	970.7
	CRF4(V)	0.0	0.0	52.2	0.0	0.0
	<b>Total</b>	-1417.6	1.9	24.9	1.0	-74387.3
2005	CRF 4A.2	-3003.3	-6.8	20.2	0.8	44273.8
	CRF 4(II)	124.7	8.7	91.3	0.2	1336.7
	CRF4(V)	0.0	0.0	52.2	0.0	
	<b>Total</b>	-2878.6	1.9	20.2	1.0	-150947.4
2010	CRF 4A.2	-4056.3	-6.8	18.4	0.8	59833.4
	CRF 4(II)	141.9	8.7	94.0	0.1	1536.0
	CRF4(V)	94.4	0.0	52.2	0.0	
	<b>Total</b>	-3820.0	1.9	18.7	1.0	-198133.2
2015	CRF4A.1	-4154.0	-6.8	18.5	0.8	61276.5
	CRF 4A II	155.5	8.7	94.0	0.2	1692.2
	CRF4(V)	12.6	0.0	52.2	0.0	
	<b>Total</b>	-3985.9	1.9	18.5	1.0	-208973.2
2016	CRF4A.1	-4218.1	-6.8	18.6	0.8	62224.0
	CRF 4A II	158.7	8.7	94.0	0.2	1728.6
	CRF4(V)	2.6	0.0	52.2	0.0	
	<b>Total</b>	-4056.9	1.9	18.6	1.0	-212693.0
2017	CRF4A.1	-4074.2	-6.8	19.0	0.8	60097.7
	CRF 4A II	163.5	8.7	94.0	0.2	1784.9
	CRF4(V)	137.4	0.0	52.2	0.1	
	<b>Total</b>	-3773.3	1.9	19.0	1.0	-197832.7
2018	CRF4A.1	-3725.3	-6.8	19.9	0.8	54942.1
	CRF 4A II	166.9	8.7	94.0	0.2	1823.8
	CRF4(V)	35.3	0.0	52.2	0.0	
	<b>Total</b>	-3523.1	1.9	19.9	1.0	-184720.3
2019	CRF4A.1	-3574.2	-6.8	20.5	0.8	52709.7
	CRF 4A II	169.9	8.7	94.0	0.2	1858.4
	CRF4(V)	4.1	0.0	52.2	0.0	
	<b>Total</b>	-3400.2	1.9	20.5	1.0	-178281.3

### 6.3.5.9 Recalculations for lands converted to forest land (CRF 4.A.2)

Recalculations for the forest category 4A.2 were due to:

- The harvests from 2006-2018 was corrected in the CBM simulation, harvest was previously assigned to incorrect years (i.e. the 2007 harvest was scheduled in 2006 etc). The recalculation results in slightly different allocations of harvest from different species, or between clearfell and thinnings, but no differences in the total harvest over the period. The effect of the altered harvest influences stock changes in all C pools, but overall differences in removal was small (a change in net emissions of 0.9 to 13.1%).
- Forest fire statistics were revised and used to update forest fire data for the period 2007 to 2018.



*Figure 6.14 Comparison of category 4.A.2 emissions/removals for the 2020 and 2021 submissions*

The overall recalculation resulted in a -0.44 to 13.6 percent difference in net removals or emissions over the period 2006-2019 for the 2021 submission, compared to the 2020 submission.

### 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. Historical deforestation trends 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. 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<sup>7</sup>. 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.

<sup>7</sup> <http://life04.raisedbogrestoration.ie/index.html>

In 2019, the limited felling licence records and lands taken out database identified deforested areas of 0.129 kha to grasslands, wetland and settlements (see chapter 11 and Table 6.18). 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 2016 NFI. The 2017 data is based on felling licence information and the lands taken out database (see 6.3.2.4).

**Table 6.18 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	0.021	0.006	0.008	0.006	0.010	NO	NO	NO	0.002	NO
1995	0.436	0.029	0.308	0.029	0.051	NO	NO	NO	0.078	NO
2000	2.627	0.258	1.775	0.086	0.222	NO	0.171	0.114	0.459	0.057
2005	6.912	1.402	3.776	0.373	1.079	NO	1.024	0.684	1.033	0.344
2010	14.112	5.402	5.376	0.373	3.879	2.000	1.824	1.484	3.033	1.544
2011	15.712	5.802	6.576	0.373	3.879	2.000	2.224	1.884	3.033	1.544
2012	16.512	6.602	6.576	0.373	4.679	2.800	2.224	1.884	3.033	1.544
2013	18.112	7.002	7.776	0.373	4.679	2.800	2.624	2.284	3.033	1.544
2014	18.512	7.402	7.776	0.373	4.679	2.800	3.024	2.684	3.033	1.544
2015	19.312	8.202	7.776	0.373	4.679	2.800	3.824	3.484	3.033	1.544
2016	20.112	8.602	8.176	0.373	4.679	2.800	4.224	3.884	3.033	1.544
2017	20.335	8.749	8.191	0.373	4.862	2.922	4.249	3.909	3.033	1.544
2018	20.526	8.854	8.249	0.376	4.973	3.001	4.272	3.932	3.033	1.544
2019	20.655	8.922	8.260	0.377	5.081	3.059	4.282	3.942	3.033	1.544

\* 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):

$$C_{L(Total)} = C_{L(AB)} + C_{L(BB)} = TOTAL_{(Biomass)lost} \quad (\text{eq 6.3.7})$$

The target harvest for deforested lands for CBM 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<sup>-1</sup> (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 6.3.8 and 6.3.9 above).

$$TOTAL_{(AB)} = (V \times D \times BEF \times CF) \times 1/(1 - R) \quad (\text{eq 6.3.8})$$

$$TOTAL_{(BB)} = TOTAL_{(AB)} \times R \quad (\text{eq 6.3.9})$$

The equations are similar to those used in the 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<sup>-1</sup>), BB (17.2 t C ha<sup>-1</sup>), litter and deadwood (16.4 t C ha<sup>-1</sup>) 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 IPCC GPG 2006. 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<sup>-1</sup>),
- EU LIFE bog restoration projects in 2007 (400 ha, biomass stock of 176 t C ha<sup>-1</sup>),
- Wind farm conversions in 2007 (400 ha, biomass stock of 230 t C ha<sup>-1</sup>),
- Grassland conversion in 2009. (400 ha, biomass stock of 97 t C ha<sup>-1</sup>)

The accumulated litter and DOM pool are assumed to be immediately oxidised when deforestation occurs. The approach adopted to apply an instantiations 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 Ch11 for 1<sup>st</sup> 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 wetland soil 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 instant 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, we have no data to support this, so the conservative approach of instantiations oxidation is applied.

**Table 6.19 Deforestation carbon stock changes and the harvest time series 1990-2019**

Area (kHa)		CSC (Gg C)						Net CO <sub>2</sub> Gg	Harvests
Year	Total	Living biomass			DOM	Mineral Soils	Organic soils	Total	Harvests (m <sup>3</sup> ) Modelled
		Gain	Loss	Net	Net	Net	Net		
1990	0.02	0.06	-1.71	-1.66	-0.50	-0.01	-0.02	8.06	3434
1995	0.44	1.81	-27.71	-25.89	-4.41	-0.17	-0.11	112.14	55560
2000	2.63	2.72	-71.24	-68.52	-10.85	-0.86	-0.44	295.78	142858
2005	6.91	2.72	-71.24	-68.52	-13.63	-2.29	-2.09	317.26	142858
2010	14.11	5.44	-45.69	-40.25	-6.01	-5.76	-6.40	214.22	94537
2011	15.71	8.16	-56.57	-48.41	-28.58	-4.53	-6.59	323.07	97715
2012	16.51	NO	-42.22	-42.22	-12.80	-4.51	-7.31	245.09	86063
2013	18.11	8.16	-183.19	-175.03	-45.76	-3.81	-7.50	851.01	386868
2014	18.51	NO,IE	-0.99	-0.99	0.00	-3.80	-7.69	45.76	2216
2015	19.31	NO,IE	-252.92	-252.92	-44.06	-3.69	-8.06	1132.0	521347
2016	20.11	2.72	-27.62	-24.90	-4.49	-3.45	-8.25	150.66	59267
2017	20.33	0.11	-7.63	-7.53	-0.98	-3.36	-8.37	74.21	16092
2018	20.53	0.39	-7.61	-7.22	-0.49	-3.22	-8.53	71.35	16050
2019	20.65	0.07	-5.81	-5.74	-0.58	-3.06	-8.59	65.87	12248

### 6.3.6.2 Mineral Soils

Carbon stock changes in mineral soils converted to grasslands is now 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 6.20). The mean SOC value for the 4 major World Reference Base soil classes were used a tier 2 SOC<sub>ref</sub> values as specified in Vol4 Ch2 equation 2.25 of the IPCC GPG 2006.

**Table 6.20 Relationships between general soil group, WRB soils and IPCC reference soils and tier 2 SOC<sub>ref</sub> values for major soil types**

Generalised soil groups	WRB ref	Soil code	IPCC ref	SOC <sub>ref</sub> (T2)	
				Mean	Sdev
Acid Brown Earth, Brown Earth	Cambisol	CA	HAC soil	<b>94.24</b>	<b>36.28</b>
Gley (undefined), Groundwater gleys, Surface-water gleys, Alluvial soil	Gleysols, Stagnosols, Fluvisols	G	Wet soils	<b>109.44</b>	<b>45.28</b>
Luvissols, Grey Brown Podzolics, Lithosols, Rendzinas	Luvissols, Leptosols	L	HAC soil	<b>105.01</b>	<b>51.04</b>
Podzols, Iron-pan Podzols, Brown Podzolics	Podzols	P	Spodic soils	<b>93.16</b>	<b>41.92</b>

Land use change factors (F<sub>lu</sub>) were derived for three land use categories (Table 6.20). However, since there is an interaction between F<sub>lu</sub> 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 6.21) to each other (see average values for land uses), F<sub>lu</sub> factors were derived for the four soil groups. The default transition period of 20 years was used.

Table 6.21 Tier 2  $F_{LU}$  values for the major soil types (see code in Table 6.20)

Soil Group	Land use factor ( $F_{lu}$ )			
	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
<b>Average</b>	<b>0.87a</b>	<b>1.04a</b>	<b>1.05a</b>	<b>0.92a</b>
<b>IPCC tier 1</b>	<b>0.69*</b>	<b>1</b>	<b>1.14**</b>	<b>0.98***</b>

\* Mean  $F_{LU}$  values with different alphabetical letters are significantly different to each other based on type III ANOVA and Tukey's 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% of SOC is emitted over a 20-year period in these soils. A mean SOC stock of 110 t C ha<sup>-1</sup> was used based on highest SOC<sub>ref</sub> value (see Table 6.20), 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 (see Ch 11);
- 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<sub>2</sub> from mineral soils because there is no activity data to determine the percentage green area in urban areas.

Mineralisation emissions of N<sub>2</sub>O due to the loss of SOC ( $F_{som}$ ) 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<sub>2</sub> 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<sup>-1</sup> (Table 2.1 of the 2013 IPCC Wetland Supplement), and off-site EF<sub>DOC</sub> of 0.31 t C ha<sup>-1</sup> is 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<sub>4</sub> emissions from deforested grasslands (Eq. 2.6 of 2013 IPCC Wetland Supplement). For CH<sub>4</sub>-land emissions the default EF<sub>CH<sub>4</sub>-land</sub> of 39 kgCH<sub>4</sub> ha<sup>-1</sup> and FRAC<sub>ditch</sub> 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<sub>drain</sub> of 527 kg CH<sub>4</sub> ha<sup>-1</sup> is used (Table 2.4 of the 2013 IPCC Wetland Supplement).

Default emission factors (1.6 kg N-N<sub>2</sub>O ha<sup>-1</sup>, 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<sub>2</sub>O 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 reported using eq. 6.3.23 and 6.3.24, described in section 6.3.3.1.2 (Soils). Emissions of CH<sub>4</sub> and N<sub>2</sub>O in deforestation to settlements and other lands are not reported under Convention reporting but are reported under the KP.

**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<sub>2</sub> emissions, default on-site EF<sub>-land</sub> 2.8 t C ha<sup>-1</sup> and the EF<sub>DOC</sub> of 0.31 t C ha<sup>-1</sup> is used (Table 2.1 and 2.2 of the the 2013 IPCC Wetland Supplement).

**Wetlands (4D):** For CH<sub>4</sub>, CH<sub>4-land</sub> emissions the default EF<sub>CH<sub>4-land</sub></sub> of 6.1 kg CH<sub>4</sub> ha<sup>-1</sup> and FRAC<sub>ditch</sub> of 0.05 is used (Tables 2.3 and 2.4 of the 2013 IPCC Wetland Supplement). The emission factor drained peat extraction sites of EF<sub>drain</sub> of 542 kg CH<sub>4</sub> ha<sup>-1</sup> is used (Table 2.4 of the 2013 IPCC Wetland Supplement). Default emission factors (1.6 kg N-N<sub>2</sub>O ha<sup>-1</sup>, 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<sub>2</sub>O 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 biogeochemical 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<sub>CO<sub>2</sub></sub> 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<sub>DOC-rewetted</sub> of -0.24 (Table 3.2 of the 2013 IPCC Wetland Supplement). EF for CH<sub>4</sub> due to rewetting is 92 kg CH<sub>4</sub> ha<sup>-1</sup> (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 (Tables 6.24). The only different sources of uncertainty in this analysis (see Table 6.22 and 6.23) are the uncertainty due different activity data used for deforestation areas and additional pools, particularly for category 4(III).

**Table 6.22 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 CH <sub>2</sub> , 2006 IPCC Guidelines)
I	Drained area	N <sub>2</sub> O and CH <sub>4</sub> drained	12.30	Conf. interval of NFI analysis
J	N <sub>2</sub> O emission factors drainage	N <sub>2</sub> O emissions	119.00	Wetland Supplement Table 2.5 and Yamulki et al., 2013
K	CH <sub>4</sub> EF ditches	CH <sub>4</sub> emissions	87.20	Wetland Supplement Table 2.4
L	CH <sub>4</sub> EF lands	CH <sub>4</sub> emissions	126.00	Wetland Supplement Table 2.3
M	N <sub>2</sub> O EF mineralisation	N <sub>2</sub> O 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 <sub>2</sub>	So	69.81	Wetland Supplement Table 2.1 and 2.2
Q	Rewetting CO <sub>2</sub>	So	125.36	Wetland Supplement Table 3.1and 3.2
R	Rewetting CH <sub>4</sub>	CH <sub>4</sub> 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 6.23 Combined uncertainty estimates for deforested land**

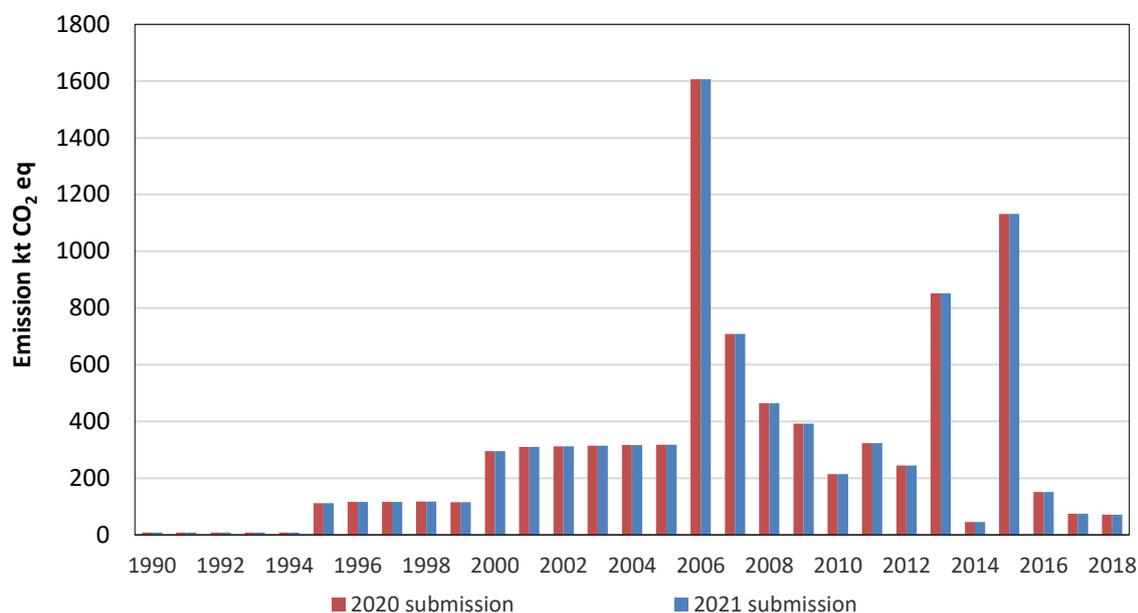
	Component	Equation in NIR	% uncertainty	Uncertainty of combined products (code)
LB net	Biomass	Eq 6.3.2 and 6.3.9	61.71	A, B, C, D
DOM	DOM (deadwood and litter)	Eq 6.3.16	64.48	B, C, D, E, F
SO	Soils	Eq 11.23 (So) and Wetland Supplement	197.50	D, G, N, O, P, Q, S
N <sub>2</sub> O	N <sub>2</sub> O drainage	Wetland Supplement	128.43	D, I J
CH <sub>4</sub>	CH <sub>4</sub> drain and rewetting	Wetland Supplement	285.01	I, K, L, R

*Table 6.24 Uncertainty estimates for deforested land*

Year	Category	Year emission/reductions (Gg CO <sub>2</sub> eq)	Base year emission/reductions (Gg CO <sub>2</sub> eq)	Combined uncertainty in year (±%)	Contribution to total variance in year (fraction)	Mean trend in year in relation to base-year (% mean trend)
<b>1990</b>	CRF 4B-E	7.80	7.80	48.59	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
	<b>Total</b>	<b>8.24</b>	<b>8.24</b>	<b>47.32</b>	<b>1.00</b>	<b>na</b>
<b>2000</b>	CRF 4B-E	295.78	7.80	53.22	0.91	3694.06
	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
	<b>Total</b>	<b>317.83</b>	<b>8.24</b>	<b>47.47</b>	<b>1.00</b>	<b>3759.43</b>
<b>2005</b>	CRF 4B-E	317.26	7.80	50.90	0.77	3969.68
	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
	<b>Total</b>	<b>381.42</b>	<b>8.24</b>	<b>53.40</b>	<b>1.00</b>	<b>4531.62</b>
<b>2010</b>	CRF 4B-E	214.22	7.80	59.52	0.49	2647.95
	CRF 4 (II)	9.52	0.01	151.56	0.05	70226.15
	CRF4 (III)	183.17	0.43	66.00	0.46	42915.74
	<b>Total</b>	<b>406.92</b>	<b>8.24</b>	<b>86.71</b>	<b>1.00</b>	<b>4841.24</b>
<b>2015</b>	CRF 4A.2	1132.00	7.80	51.93	0.78	14420.69
	CRF 4 II	16.77	0.01	188.24	0.04	123764.42
	CRF4III	197.33	0.43	66.00	0.17	46239.38
	<b>Total</b>	<b>1346.10</b>	<b>8.24</b>	<b>49.16</b>	<b>1.00</b>	<b>16245.75</b>
<b>2016</b>	CRF 4A.2	150.66	7.80	67.89	0.39	1832.57
	CRF 4 II	18.00	0.01	194.30	0.13	132824.87
	CRF4III	193.31	0.43	66.00	0.48	45296.30
	<b>Total</b>	<b>361.97</b>	<b>8.24</b>	<b>104.86</b>	<b>1.00</b>	<b>4295.37</b>
<b>2017</b>	CRF 4A.2	74.21	7.80	116.81	0.47	851.88
	CRF 4 II	18.24	0.01	193.25	0.12	134657.27
	CRF4III	190.56	0.43	66.00	0.41	44651.63
	<b>Total</b>	<b>283.02</b>	<b>8.24</b>	<b>140.80</b>	<b>1.00</b>	<b>3336.67</b>
<b>2018</b>	CRF 4A.2	71.35	7.80	121.39	0.35	815.20
	CRF 4 II	18.38	0.01	192.42	0.14	135679.39
	CRF4III	186.14	0.43	66.00	0.50	43612.59
	<b>Total</b>	<b>275.87</b>	<b>8.24</b>	<b>141.92</b>	<b>1.00</b>	<b>3249.91</b>
<b>2019</b>	CRF 4A.2	65.87	7.80	129.62	0.35	744.96
	CRF 4 II	18.50	0.01	191.91	0.15	136512.96
	CRF4III	182.18	0.43	66.00	0.50	42681.46
	<b>Total</b>	<b>266.54</b>	<b>8.24</b>	<b>145.14</b>	<b>1.00</b>	<b>3136.63</b>

### 6.3.6.5 Recalculations for deforestation

There were no recalculations for deforested land areas in the 2021 submission (Figure 6.15).



*Figure 6.15 Comparison of deforestation emissions for the 2020 and 2021 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 approach adopted is broadly consistent with the 2013 Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol approach B1 but there are some differences to ensure a consistent approach between Kyoto Protocol and UNFCCC reporting of HWP, namely all harvest from deforested lands are immediately oxidised and HWP inflows from afforested land since 1990 for the 1st commitment period are not included in HWP removals under KP reporting.

The primary activity data used for estimating HWP CSC is the EUROSTAT and FAO data from 1961 to 2019. The FAO/EUROSTAT data is used to calibrate the FORCARB and CFS CBM 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 2019 are shown in CRF Table 4Gs.2. The methods used to derive HWP for afforested (land converted to forests), land remaining forest domestically produced HWP is outlined in the following step 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 firw and fplp ratios to derive the volume of SW, WBP and PPB (see 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<sup>-3</sup> 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 ( $WP_j$ ):

$$WP_j = e^{0.015(\text{year}-1961) \times tC1961_j} \quad (\text{eq 6.3.10})$$

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  $\text{yr}^{-1}$ , 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 6.25 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 <sup>3</sup>	m <sup>3</sup>	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	0
1995	0.973	659910	327035	151119	87972	NO	0
2000	0.960	852517	715207	195226	192391	NO	0
2005	0.908	921476	794376	211018	213687	NO	0
2010	0.947	731414	758484	167494	204032	NO	0
2011	0.954	726243	703852	166310	189336	NO	0
2012	0.916	715888	655557	163938	176345	NO	0
2013	0.899	741236	643558	169743	173117	NO	0
2014	0.902	817857	697548	187289	187640	NO	0
2015	0.894	809425	687536	185358	184947	NO	0
2016	0.911	899608	704883	206010	189614	NO	0
2017	0.896	948192	749233	217136	201544	NO	0
2018	0.917	929900	740985	212947	199325	NO	0
2019	0.917	812402	647357	186040	174139	NO	0

The tier 2 first order decay model Forestry production and trade data from 1961-2019 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 2006 model:

$$C_{i+1} = e^{-k} \times C_i + \left[ \frac{(1-e^{-k})}{k} \right] \times Inflow_i \quad (\text{eq 6.3.11})$$

$$\Delta C_i = C_{i+1} - C_i \quad (\text{eq 6.3.12})$$

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  $\text{yr}^{-1}$  ( $k = \ln(2)/\text{HL}$ , 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  $\text{yr}^{-1}$

$\Delta C_i$  = carbon stock change of the HWP category during year  $i$ , kt C  $\text{yr}^{-1}$

Default half-lives of two years for paper, 25 years for wood-based panels, and 35 years for saw[n] wood<sup>8</sup> 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 6.26. 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 % because national data is based on a systematic survey (Table 6.27). 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 6.27).

The uncertainty associated with domestically produced HWP from category 4A1 (or FM) and 4A2 (AR, Table 6.28) were derived using the same approach adopted for other forest categories (see eq. 6.3.34 and 6.3.35) using sources of uncertainty shown in Table 6.27).

The base year removals were zero for HWP from category 4A2 (AR) because there were no activities prior to 2007 (Table 6.28). Therefore, the mean trend changes for the category (expressed as a percentage) is undefined (divided by zero).

<sup>8</sup> Product categories, half-lives and methodologies outlined in para 27, page 31 of FCCC/KP/AWG/2010/CRP.4/Rev.4

**Table 6.26 Detailed inflows and CSC for different HWP categories from harvest forest land (including deforestation)**

Year	Sawn wood (kt C)			kt CO <sub>2</sub>	WBP (kt C)			kt CO <sub>2</sub>	Paper (kt C)			kt CO <sub>2</sub>	Total
	Gain	Loss	Net	In use	Gain	Loss	Net	In use	Gain	Loss	Net	In use	kt CO <sub>2</sub>
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	186.04	-87.47	98.57	-361.42	174.14	-104.18	69.96	-256.51	0.00	0.00	0.00	0.00	-617.93

**Table 6.27 Detailed inflows and CSC for different HWP from category 4.A**

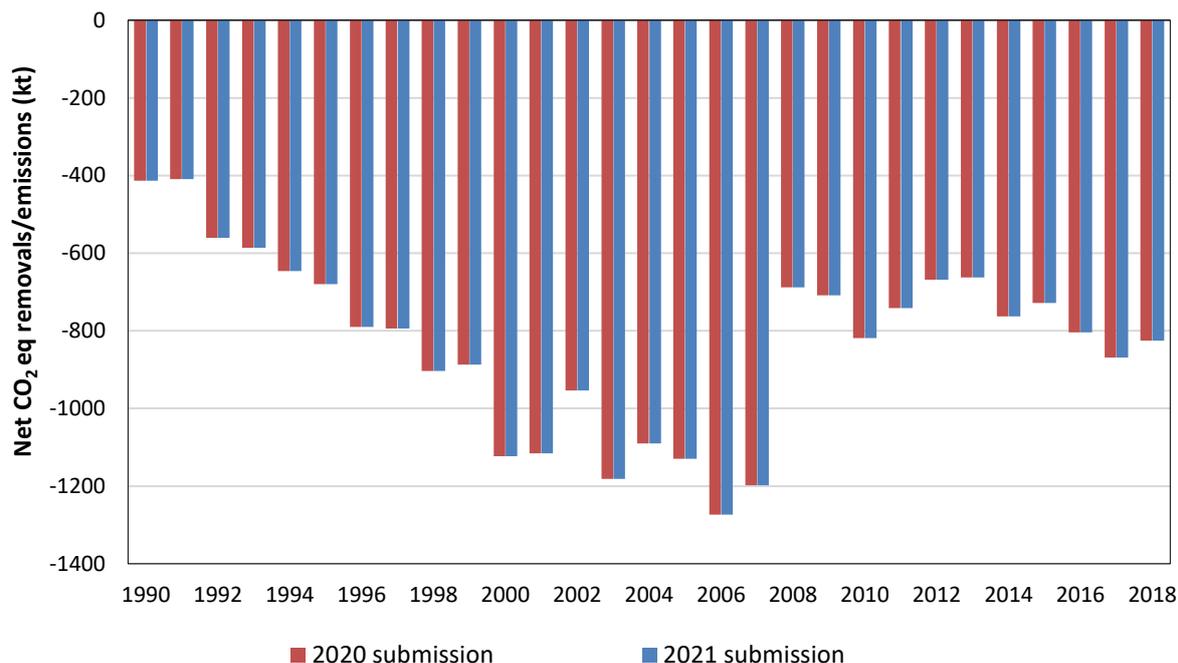
Code	Component	Sub-category	% Uncertainty	Source
A	HWP categories	SW, WBP, Pulp	15.00	Pg 2.135 Section 2.8.3 Ch IPCC 2013 supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol
B	FAO data	All	15.00	Table 12.6 Ch 12 2006 IPCC Guidelines
C	C conversion factor from dry weight	All	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		34.28	

**Table 6.28 Uncertainty of HWP estimates for all forest harvests**

Year	Year emission/reductions (kt CO <sub>2</sub> eq)	Base year emission/reductions (kt CO <sub>2</sub> eq)	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	-412.04	24.24	110.35
2018	-825.66	-411.04	24.24	99.90
2019	-617.93	-413.04	24.24	49.60

### 6.3.7.3 Recalculations in HWP

There was no recalculation for HWP pools (Figure 6.16). The adjustment to afforestation harvest (see section 6.3.5.9) did not influence HWP estimates because the correct annual harvest allocations are assigned to the HWP inflows.



*Figure 6.16 Comparison of HWP removals for the 2020 and 2021 submissions*

#### 6.3.7.4 Planned improvements for Forest Land (4.A)

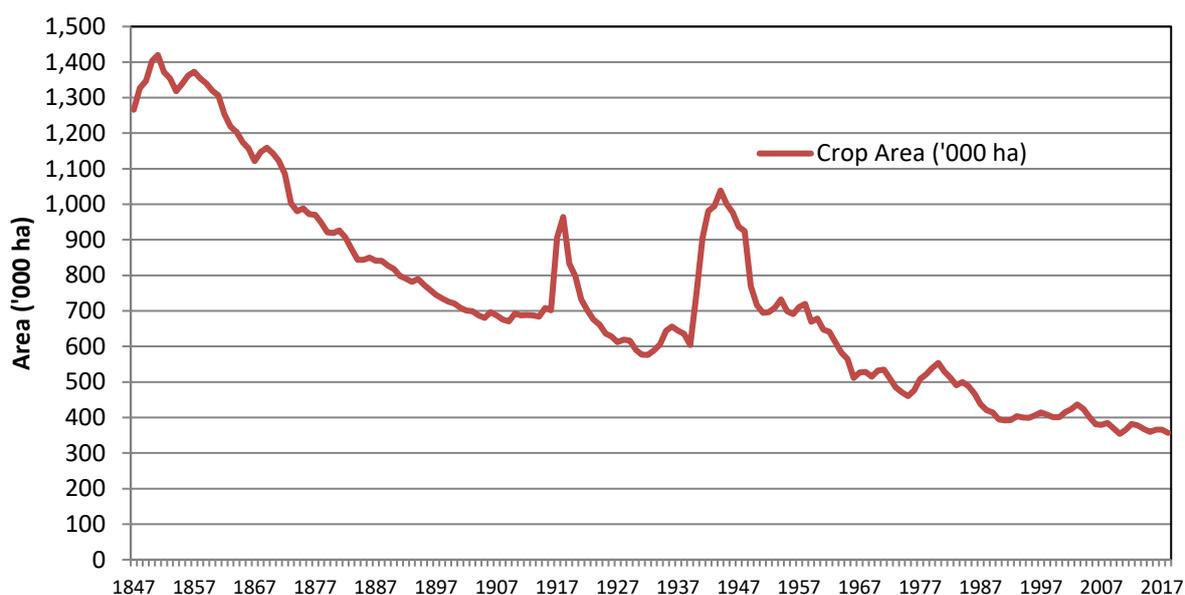
Currently there are no planned improvement to the forest land use inventory. However, this will be reviewed when an EPA funded project, which is investigating Tier 2 SOC<sub>ref</sub> and F<sub>li</sub> factors for estimating CSCs in mineral soils, is completed in 2021. Results from the CFOREP project investigated the use of two internationally available forest fire datasets, the European Forest Fire Information System (EFFIS) rapid damage assessment (RDA), and the NASA Fire Information for Resource Management System (FIRMS) were used to identify the spatial location of forest fires in Ireland. This was validated against ground collected data. The EFFIS-RDA system only correctly identified 48% of the areas burned (467 ha) and did not identify 54% of the burned forest areas. The EFFIS system incorrectly identified 3,116 ha of forest as being burned (an 87% level of commission). The high commission error may be a result of the low resolution of the MODIS data (there is a 30-ha detection limit), which may overestimate the areas of forests fires. The EFFIS\_RDA system is clearly not suitable to use for identifying and reporting of forest fires under the requirement set out under the COP decision 2/CMP7. Even if the system was used as a preliminary guide to identify potential areas, the high level of omission and low resolution of the MODIS data means that small forest fire areas will not be detected. Other data sources are being explored to develop a method to spatially track forest fires in Ireland.

## 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, underlying, 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, 2017, 2018, 2019, 2020 and 2021 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.

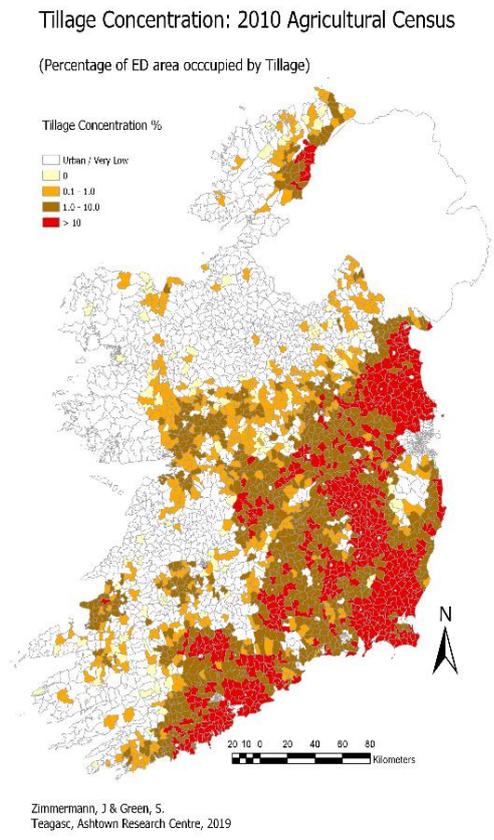
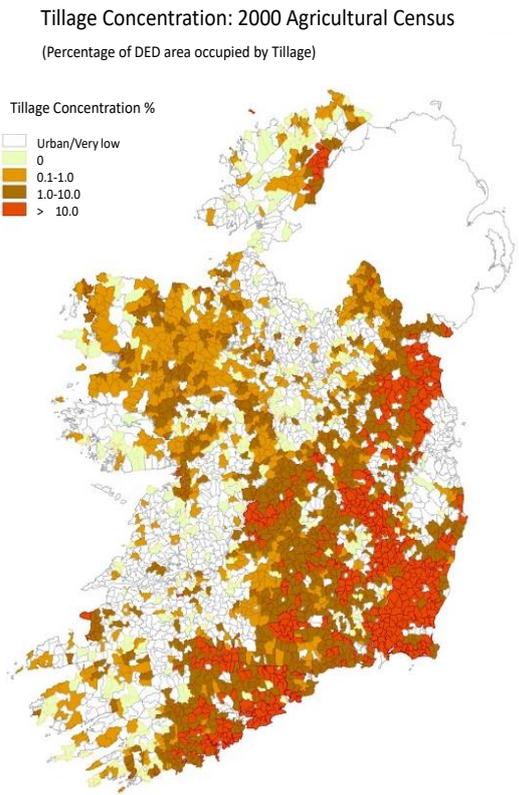
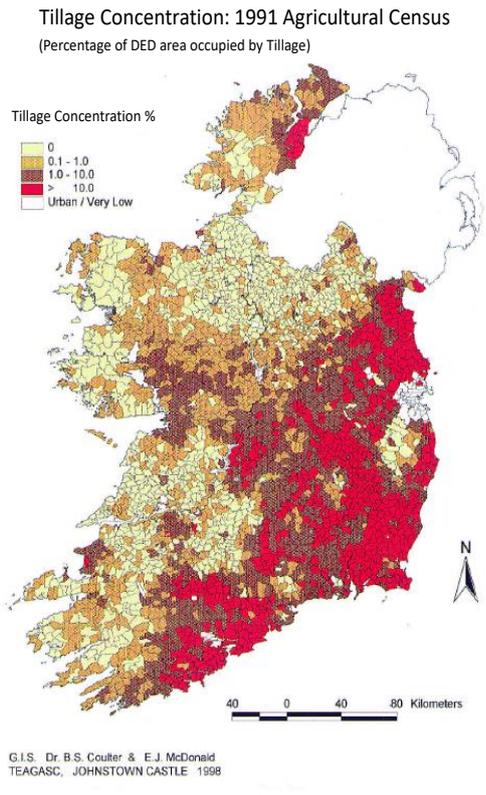
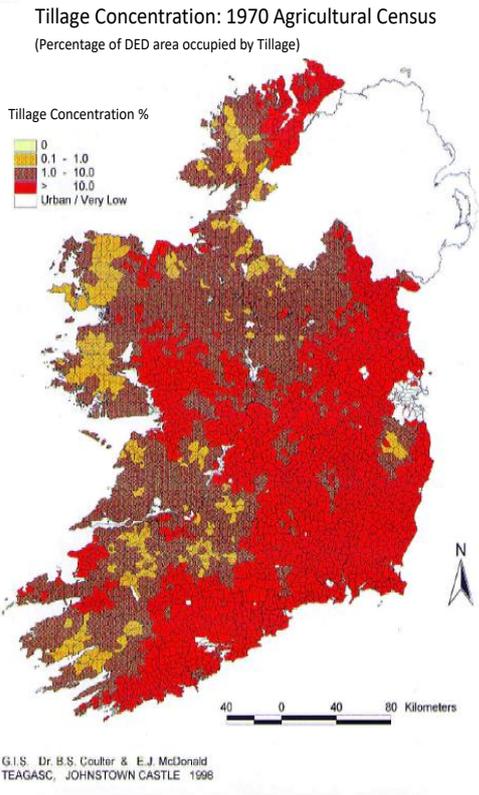
Based on the analysis of LPIS, Croplands are identified as those lands which have been cultivated (to grow a crop) in the reporting year, and those lands which are under temporary grassland, but have been recorded as having been also used to grow a crop (cultivated) at some time since 2000. Crops and 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 it is assumed that the main factor influencing changes in long term carbon profile is the period spent under 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.

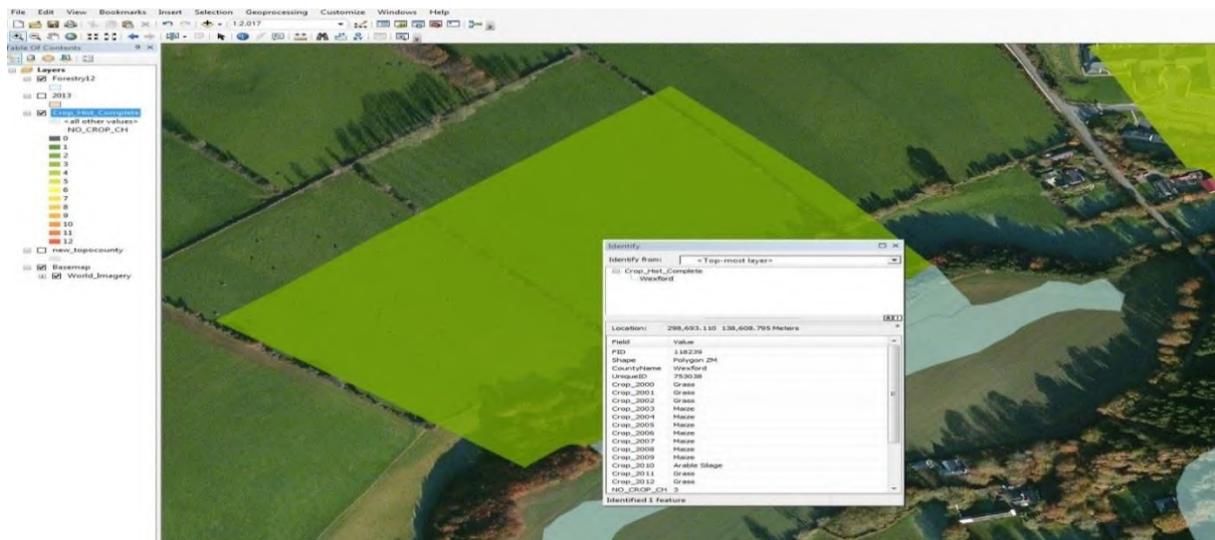
The Central Statistics Office, CSO, provides annual statistics for Utilised Agricultural Area under various land uses, including a detailed breakdown on various crop types and grassland management (pasture, rough grazing, hay and silage). However, the CSO data does not differentiate between permanent and temporary grasslands.

An analysis of historical areas under crops shows a significant decline in crops over a sustained period of decades (Figure 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 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 (SOCref) 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 6.29, based on detailed national assessment of soil carbon stocks in Ireland (Tomlinson et al., 2005). The

values of SOC<sub>ref</sub> appropriate to each soil association may then be assigned using the correspondence to IPCC classes given in Table 6.29. 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<sub>ref</sub>.

### 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 2020 submission are:

- Central Statistics Office annual statistics of Utilised Agriculture Area (1990-2019);
- Land Parcel Information System data (2000-2019) 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 (1990-2019);
- 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 6.29 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 <sub>ref</sub> (t C/ha)	95	85	115	71	NA	

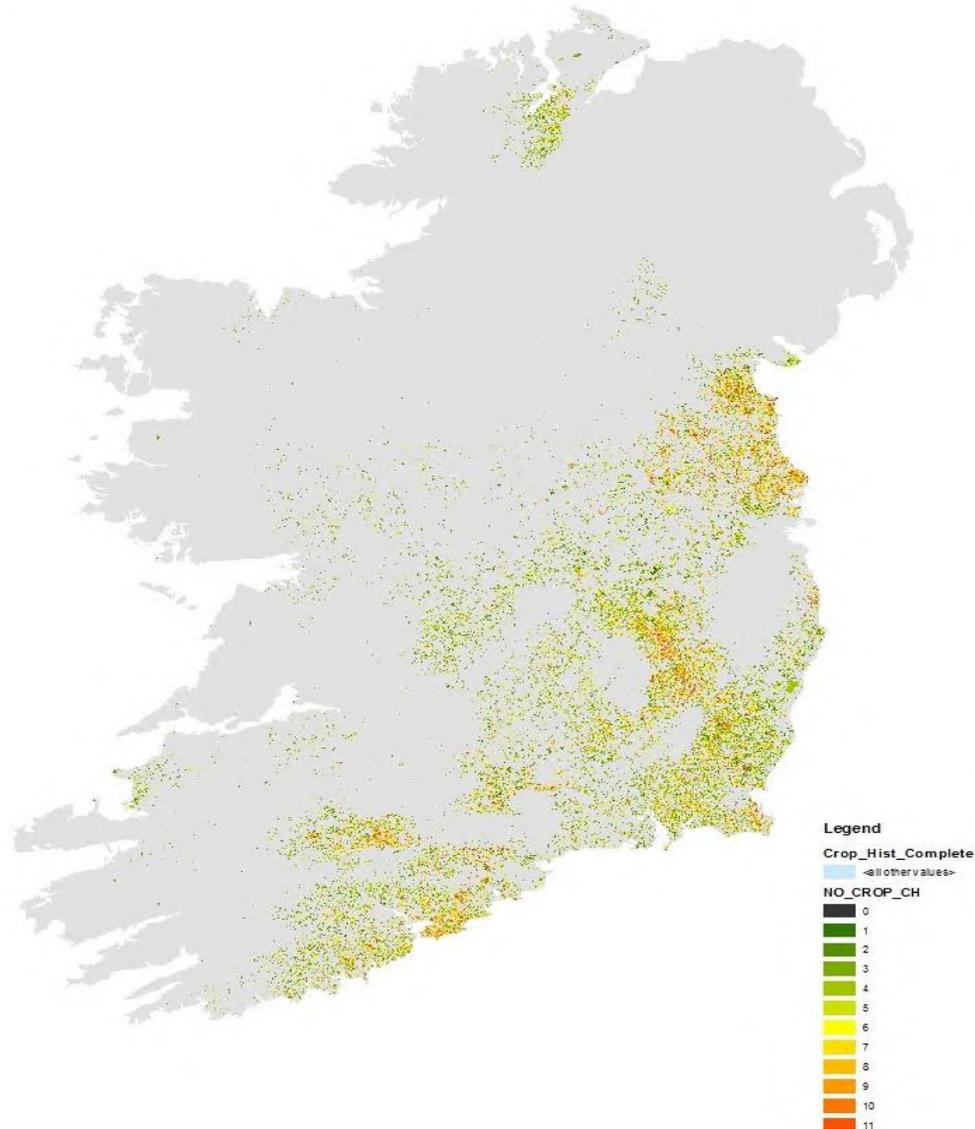
### 6.4.3 Cropland Areas

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 whose 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 2019 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 2000-2019, 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 2000-2019 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.

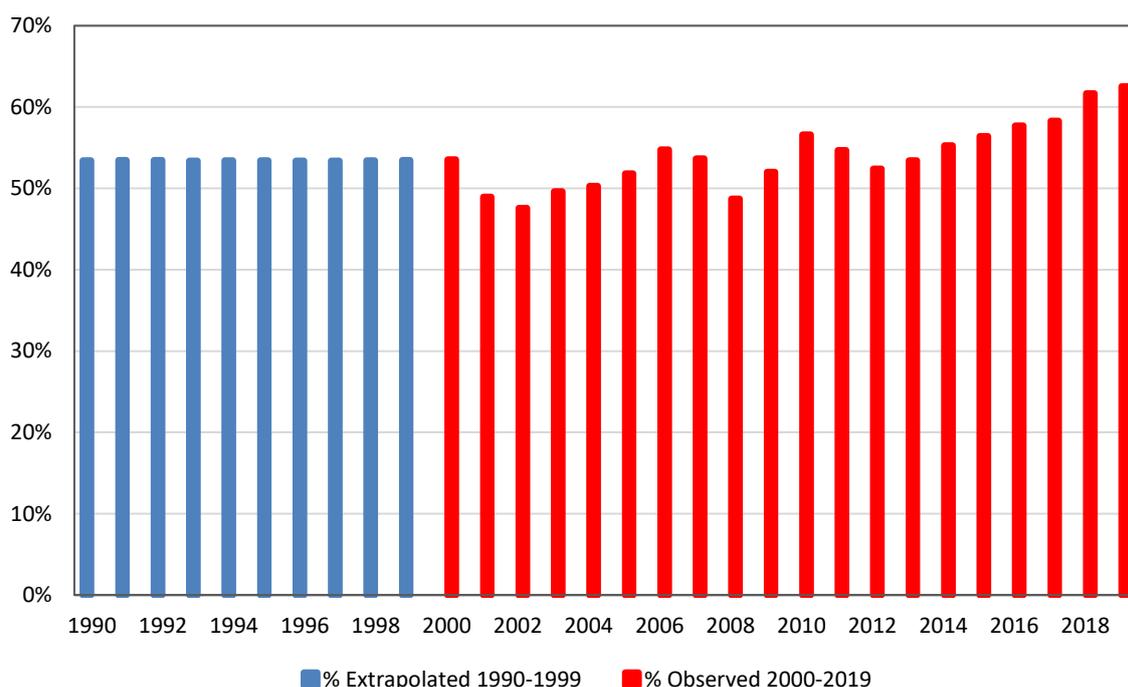
The analysis has not provided evidence of deforestation to Cropland. Likewise, the analysis does not identify an instance of conversion of Wetlands, Settlement or Other Land to Cropland. Therefore, transition of land to Cropland does not occur, and is assigned the notation key "NO" in the CRF tables.

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 were 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 137,165 land parcels can be identified as having a complete cropping history. These are condensed into 8,103 management (crop rotation) patterns, plus one pattern of continuous cropping. Table 6.30 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 6.30 Examples of binary coding of cropland parcel history**

Pattern Id	Code	Number of Parcels	Sum Area (ha)	Number of years of Grass
A	000000000000	35897	159930.6	0
B	000001111111	3558	11180.48	8
C	110111111111	1511	7695.15	12
D	110000000000	1431	5569.52	2
E	111111100111	899	3159.8	11
F	110011111111	840	3317.04	11
G	111001111111	824	2880.86	11
H	000000000100	211	636.19	1
I	111110000111	127	416.92	8
J	000001100000	93	295.82	2
K	000000111100	83	300.05	4
L	111100000001	83	299.76	5
M	001000000000	81	341.9	1
N	000101111111	79	373.34	8
O	000010111111	77	474.12	7
P	000001011111	75	210.82	6
Q	001100000000	73	309.55	2



**Figure 6.21 Proportion of Cropland cohort which is under temporary grassland each year**

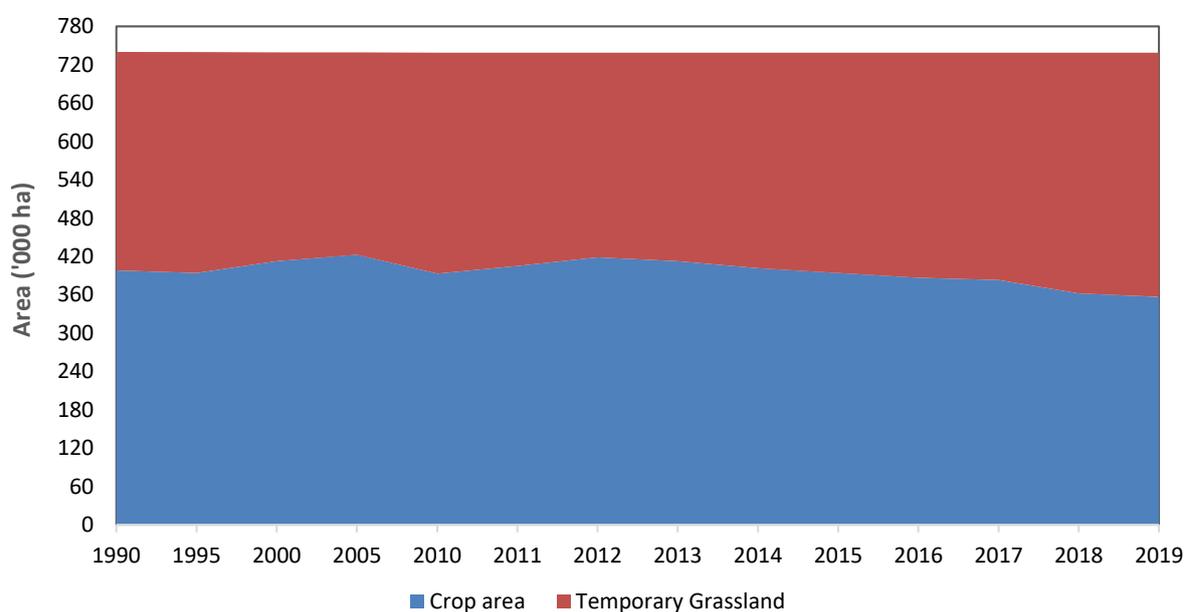
It is interesting to note the difference in histories of crop parcels and temporary grassland parcels, shown in Table 6.30. Not surprisingly, if in 2012 a parcel was identified under a crop, then it is more likely to have been under crops in previous years, and spent relatively less time under temporary 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 time 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 2000-2019. 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 2000-2019. 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 2000-2019.

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% 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 2019**

Figure 6.22 shows the shows the time series of Cropland area from 1990 – 2019, 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 2000-2019, 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 2000-2019, 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 2000-2019 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 2000-2019 has been assumed as representative for years 1900-1999.

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<sup>-1</sup> and the carbon content of dry matter is 0.5 per cent. The default value of 5 t dry matter ha<sup>-1</sup> from Table 6.4 Vol 4. of the 2006 IPCC guidelines 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:

$$\Delta C = A * [ (C_{\text{after}} - C_{\text{before}}) + DC_{\text{growth}} ] \quad (\text{eq 6.4.1})$$

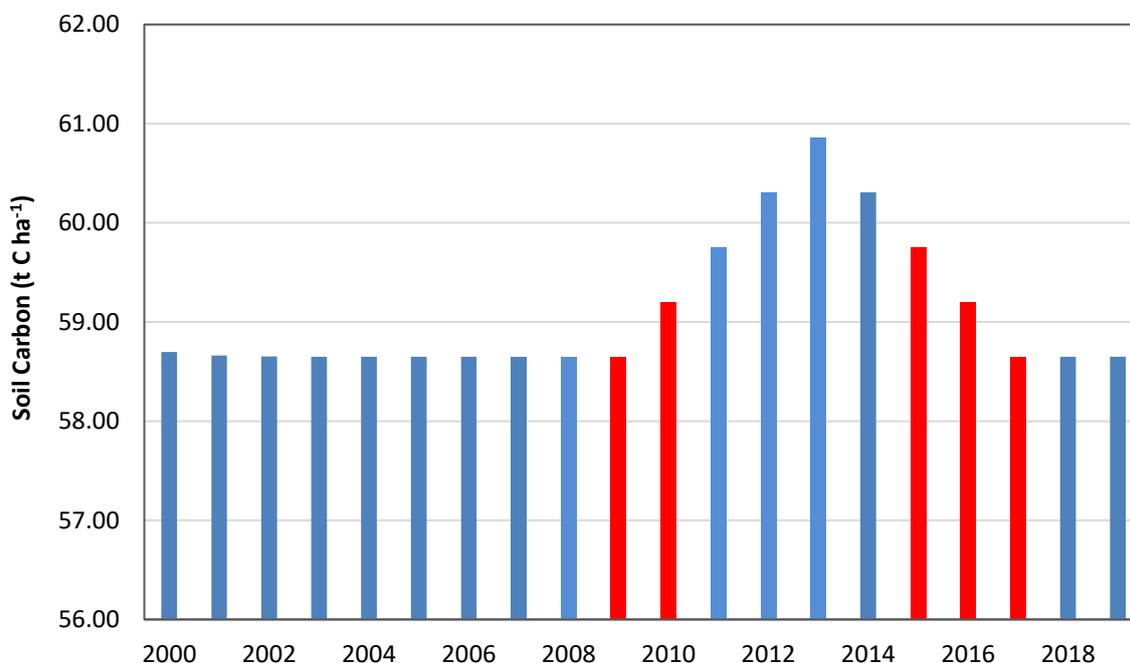
$$\Delta C = A * [ (0.0 - 13.6.0 * 0.5) + 5.0 ]$$

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 6.31 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 8,103 rotation patterns and plus one pattern of continuous cropping identified, representative of activity on 137,165 parcels of land.

**Table 6.31 Example of crop and temporary grassland rotation pattern**

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
	Crop	Crop	Crop	Crop	Crop	Crop	Crop	Crop	Crop	Crop
Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
	Grass	Grass	Grass	Grass	Crop	Crop	Crop	Crop	Crop	Crop



**Figure 6.23 Estimated Soil Carbon per hectare based on the crop rotation pattern outlined in Table 6.31 for the period 2000-2019**

### 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.

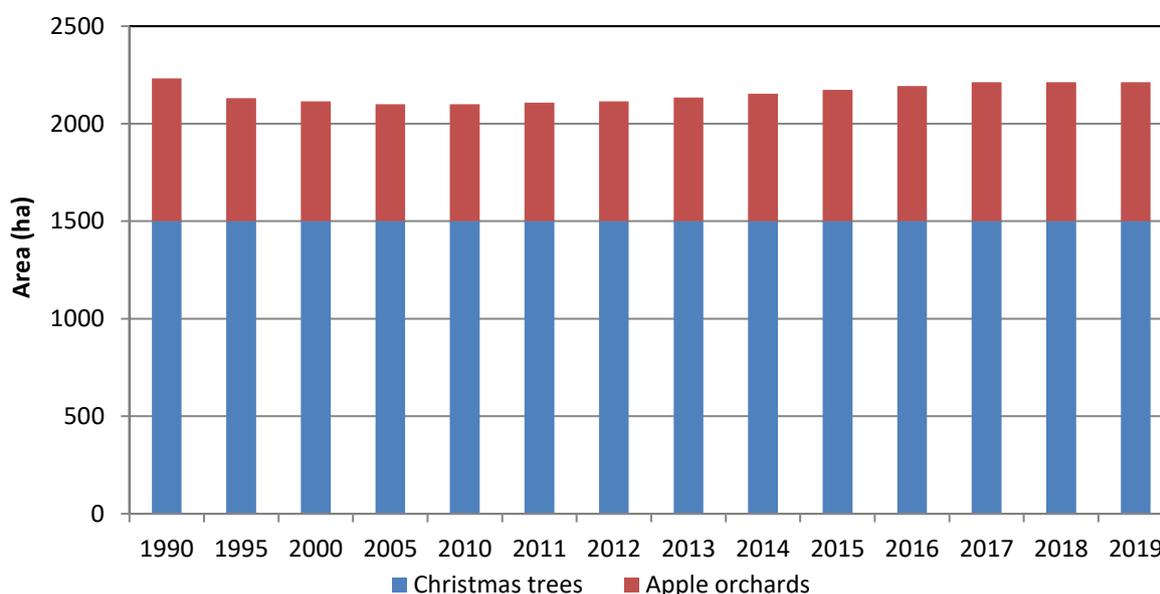
The areas of fruit orchards is included in the CSO “Fruit” category, however, this category also includes soft, non-woody fruit plants, including the strawberry crop. The area under Fruit is in a long term decline, which, appears to reflect an industry trend towards indoor, protective environments for strawberry production which have a reduced area footprint. Therefore, the annual CSO statistics are not a suitable proxy for 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<sup>9</sup> 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 Production estimates between 300,000 and 500,000 trees were planted each year. Bord Bia<sup>10</sup> currently estimates the market for Christmas trees from Irish producers to be between 500,000 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 an 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 1990-2019*

<sup>9</sup><http://www.intertradeireland.com/media/A%20Review%20of%20the%20All-Island%20Horticulture%20Industry.pdf>

<sup>10</sup><http://www.bordbia.ie/industry/manufacturers/insight/publications/MarketReviews/Documents/Export-Performance-and-Prospect-2015.pdf>

$$\Delta C_B = \Delta C_G + \Delta C_{conversion} - \Delta C_L \quad (\text{eq 6.4.2})$$

Where  $\Delta C_B$  = annual change in biomass stock in perennial crops

$\Delta C_G$  = 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 ( $63 \text{ t C ha}^{-1}$ ) 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  $63 \text{ t C ha}^{-1}$  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  $5.0 \text{ t C yr}^{-1}$ , from Table 5.8 of Chapter 5 Vol 4 of the 2006 IPCC Guidelines.

$\Delta C_L$  = 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.

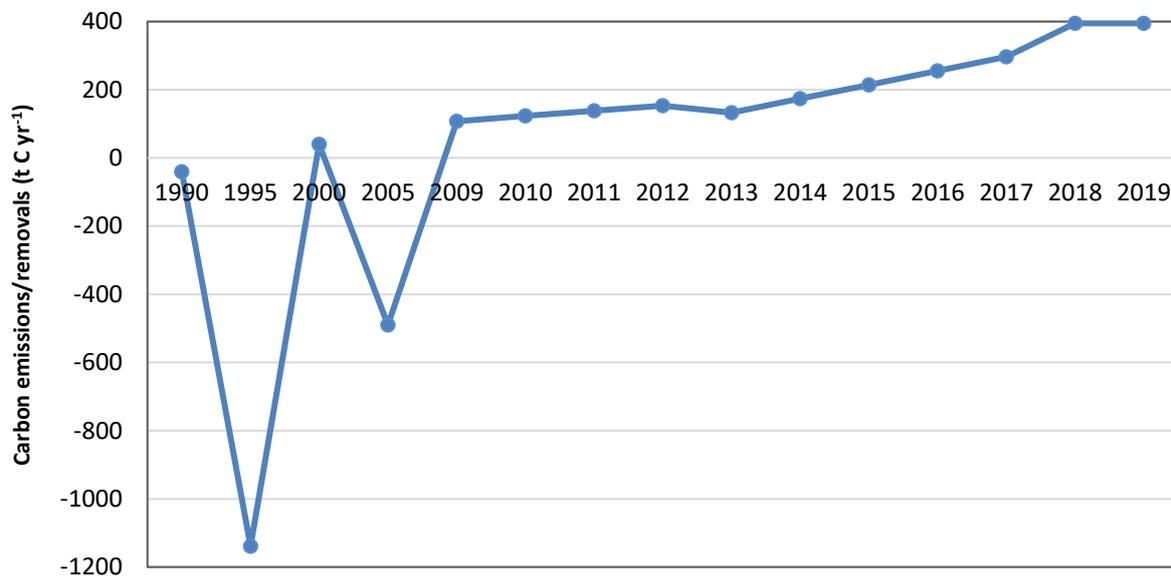


Figure 6.25 Carbon Stock Change in Biomass in Perennial Crops

### 6.4.5 Cropland Dead Organic Matter/Litter

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:

$$\Delta C = A * (SOC_0 - SOC_{0-T}) / T \quad (\text{eq 6.4.3})$$

$$SOC = SOC_{ref} * F_{LU} * F_{MG} * F_i$$

where

- $\Delta C$  = 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 Table 2.3 in Ch 2 of the 2006 IPCC Guidelines for the land uses defined for Ireland (Table 6.3). 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. As discussed in section 6.4.2 no cultivation occurs on organic soils.

*Table 6.32 Adjustment Factors for SOC*

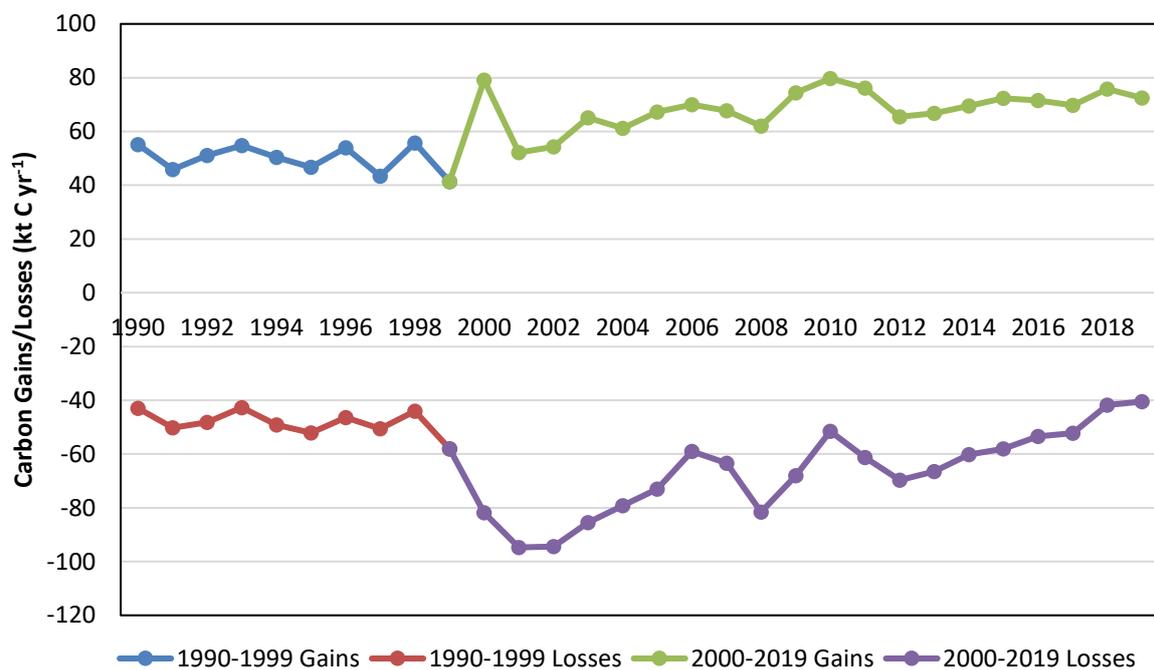
Land Use	$F_{LU}$	$F_{MG}$	$F_i$	Adjustment factor, AF
Cropland	0.69	1.0	1.0	0.69
Improved grassland	1.0	1.0	1.14	1.14
Unimproved grassland	1.0	1.0	NA	1.0
Temporary grassland	0.82	1.0	1.0	0.82
Rough grazing	1.0	0.95	NA	0.95
Other non-agricultural land (Native grassland)	1.0	1.0	NA	1.0

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 binomial probability equal to the observed proportion of crop years in the period from 2000-2019. 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 6.33 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 6.33 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 overlaid with the CORINE datasets for the years 2000, 2006, 2012 and 2018 it has identified that on average approximately 4 per cent (Table 6.34) 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 2019 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<sup>11</sup> 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<sup>2</sup> 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 6.34 Land Cover/Use associated with NASA FIRMS instances fires and the average proportion of fires detected**

Land Use	Proportion of All Fires Detected
Forest	10.9%
Cropland	4.9%
Grassland	19.4%
Wetlands	63.8%
Settlement	1.0%
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 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<sub>4</sub> and N<sub>2</sub>O only.

Emissions of CH<sub>4</sub> and N<sub>2</sub>O 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<sub>fire</sub> = amount of greenhouse gas emissions from fire, in tonnes of gas (CH<sub>4</sub>, N<sub>2</sub>O),

A = area burnt, ha,

M<sub>B</sub> = mass of fuel available for combustion, tonnes ha<sup>-1</sup>. This includes biomass, litter and DOM. For Tier 1 Litter and DOM are assumed zero for croplands remaining croplands.

C<sub>f</sub> = combustion factor, dimensionless,

The default value for M<sub>B</sub> .C<sub>f</sub> is 4.0 from Table 2.4in the Chapter 2 Vol 4 2006 IPCC Guidelines

G<sub>ef</sub> = is the emission factor, g kg<sup>-1</sup> dry matter burnt. The default values for cropland are CH<sub>4</sub>= 2.7 g kg<sup>-1</sup> dm<sub>burnt</sub>, N<sub>2</sub>O =0.07 g kg<sup>-1</sup> dm<sub>burnt</sub>.

<sup>11</sup> 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 2000-2019 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 2000-2019 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%..

### 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.

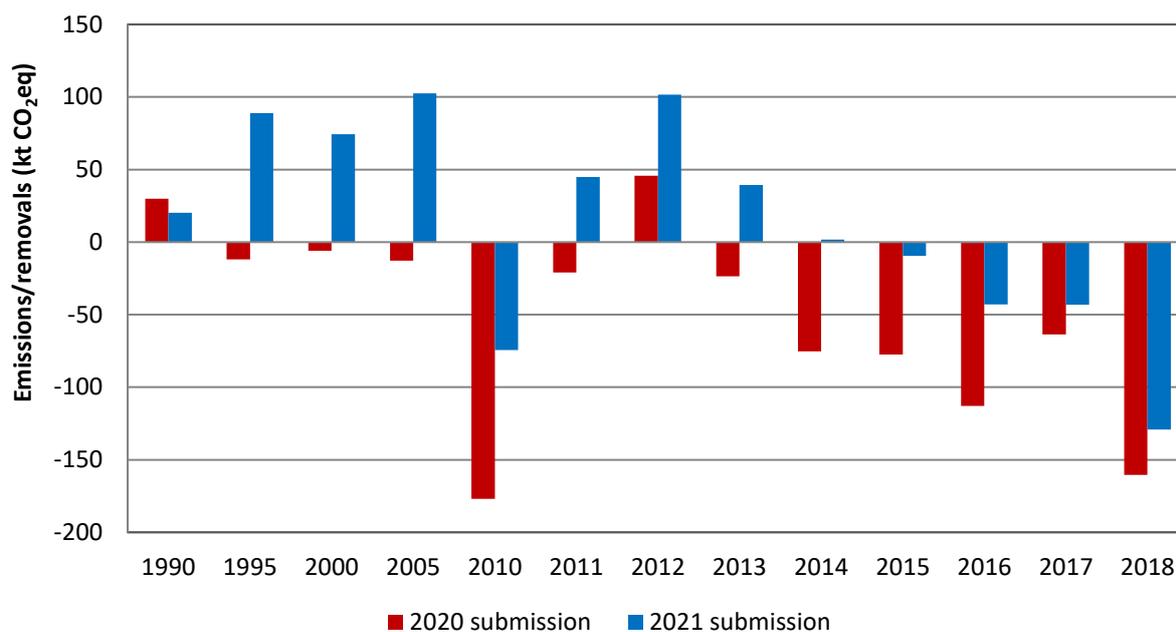
## 6.4.10 Category Specific QA/QC and verification

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. This has led to recalculation of emissions and removals for all years in the reporting period.

Figure 6.27 shows a comparison between 2020 and 2021 submissions of estimated total emissions and removals associated with Croplands. The difference is driven by the impact of the refinement of the analysis of the LPIS spatial dataset. While the revised analysis of croplands over the last number of submissions is a more accurate assessment of impact of the management of croplands, it also reflects a high degree of inter-annual variability within the category.



*Figure 6.27 Comparison between the 2020 and 2021 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, 2017, 2018, 2019, 2020 and this the 2021 submission 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. 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. The inventory agency has funded a project (due for completion at the end of 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 extent and management of hedgerows in the past.

## 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 trends 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 stabilising at approximately 4.3 million hectares. This points to a significant intensification in the management and use of grassland through the 20<sup>th</sup> 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 a Tier 1 approach to reporting greenhouse gas emissions associated with those areas defined as Grassland land use.

#### Activity data

The primary sources of activity data for Grassland used for the 2021 submission:

- Central Statistics Office annual statistics of Utilised Agriculture Area (1990-2019);
- Land Parcel Information System data (2000-2019) 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);
- Activity within the Construction Sector from CSO (1990-2019);
- Fire Information for Resource Management System (FIRMS) NASA;
- National forest fire statistics see Table 6.8;

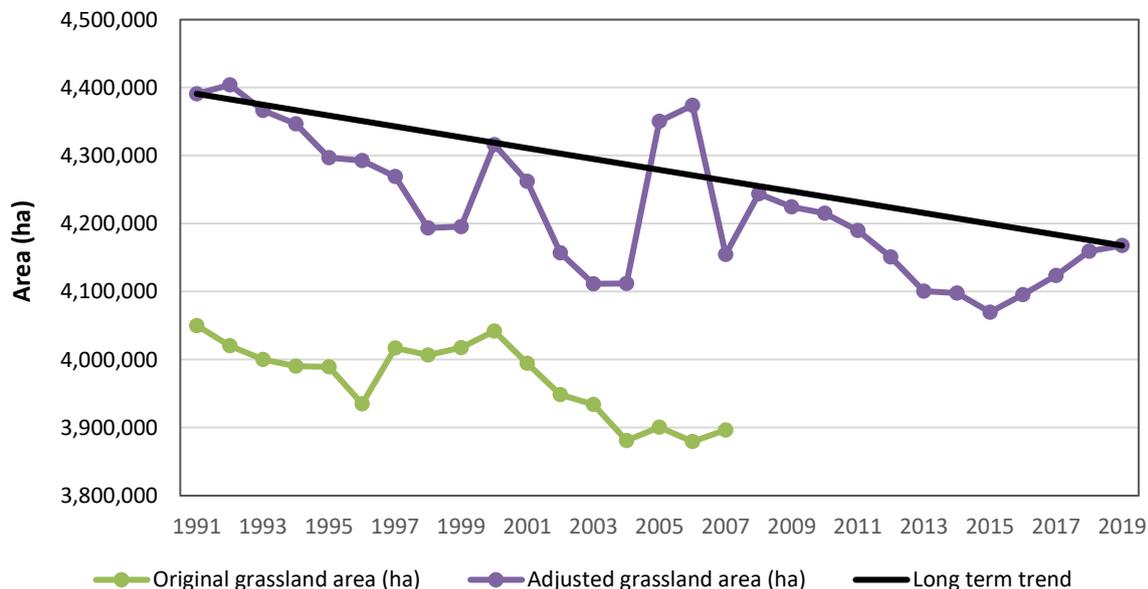
- National Forest Inventory 2006, 2012 and 2017

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 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, the last major change in methodology.



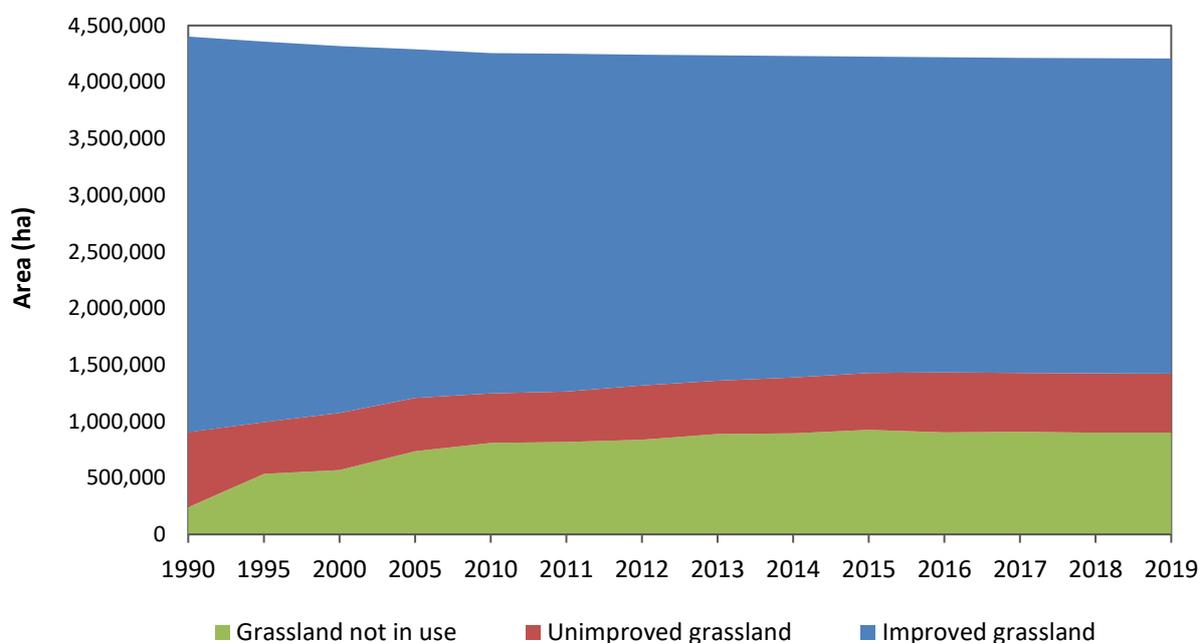
**Figure 6.28 Plot of original CSO data for Grassland areas and adjusted data for the years 1991-2007 based on the extrapolation of long term trends from 1991 to 2007 and 2008-2019**

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 native 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.

In the 2015 submission, a revised methodology was applied to estimate the area of temporary grassland within the Cropland land use category. The CSO estimate of agricultural grassland does not include this sub-division of grasslands. Therefore, the area of improved grasslands reported by the CSO is adjusted to take account of these areas of temporary grasslands reportable under the Cropland category.

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.

The area of grassland not in use has increased, in so far as the area of land reported as utilised has decreased at a rate greater than the demand for land for afforestation and new settlement. This is reflective of the response to government policy on hill farming, which sought to decrease over grazing on vulnerable commonage and mountain areas, and other policies and market drivers which encourage consolidation of livestock activities and more intense management of grasslands on lowlands. Therefore, there has been a decline in the reported agricultural land area, with conversion to Forest Land and “reversion” to not in use the principle drivers of trends. The grazing of unimproved grasslands leads to degradation of the soil, with consequent emission of carbon.



*Figure 6.29 Trends in Grassland use 1990-2019*

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 quantify 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. It is assumed here that 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<sub>4</sub> and N<sub>2</sub>O associated with the drainage activity.

The Tier 1 methodology from the 2006 IPCC Guidelines, described in Section 2.3.3.1, and eq 2.26 (see eg 6.54.1 below) for estimating emissions from organic soils is to assign a direct annual carbon loss rate that accounts for the oxidation of organic matter due to drainage, tillage or disturbance of the land area concerned. The default emission factors of 5.3 t C ha<sup>-1</sup> yr<sup>-1</sup> for shallow drained managed grassland soils in cold temperate climatic regions given in the Chapter 2 of the 2013 Wetlands Supplement to the 2006 IPCC Guidelines are adopted for Ireland. Tier 2 EFs are used for forests on organic soils converted to grassland based on country specific information.

$$L_{organic} = A \cdot EF \quad \text{(eq 6.5.1)}$$

Where  $L_{organic}$  is the annual carbon loss due to drainage

A is the area of grasslands on drained organic soils

EF is the emission factor for the template climate in t C ha<sup>-1</sup> yr<sup>-1</sup>.

The adoption of the revised emission factor from the 2013 Wetlands Supplement 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.

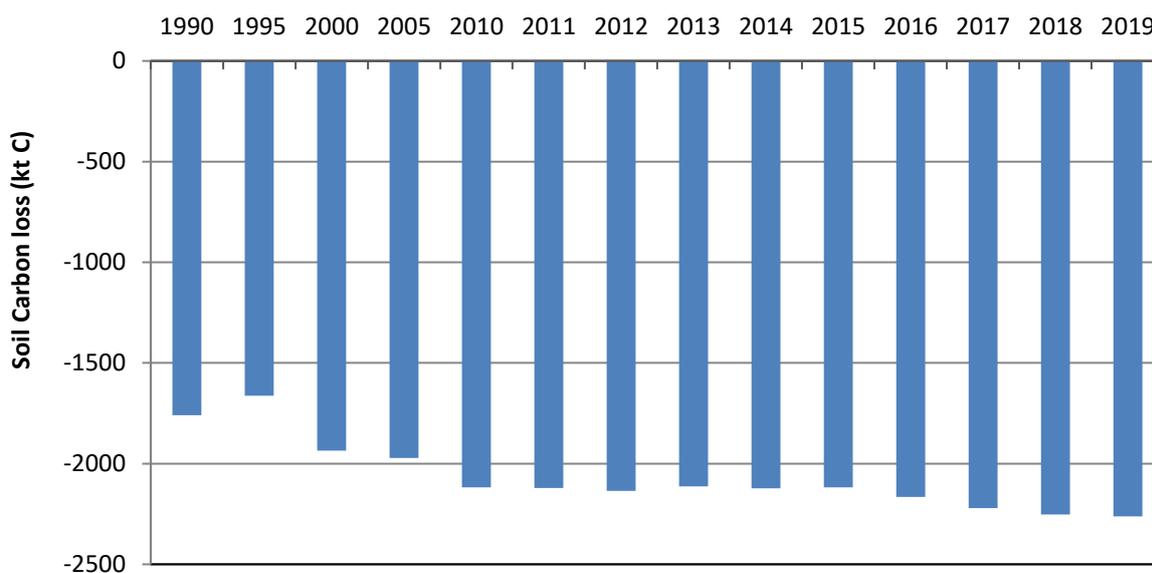


Figure 6.30 Time series of carbon loss from drained organic soils under grassland

### Rewetting of previously drained organic soils under grassland area

There has been a gradual decline in the total area of grasslands utilised for agriculture. It is inappropriate to classify these lands, which are not identified in the agricultural statistics as “abandoned” lands, as this implies a release from ownership, and responsibility. Rather these lands are considered to revert to a not in use status, which can involve natural rewetting (raising of the water table) due to poor maintenance of drainage systems. The decision to allow an area of land rewet in this way, is a deliberate response to policy and market drivers, and is reversible.

The estimate of the area of rewetted grassland on organic soils is based on the assumption that a fixed proportion of the change in area of utilised grasslands is organic soil, which will revert to a wet status.

The Tier 1 methodologies for emissions and removals associated with rewetting of previously drained organic soils are presented in Chapter 3 of the 2013 Wetlands Supplement to the 2006 IPCC guidelines

There are three sources of emissions and removals associated with this rewetting:

1. CO<sub>2</sub> removals from the atmosphere due to uptake to soil;
2. CO<sub>2</sub> losses in the form of dissolved organic carbon into the water system;
3. CH<sub>4</sub> emissions due to rewetting.

$$CO_2 - C_{rewetted\ organic\ soil} = CO_2 - C_{composite} + CO_2 - C_{DOC} + L_{fire} - CO_2 - C_e \quad (\text{eq 6.5.2})$$

Where  $CO_2 - C_{rewetted\ organic\ soil}$  = CO<sub>2</sub> as C removals and emissions from rewetted organic soils, t C yr<sup>-1</sup>.

$CO_2 - C_{composite}$  = emissions and removals from soil and non-tree vegetation t C yr<sup>-1</sup>

$CO_2 - C_{DOC}$  = emissions from dissolved organic carbon exported from rewetted organic soils, t C yr<sup>-1</sup>

$L_{fire} - CO_2 - C$  = emissions from fires on these soils.

CO<sub>2</sub> removals from the atmosphere due to uptake to soil ( $CO_2 - C_{composite}$ )

A simplified version of Eq 3.4 in the 2013 Wetlands Supplement can be applied to Ireland

$$CO_2 - C_{composite} = A \cdot EF_{CO_2} \quad (\text{eq 6.5.3})$$

Where A = area of nutrient poor rewetted organic soils, and  $EF_{CO_2}$  = emission factor for nutrient poor, soils in temperate climate zone and is equal to -0.23 t C ha<sup>-1</sup>, from Table 3,1 in the 2013 Wetlands Supplement. The minus sign indicates a sink of carbon.

CO<sub>2</sub> losses in the form of dissolved organic carbon into the water system.

A simplified version of Eq 3.5 from the 2013 Wetlands Supplements can be applied to Ireland.

$$CO_2 - C_{DOC} = A \cdot EF_{DOC\ rewetted} \quad (\text{eq 6.5.4})$$

Where  $CO_2 - C_{DOC}$  = off-site emissions of CO<sub>2</sub> from dissolved organic carbon exported from rewetted soils.

A is the area of nutrient poor rewetted organic soils, and  $EF_{DOC\ rewetted}$  = the emission factor for nutrient poor soils in a temperate climate zone, the default value from Table 3.2 in the Wetlands Supplement is approximately 0.24 t CO<sub>2</sub>-C ha<sup>-1</sup> yr<sup>-1</sup>.

#### CH<sub>4</sub> emissions/removals due to rewetting

Rewetting involves introducing anaerobic conditions to the soil, which leads to decomposition of organic matter with the release of CH<sub>4</sub>. Eq 3.7 in the 2013 Wetlands Supplement provides the basis for Tier 1 approach to estimation of these emissions.

$$CH_4 - C_{rewetted\ org\ soil} = CH_4 - C_{soil} + L_{fire} \quad (\text{eq 6.5.5})$$

Where  $L_{fire}$  is the estimate of emission from fires, and is included in the Biomass Burning section 6.5.6

A simplified version of Eq 3.8 from the 2013 Wetlands Supplement can be applied to estimate emissions from the soils

$$CH_4 - C_{soil} = A_{rewetted\ org\ soil} \cdot EF_{NP,T} \quad (\text{eq 6.5.6})$$

Where A is the area of rewetted organic soils under grassland, and  $EF_{NP,T}$  is the emissions factor for  $CH_4$  emissions from nutrient poor soils in the temperate climate zone. The default value for  $EF_{NP,T}$  is  $92 \text{ kg } CH_4\text{-C ha}^{-1} \text{ yr}^{-1}$ .

### 6.5.2.5 $CH_4$ emissions due to drainage of organic soils under grassland

Section 2.2.2.1 of the 2013 Wetland Supplement to the 2006 IPCC guidelines provides a methodology for estimation of  $CH_4$  emissions and removals from drained inland organic soils. The approach requires an estimate of the area impacted by drainage, and an estimate of the density of drainage ditches constructed and maintained to achieve this drainage. For Ireland, Eq 2.6 from the 2013 Wetlands Supplement can be simplified to the following

$$CH_{4\_organic} = \left( A_{T, NP, O} \cdot \left( (1 - Frac_{ditch}) \cdot EF_{CH_4\_land} + Frac_{ditch} \cdot EF_{CH_4\_ditch} \right) \right) \quad (\text{eq 6.5.7})$$

Where  $CH_{4\_organic}$  = emissions of methane due to the drainage of peatland under grassland.

$A_{T, NP, O}$  = Area of nutrient poor, drained organic soils, in Ireland's temperate climate zone.

$EF_{CH_4\_land}$  = emission factor for methane emissions from nutrient poor soils serviced by drainage ditches in temperate zone. The default value for  $EF_{CH_4\_land}$  is  $1.8 \text{ kg } CH_4 \text{ ha}^{-1} \text{ yr}^{-1}$  from table 2.3 of the 2013 Wetlands Supplement for shallow drained soils, which is typical drainage for Ireland.

$EF_{CH_4\_ditch}$  = emission factor for methane emissions from ditches in temperate zone, draining nutrient poor soils. The default value for  $EF_{CH_4\_land}$  is  $527 \text{ kg } CH_4 \text{ ha}^{-1} \text{ yr}^{-1}$  from table 2.4 of the 2013 Wetlands Supplement, for shallow drained soils, which is typical drainage for Ireland.

$Frac_{ditch}$  = Fraction of total area of drained organic soil which is occupied by ditches. The default value suggested in the 2013 Wetland supplement is  $Frac_{ditch} = 0.05$ .

The area of nutrient poor drained grasslands on organic soil and associated  $CH_4$  emissions are presented in Figure 6.31.

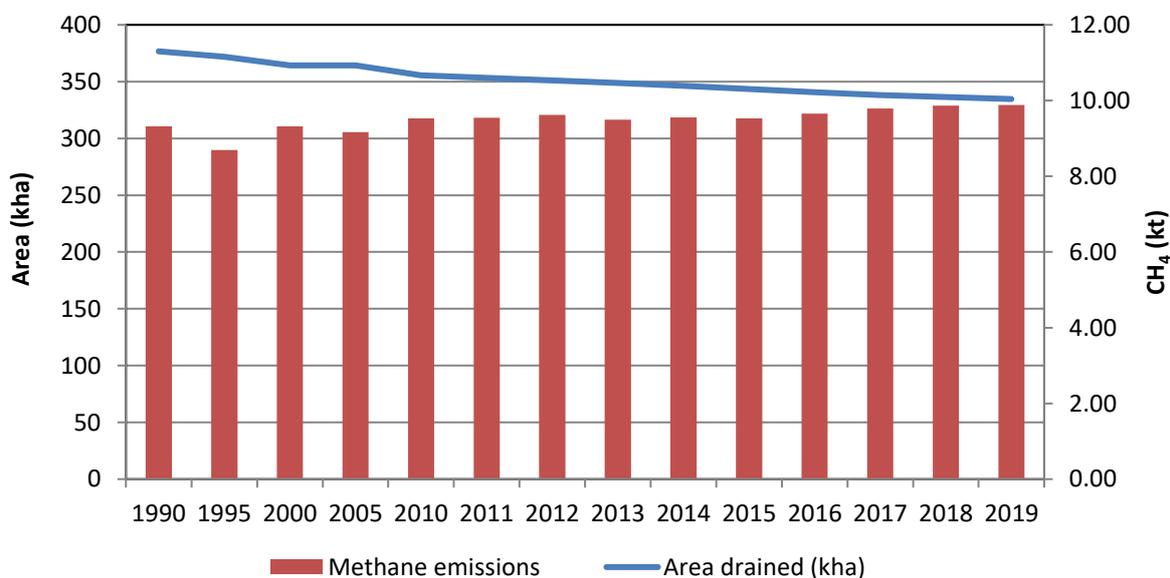


Figure 6.31 Estimate of the area drained and  $CH_4$  emissions for grasslands on organic soil

### 6.5.3 Land converted to Grassland

In the period 1990-2019, 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 identified that on average approximately 19 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 51.3 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 is deployed, in 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 at a national level.

It 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<sub>4</sub> and N<sub>2</sub>O are calculated using eq 2.27 from Chapter 2 Vol 4 of the 2006 IPCC Guidelines, and shown below. 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 6.35.

$$L_{fire} = A \cdot M_B \cdot C_f \cdot G_{ef} \cdot 10^{-3} \quad (\text{eq 6.5.8})$$

Where  $L_{fire}$  = amount of greenhouse gas emissions from fire, in tonnes of gas (CH<sub>4</sub>, N<sub>2</sub>O),

A = area burnt, ha,

MB = mass of fuel available for combustion, tonnes ha<sup>-1</sup>. This includes biomass, litter and dom. For Tier 1 Litter and DOM are assumed zero for grasslands remaining grasslands.

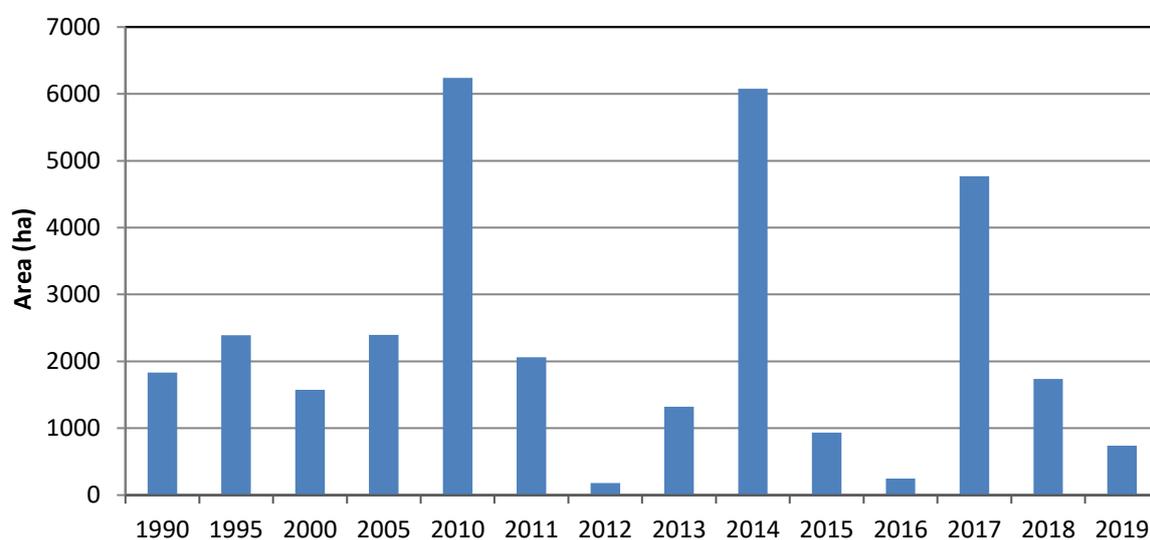
Cf = combustion factor, dimensionless,

The default values for grassland for MB are from Table 2.4 in 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,  $g\ kg^{-1}\ dm_{burnt}$ . The default values for grassland are  $CH_4=2.3\ g\ kg^{-1}\ dm_{burnt}$ ,  $N_2O=0.21\ g\ kg^{-1}\ dm_{burnt}$ .

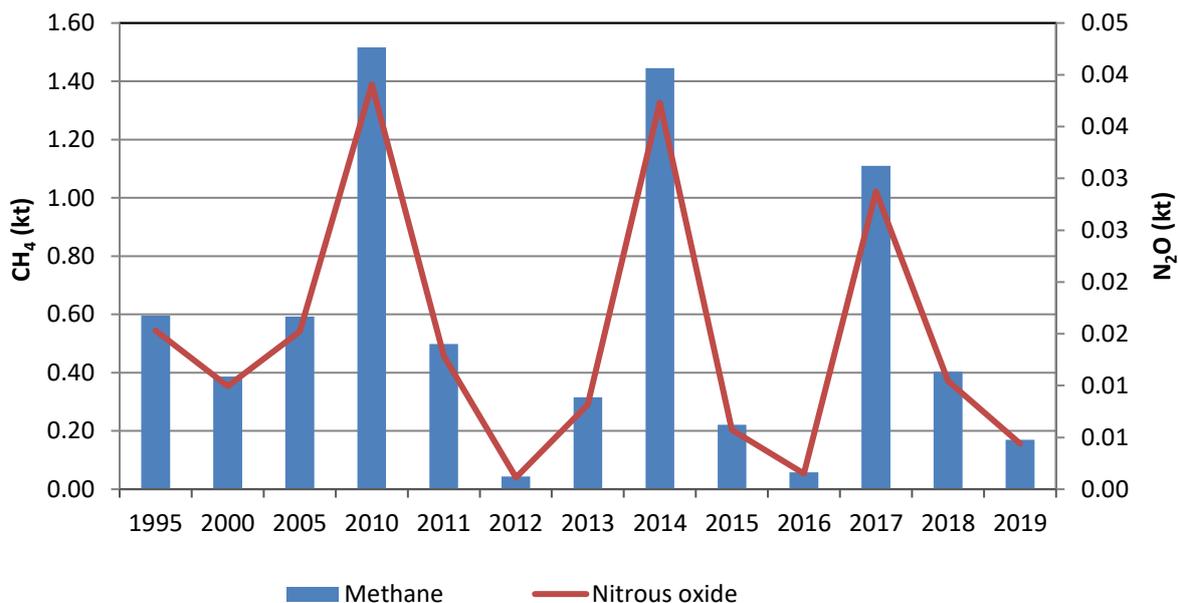
**Table 6.35 Default parameters for use in Equation 6.5.8**

	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



**Figure 6.32 The estimated area of grassland subjected to biomass burning 1990-2019**

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 6.33.



*Figure 6.33 Estimated CH<sub>4</sub> and N<sub>2</sub>O 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 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 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.

### 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.

### 6.5.7 Grassland category specific recalculations and impact on the emission trend

Recalculations to emissions and removals in the Grassland category in this submission are due to revised assessment of land area statistics with respect to grasslands. The net effect of these recalculations is a 1.3 per cent on average increase in emissions across the timeseries (Figure 6.34).

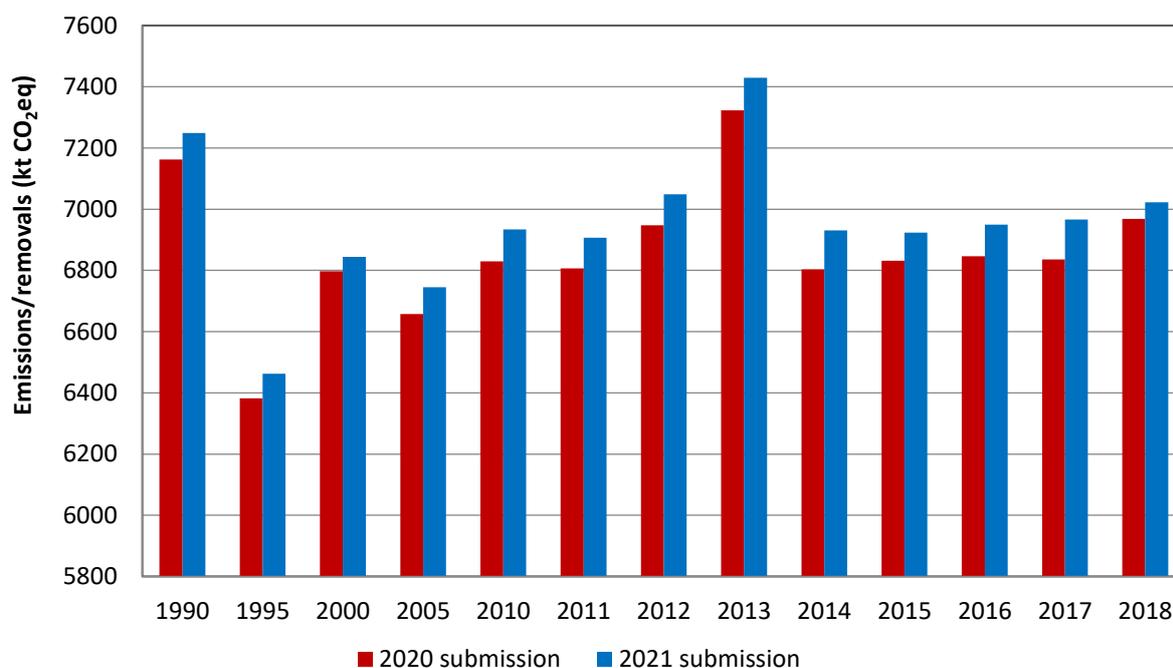
### 6.5.8 Grassland category specific planned improvements

The inventory agency aims to enhance this analysis 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 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 Grassland, this refers to primarily hedgerows. The inventory agency has funded a project (due for completion at the end of 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 extent and management of hedgerows in the past.

Furthermore the emission and management factors associated with the drainage of organic and wet soils in Ireland is currently being assessed, the results of which will be integrated with emissions and removal estimates for the grassland land use as they become available.



*Figure 6.34 Grassland recalculations between the 2020 and 2021 submissions for the period 1990-2018*

## 6.6 Wetlands (4.D)

### 6.6.1 Wetland Areas

The term Wetlands as applied to Ireland refer to unmanaged wetlands and managed peatlands, which are those wetland areas drained for the purpose of commercial exploitation and harvesting of peat for energy and horticultural products. Unmanaged wetlands includes peatlands not commercially exploited, inland marshes, salt marshes, moors and heathland and intertidal flats. The national wetland area is therefore split into two types, unmanaged wetland and managed peatland (Table 6.3).

There is a long history of peatland drainage for peat extraction over the centuries, with peak activity thought to have occurred in the 1920s, (Clarke 2006). In general, traditional methods of peat extraction culminated in the abandonment of a peat body once the level of peat extraction reached the water table maintained by the series of drainage ditches constructed to enable extraction. Thereafter the drainage ditches were allowed to fall into disrepair, and gradually rewetting of the abandoned extraction site occurred. Therefore, it is reasonable to assume all non-commercial peat extraction sites abandoned prior to 1990, although severely degraded as regards ecosystem function, were returned to rewetted status, prior to 1990.

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.

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. The main land use transition from unmanaged wetlands has been demand from afforestation.

A small area of land is reported as converted to wetland due to deforestation. These are included in the unmanaged wetland area, to differentiate from peat extraction (managed peatland), and to reflect the land use intent of the action, which is to restore natural ecosystem function. It is assumed natural regeneration of biomass occurs over a period of five years to a maximum biomass of 3 t C ha<sup>-1</sup>. It is also assumed soil carbon loss from these rewetted lands has ceased.

### 6.6.3 Managed/Exploited Wetland Areas

The commercial exploitation of peatlands is dominated by Bord na Mona (BnM, the Irish Peat Board). 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 has been investigated, and achieved with some success. The areas reported under category 5.D.1 Wetlands Remaining Wetlands includes all lands drained, whether the peat remains covered by vegetation or is exposed, reflecting the intent to commercially exploit. Bord na Mona manages its peat reserves to meet present 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. Until recently, BnM held a small area of un-drained wetlands in reserve. However, these lands have been transferred to the National Parks and Wildlife Service (NPWS) for conservation.

Also, a small area of exploited wetland has been restored to ecosystem function through drainage management and rewetting. This has led to an uptake of carbon in the revitalised biomass.

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 is poorly quantified. The land area devoted to private harvesting of peat is estimated to be currently in the region of 400 ha with the quantity of residential sod peat estimated from the national energy balance and a bulk density estimate of  $0.25 \text{ t m}^{-3}$  (McGoff et al. 2007). This approach ensures consistency between the quantities of sod peat combusted in 1.A.4.b Residential and the area of private peat exploitation in LULUCF.

The 2015, 2016, 2017, 2018, 2019, 2020 and this the 2021 submission include an analysis of GHG emissions and removals associated with peat extraction and use of peat in Horticultural products. BnM is 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 and assumes the other commercial enterprises adopt similar management practices as BnM.

## 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  $3 \text{ t C ha}^{-1}$  is adopted (Cruickshank et al, 2000). The vegetation types differs from pristine peatland due to the influence of drainage initiated when the land was first acquired by BnM.

Table 6.18 in Section 6.3.6 6 provides the area of forest land converted to wetlands for the years 1990-2019. 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<sup>-1</sup>yr<sup>-1</sup> up to an equilibrium of 3 t C ha<sup>-1</sup>.

### 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. These peatlands are nutrient-poor raised bogs or rain-fed blanket bogs for which a country specific emission factor of 1.68 t C ha<sup>-1</sup> has been derived (Wilson et al., 2015) which is lower than the Tier 1 carbon emission factor of 2.8 t C ha<sup>-1</sup>, for boreal and temperate climatic regions provided in Table 2.1, in the 2013 Wetlands Supplement to the 2006 IPCC Guidelines. The land area in respect of the soils carbon pool is the value that appears in CRF Table 4.D.1. This area is significantly larger than that relevant to the estimation of carbon stock change in biomass, as the land is drained on a continuous basis, whilst biomass change occurs in the first year of extraction.

The 2013 Wetlands Supplement to the 2006 IPCC Guidelines also provides guidance on estimation of C loss through dissolved C entering the drainage system. This is based on the assumption of flows of C through extensive drainage systems. The Tier 1 methodology assigns an emission factor of C loss per hectare drained.

### 6.6.5 Emissions of Non-CO<sub>2</sub> Gases

#### 6.6.5.1 N<sub>2</sub>O emissions due to drainage of peatland for peat extraction

The Tier 1 methodology for estimation of N<sub>2</sub>O emissions from drainage of organic soils for peat extraction is revised in Section 2.2.2.2 of the 2013 Wetlands Supplement to the 2006 IPCC Guidelines. Eq 2.7 in the 2013 wetlands Supplement can be simplified to eq 6.6.1, for Ireland, and nutrient poor soils.

$$N_2O - N_{os} = F_{OS,G,temp,NP} \cdot EF_{2,G,Temp,NP} \quad (\text{eq 6.6.1})$$

Where N<sub>2</sub>O-N = N<sub>2</sub>O emissions, as N, for drained organic soils,

F<sub>os</sub>= Area of drained organic soils,

EF<sub>2</sub>= is the emission factor for N<sub>2</sub>O losses from drained organic soils

G = Peat extraction land use

Temp= temperate climate zone

NP= indicates nutrient poor soils, which are typical of peatland in Ireland.

The default emission factor EF<sub>2</sub> of 0.3 kg N<sub>2</sub>O-N ha<sup>-1</sup> yr<sup>-1</sup> for nutrient poor drained organic soils drained for peat extraction from Table 2.5 in the 2013 Wetlands Supplement to the 2006 IPCC Guidelines.

### 6.6.5.2 CH<sub>4</sub> emissions due to drainage of peatland for peat extraction

Section 2.2.2.1 of the 2013 Wetland Supplement to the 2006 IPCC Guidelines provides methodology for estimation of CH<sub>4</sub> emissions and removals from drained inland organic soils. The approach requires an estimate of the area impacted by drainage, and an estimate of the density of drainage ditches constructed and maintained to achieve this drainage.

For Ireland, Eq 2.6 from the 2013 Wetlands Supplement can be simplified to the following:

$$CH_{4\_organic} = \left( A_{T, NP, O} \cdot \left( (1 - Frac_{ditch}) \cdot EF_{CH_4\_land} + Frac_{ditch} \cdot EF_{CH_4\_ditch} \right) \right) \text{ (eq 6.6.2)}$$

Where CH<sub>4\_organic</sub> = emissions of methane due to the drainage of peatland

A<sub>T, NP, O</sub> = Area of nutrient poor, drained organic soils, in Ireland's temperate climate zone.

EF<sub>CH<sub>4</sub>\_land</sub> = emission factor for methane emissions from nutrient poor soils serviced by drainage ditches in temperate zone. The default value for EF<sub>CH<sub>4</sub>\_land</sub> is 6.1 kg CH<sub>4</sub> ha<sup>-1</sup> yr<sup>-1</sup> from table 2.3 of the 2013 Wetlands Supplement for shallow drained soils, which is typical drainage for Ireland.

EF<sub>CH<sub>4</sub>\_ditch</sub> = emission factor for methane emissions from ditches in temperate zone, draining nutrient poor soils. The default value for EF<sub>CH<sub>4</sub>\_land</sub> is 542 kg CH<sub>4</sub> ha<sup>-1</sup> yr<sup>-1</sup> from table 2.4 of the 2013 Wetlands Supplement, for shallow drained soils, which is typical drainage for Ireland.

Frac<sub>ditch</sub> = Fraction of total area of drained organic soil which is occupied by ditches. The default value suggested in the 2013 Wetland supplement is Frac<sub>ditch</sub> = 0.05.

### 6.6.6 Emissions due to Extraction and Use of Horticultural Peat

The carbon loss to the atmosphere due to the extraction and use of horticultural peat was estimated for the first time in the 2015 submission. Ireland has developed a significant domestic and international market for horticultural peat products. The 2016 submission included revised exports values for selected years, as recorded by Eurostat. One of the dominant producers in the market is the state owned Bord Na Mona, which, as stated above is also the dominant producer in the industrial extraction of peat for combustion in the Energy subsectors. This approach is continued in the 2021 submission and was updated in 2020 to reflect a change in the proportions of the market supplied by Bord Na Mona and private horticultural peat companies.

In communication with industry experts, it is estimated that 85% 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.

#### 6.6.6.1 On-site emissions

Bord Na Mona provide the details on the area of peatland which are drained for extraction, which includes areas used for horticultural products. Therefore, the direct emissions associated with Bord Na Mona lands are already included in the analysis above.

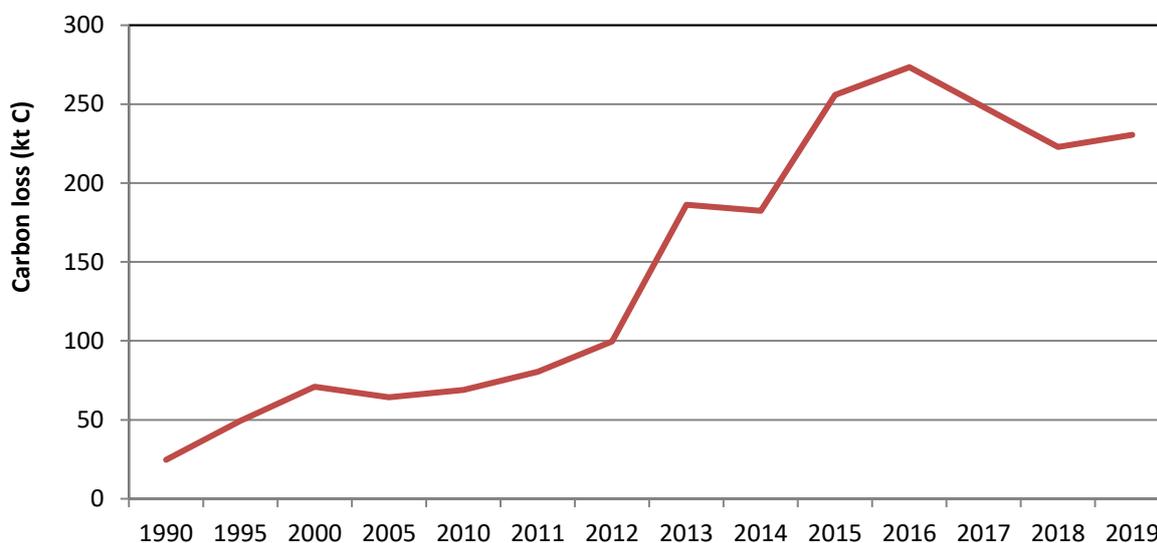
The activities of private horticultural peat companies also supplying domestic and international markets are not included in the above analysis.

It is necessary to estimate the area of peatland needed to be drained in order to supply this private industry market. It is assumed that the private industry adopt similar extraction techniques to those employed by Bord Na Mona. That is a depth of peat of between 10-15cm is extracted each year.

### 6.6.6.2 Off-site emissions

The CSO activity data records exports of peat products by weight. It is assumed that all products are 100 per cent air dried peat, unless other information of product constituents is available.

The 2006 IPCC guidelines, Vol 4 Chapter 7 section 7.2.1, provide a Tier 1 methodology and emission factor for carbon loss by weight of product. 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. Off-site carbon loss for the timeseries is presented in Figure 6.35.



*Figure 6.35 Off-site emissions from Horticultural Peat*

### 6.6.7 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 63.8 per cent of likely fire events coincided with wetland 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.

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 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 31.9 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 6.36).

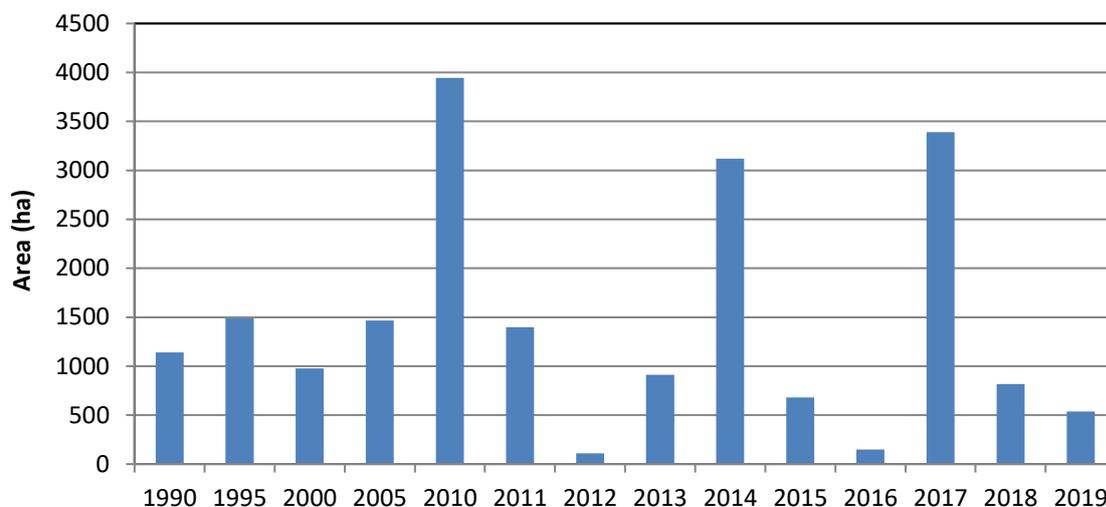


Figure 6.36 Estimate of the area of wetland subject to biomass burning

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<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O are calculated using eq 2.27 from Chapter 2 Vol 4 of the 2006 IPCC Guidelines, and are shown in Figure 6.37 respectively.

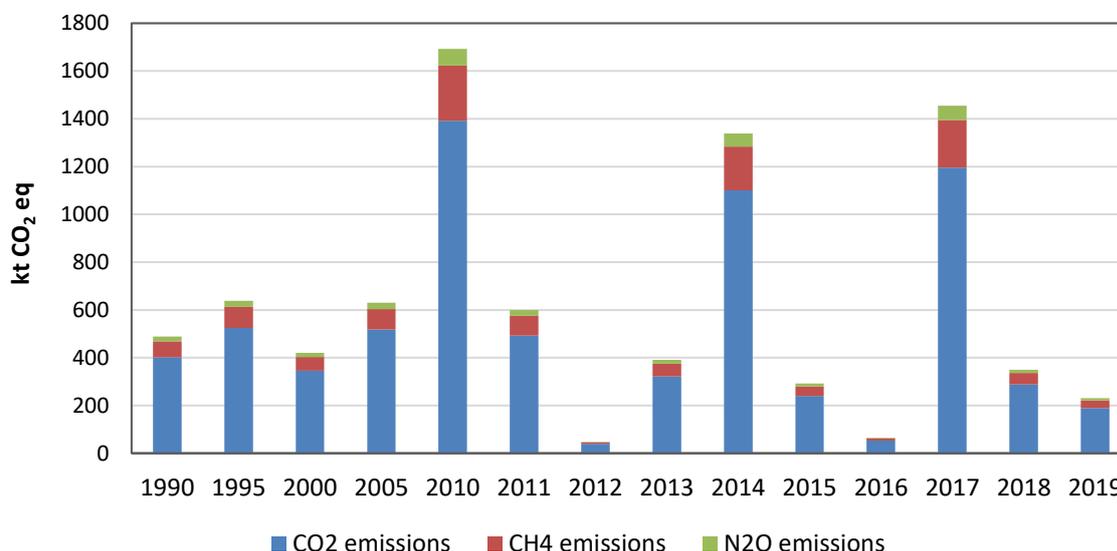


Figure 6.37 Estimate emissions (kt CO<sub>2</sub> eq) due to biomass burning on wetlands

The approach requires an estimate of the area burnt and provides appropriate default values for each of the parameters.

$$L_{fire} = A \cdot M_B \cdot C_f \cdot G_{ef} \cdot 10^{-3} \quad (\text{eq 6.6.3})$$

Where  $L_{fire}$  = amount of greenhouse gas emissions from fire, in tonnes of gas (CH<sub>4</sub>, N<sub>2</sub>O),

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  $M_B \cdot C_f$  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. The default values for cropland are  $CO_2=362$  g $kg^{-1}$   $dm_{burnt}$ ;  $CH_4= 9.0$  g  $kg^{-1}$   $dm_{burnt}$ ;  $N_2O =0.21$  g  $kg^{-1}$   $dm_{burnt}$ .

### 6.6.8 Uncertainty in Wetlands

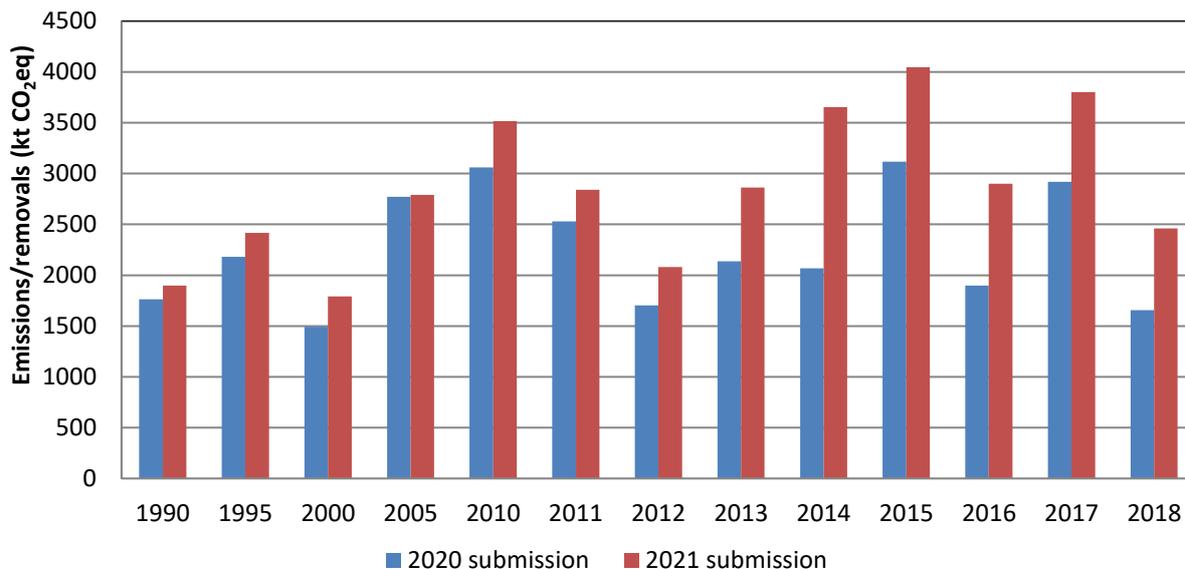
Drainage of organic soils within the Wetland land use category is significant by virtue of uncertainty in areal extent and emission factors used. Uncertainty analysis reveals that these two components contribute in equal measure to overall uncertainty.

The area of peatland drained for peat extraction is 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 compete 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. A similar issue arises with the use of proxy data from the national energy balance to estimate the area of peatland drained to meet demand for residential heating by the private, non-commercial sector.

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.

### 6.6.9 Wetlands recalculations and impact on emission trend

The main source of recalculations in Wetlands is associated with the correction of a transcription error associated with the summation of offsite emissions from horticultural peat harvesting (Figure 6.38). Additionally, revised data on the areas of land on which biomass burning occurred national contributed to the recalculation. The average recalculation across the timeseries is 20.9 per cent increase in emissions with significant interannual variability



*Figure 6.38 Comparison between the 2020 and 2021 submissions of estimated total emissions associated with the Wetlands category*

### 6.6.10 Wetlands category specific planned improvements

The inventory agency is currently funding a project aimed at investigating the peatland properties influencing greenhouse gas emissions and removals from peatlands in Ireland. This project includes a review of current models and tools used to assess peatland condition, and the significance of peatland properties and management in modelling GHG emissions. The characterisation of peatland types and their associated edaphic and ecosystem properties is also being investigated. This project is nearing completion. The results of this work will be integrated into methodological approaches for the sector as and when they become available. Similarly as discussed for the Cropland and Grassland land uses, the development of a spatial land use map will allow for refinements to the areal extent of peatlands in Ireland for reporting purposes in future years.

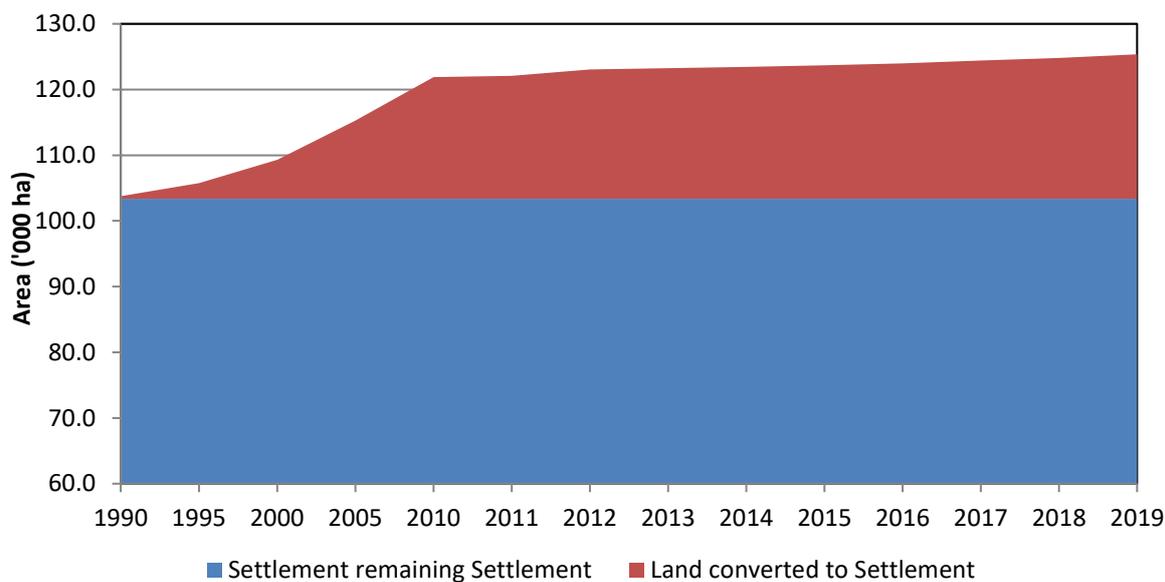
## 6.7 Settlements (4.E)

### 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 6.39. It is assumed Settlement remaining Settlement is constant since 1990. All new settlement activity is categorised as “in transition”.



*Figure 6.39 Estimated area of Settlements 1990 to 2019*

## 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 available as yet.

Table 6.18 includes the area of forest land converted to settlements for the years 1990-2019. 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<sub>2</sub>O 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*”<sup>12</sup> in 2012 suggested a nitrogen content of between 7.5 kg t<sup>-1</sup> for home composted organic waste which is used to estimate N<sub>2</sub>O 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.

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<sup>12</sup>

<http://www.rx3.ie/MDGUploadedFiles/file/rx3publications/rx3%20Organics%20Market%20Report%20300%20dpi.pdf>

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 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 6.40 presents a comparison between the 2020 and 2021 submissions of estimated total emissions associated with Settlements. Minor recalculations were undertaken for the years 2017 and 2018, on foot of updated statistics on sealed surface estimates. The net effect of these recalculations is a 0.1 per cent reduction in emissions in 2017 and 0.03 per cent increase in 2018.

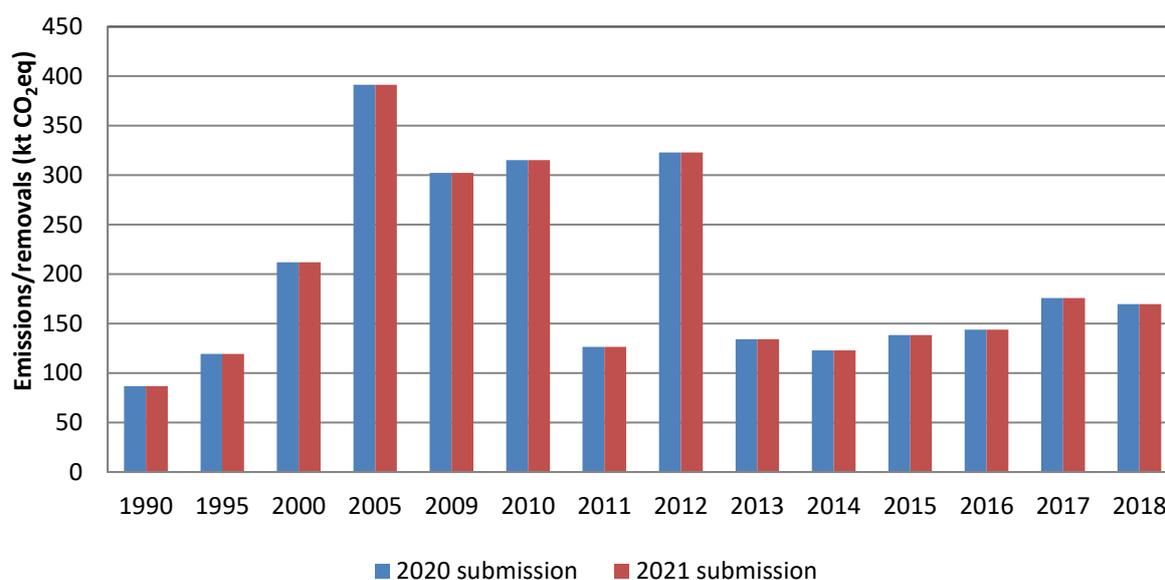


Figure 6.40 Comparison between the 2019 and 2020 submissions of estimated total emissions associated with Settlements

## 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 1990-2019. 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<sup>-1</sup> 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 small (Figure 6.41).

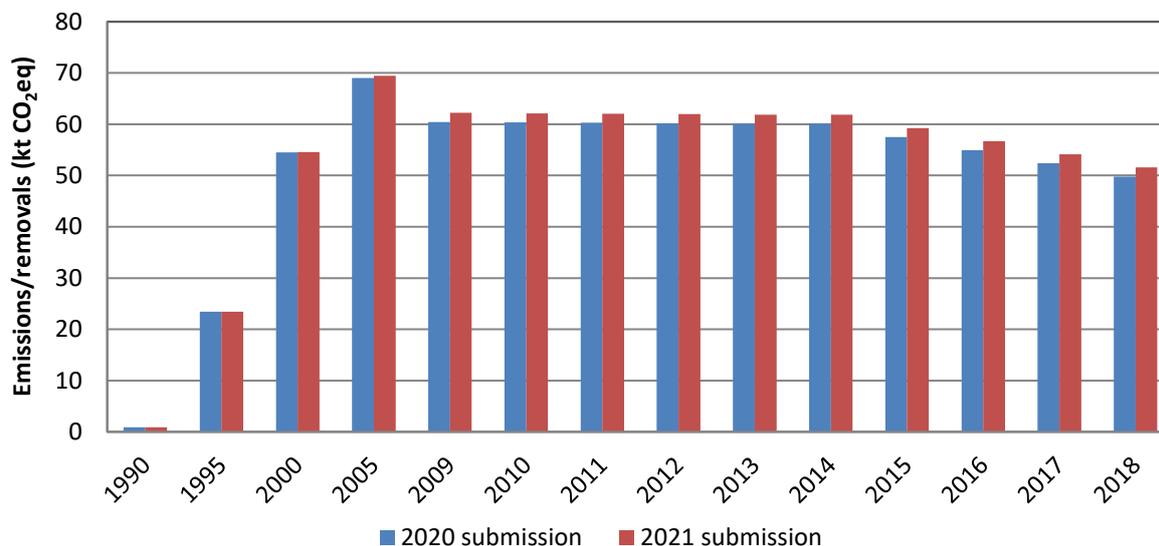


Figure 6.41 Comparison between the 2020 and 2021 submissions of estimated total emissions for Other Land

## 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 this submission for both LULUCF (Chapter 6) and activities under Article 3.3 of the Kyoto Protocol (Chapter 11) 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, both chapter 6 and 11 of this report have been substantially improved to provide additional transparency and consistency between Convention and KP reporting for LULUCF.

### 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 6.36 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 <sub>2</sub>	51.0	114.0	See Sections 6.3.4.7 and 6.3.5.7	Country Specific value of Chapter 6.3
4.B.1	Cropland Remaining Cropland	CO <sub>2</sub>	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 <sub>2</sub>	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 <sub>2</sub>	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 <sub>2</sub>	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 <sub>2</sub>	6.1	26.7	CORINE, BnM, SEAI, Expert opinion	Default value from IPCC Guidelines
4.D.2	Land Converted to Wetland	CO <sub>2</sub>	2.5	50.0	Deforestation data, Chapter 6.3	Country Specific value of Chapter 6.3
4.E.1	Settlement remaining Settlement	CO <sub>2</sub>	40.4	75.0	Expert assessment of national statistics, CORINE	Default value from IPCC Guidelines
4.E.2	Settlement in Transition	CO <sub>2</sub>	40.4	92.5	Expert assessment of national statistics, CORINE	Default value from IPCC Guidelines
4.F.1	Other Land remaining Other Land	CO <sub>2</sub>	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 <sub>2</sub>	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 <sub>4</sub>	30.0	100.0		
4.B	Cropland	CH <sub>4</sub>	100.0	39.1	Uncertainty in area of burning, scaled by reported Forest fire	Default value from IPCC Guidelines
4.C	Grassland	CH <sub>4</sub>	96.4	91.2	Uncertainty in area of burning, scaled by reported Forest fire	Default value from IPCC Guidelines
4.D	Wetland	CH <sub>4</sub>	86.0	66.5	Uncertainty in area of burning, scaled by reported Forest fire	Default value from IPCC Guidelines
4.E	Settlement	CH <sub>4</sub>	0.0	0.0	Uncertainty in area of burning, scaled by reported Forest fire	Default value from IPCC Guidelines
4.F	Other Land	CH <sub>4</sub>	0.0	0.0	Uncertainty in area of burning, scaled by reported Forest fire	Default value from IPCC Guidelines
4.A	Forest Land	N <sub>2</sub> O	30.0	100.0		Default value from IPCC Guidelines
4.B	Cropland	N <sub>2</sub> O	75.0	100.0	N <sub>2</sub> O emissions associated with burning only, Activity data same as CH <sub>4</sub> emissions for Burning	Default value from IPCC Guidelines
4.C	Grassland	N <sub>2</sub> O	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 <sub>2</sub> O	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 <sub>2</sub> O	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 unbiased? 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.

### 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 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 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. For example, the improvement to litter flow and turnover rates in conifer crops for this submission, as identified by the NIR 2012;
- 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 model has been cross-compared with the previous CARBWARE mode and is shown to improve CSC estimates for Irish forestry (section 6.10.1.3)
- CBM 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) 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 and CARBWARE

The CBM 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). 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 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, NIR2019).

For the afforestation (4A2) we refer to Figure 6.15 and related text of NIR 2019, which compared CBM and CARBWARE trends, again there is excellent agreement with the extensively validated CARBWARE model.

### 6.10.1.3 Validation of CBM with research data

#### Validation against real time forest NEE estimates

Eddy covariance measures the exchange of CO<sub>2</sub> 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 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 model outputs for corresponding species, age and yield classes. Validation of CBM forest removals (i.e. NEE) against eddy covariance show good agreement ( $r^2 = 0.84$ , Figure 6.42).

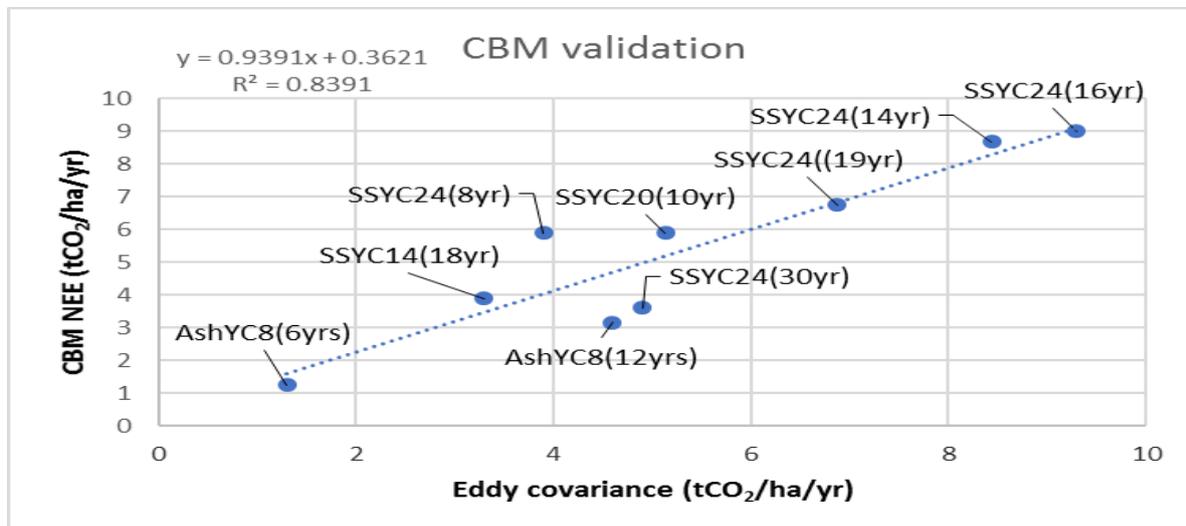


Figure 6.42 Validation of NEE estimated from CBM and eddy covariance data for different aged a Sitka spruce (SS) and Ash stands

## Validation of CBM biomass stock estimates

Research data from the COFORD research program (provided by Prof B Tobin (UCD)) was used to validate CBM C stock estimates, derived from corresponding species, yield class and silvicultural intervention categories (Table 6.37). The NFI estimated biomass stock values for Irish forests vary from 0 to 568 t C ha<sup>-1</sup> (mean value 72 t C ha<sup>-1</sup>) for the species types listed in Table 6.37. 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 6.37 A summary of the experimental validation dataset

Species	C stock range (t C ha <sup>-1</sup> )	Yield class range (m <sup>3</sup> ha <sup>-1</sup> yr <sup>-1</sup> )	Age range (years)	Number of sites (N)	Corresponding CBM 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 estimate of biomass C stocks was assessed using various statistical measures including:

- Adjusted r<sup>2</sup> and P value
- Percentage bias (Bias %)
- Root mean square error (RMSE)
- Percentage error at the 95% confidence interval (Error %)
- Students T test P value, where P values < 0.05 suggest that CBM and validation data are significantly different.

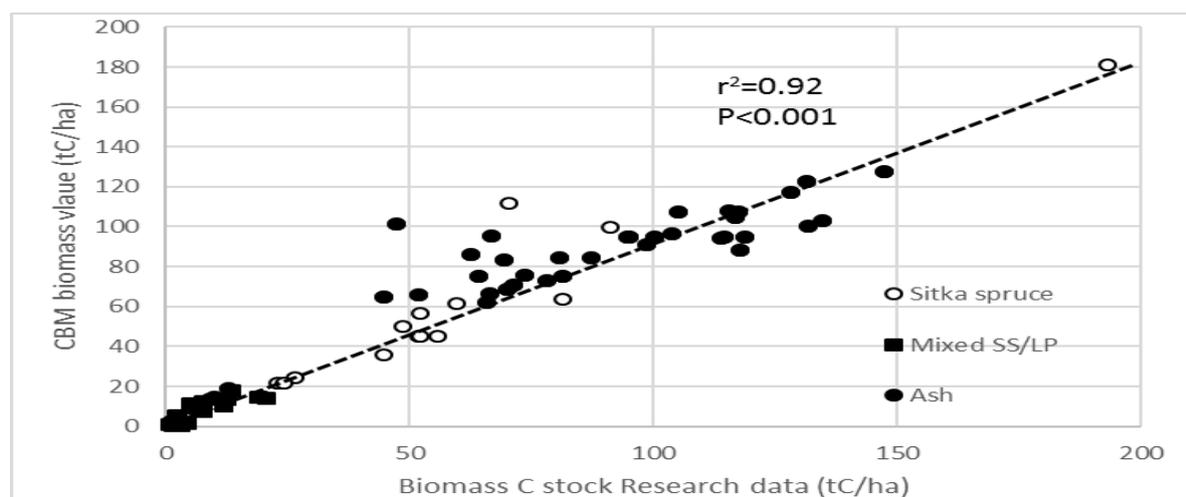


Figure 6.43 Validation of total biomass estimates from CBM and research data plots for different aged Sitka spruce, mixed Sitka spruce and Lodgepole pine (SS/LP) and Ash stands.

*Table 6.38 Independent cross validation statistics for modelled CBM and research plot total biomass stock estimates*

Species	Corresponding CBM 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
<b>Total</b>	<b>All</b>	<b>13.1</b>	<b>5.5</b>	<b>1.6</b>	<b>0.89ns</b>

Based on the statistical test carried out (see Figure 6.43 and Table 6.38) CBM predicts total biomass C stock for different forest types at a high degree of accuracy. The overall prediction error at the 95 % confidence interval is 5.5%.

## 6.10.2 Completeness and error checks in the compilation of the CRF tables

Transcription of data to the CRF reported and compilation of data in the required format can result in error of 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 see Table 6.37 and Table 6.38. 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 for using the Locator Tool (Table 6.37). 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<sub>2</sub>O 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. 6.37). DOM EFs agree slightly higher than the UK but again within the expected range. Reported IEF from organic soils are within the ranges reported. The IEFs for wildfires in Ireland is the highest reported value under the convention.

**Table 6.37 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 <sub>2</sub>	260.64	IE,NO,NA	Mg/kg biomass	8.3 to 260.64
Fire CH <sub>4</sub>	1.14	IE,NO,NA	Mg/kg biomass	0.03 to 1.14
Fire N <sub>2</sub> O	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 6.38). All of the reported IEFs for all pools are within the ranges reported for other countries.

**Table 6.38 Comparison of 2015 inventory year 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 <sub>2</sub>	151.8	IE,NO,NA	Mg/kg biomass	0.0009 to 151.8
Fire CH <sub>4</sub>	0.66	IE,NO,NA	Mg/kg biomass	0.29 to 0.03
Fire N <sub>2</sub> O	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 model for reporting forest emissions and removals for the EU LULUCF regulation was carried out in March/April 2019 (see NFAP, 2019). 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<sub>4</sub> is the gas concerned. Landfills represent a key emission category in Ireland and the emission estimates of CH<sub>4</sub> 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<sub>4</sub>)** 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<sub>4</sub>)** is a relatively recent new treatment of organic wastes for biogas recovery and is estimated for 2014 to 2019 for the first time in this submission;
- **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 2021 submission shows total GHG emissions of 904.9 kt CO<sub>2</sub> equivalent in the Waste sector in 2019, of which 5.A *Solid waste disposal* accounts for 74.8 per cent, 5.B *Biological treatment of solid waste* 4.9 per cent, 5.C *Incineration and open burning of waste* 3.6 per cent and 5.D *Wastewater treatment and discharge* 16.7 per cent. The latest estimates show that emissions in the Waste sector have decreased by 41.7 per cent from 1990 to 2019 mainly due to a 48.6 per cent decrease in CH<sub>4</sub> 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 <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O
<b>A. Solid Waste Disposal*</b>			
1. Managed Waste Disposal Sites	NA	NA, T2	NA
2. Unmanaged Waste Disposal Sites	NA	NA, T2	NA
<b>B. Biological Treatment of Solid Waste</b>			
1. Composting	NA	NA, T1	NA, T1
2. Anaerobic Digestion at Biogas Facilities	NA	NA, T1	NA, T1
<b>C. Incineration and Open Burning of Waste</b>			
1. Waste Incineration	T1	T1	T1
2. Open Burning of Waste	T1	T1	T1
<b>D. Wastewater Treatment and Discharge</b>			
1. Domestic Wastewater	NA	T1, T2	T1
2. Industrial Wastewater	NA	NA	NA
<b>E. Other</b>			
	NA	NA	NA

\*Key Category by level and trend in 2019 (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 1990-2019*

IPCC	Category	Gas	Unit	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
5.A.1	Managed Waste Disposal Sites	CH <sub>4</sub>	kt CO <sub>2</sub> eq	NO	NO	1268.2	1007.0	278.6	381.6	302.8	461.0	648.1	726.9	749.6	717.9	692.7	676.9
5.A.2	Unmanaged Waste Disposal Sites	CH <sub>4</sub>	kt CO <sub>2</sub> eq	1318.1	1592.8	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
5.B.1	Composting	CH <sub>4</sub>	kt CO <sub>2</sub> eq	NO	NO	NO	8.0	26.9	30.6	26.1	27.1	27.1	21.7	24.3	25.5	24.5	24.5
5.B.1	Composting	N <sub>2</sub> O	kt CO <sub>2</sub> eq	NO	NO	NO	5.7	19.3	21.9	18.7	19.4	19.4	15.5	17.4	18.2	17.5	17.5
5.B.2	Anaerobic digestion at biogas facilities	CH <sub>4</sub>	kt CO <sub>2</sub> eq	NO	NO	NO	NO	NO	NO	NO	NO	0.9	1.1	1.5	1.47	2.40	2.40
5.C.1	Waste incineration	CH <sub>4</sub>	kt CO <sub>2</sub> eq	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
5.C.1	Waste incineration	N <sub>2</sub> O	kt CO <sub>2</sub> eq	0.83	0.83	0.60	1.08	0.54	0.38	0.45	0.43	0.39	0.40	0.22	0.25	0.20	0.28
5.C.1	Waste incineration	CO <sub>2</sub>	kt CO <sub>2</sub> eq	83.0	83.0	58.7	106.3	53.5	37.0	44.4	42.4	38.5	39.0	22.0	24.2	20.1	27.3
5.C.2	Open burning of waste	CH <sub>4</sub>	kt CO <sub>2</sub> eq	1.05	1.27	1.73	2.32	0.42	0.64	0.21	0.14	0.13	0.14	0.13	0.14	0.17	0.22
5.C.2	Open burning of waste	N <sub>2</sub> O	kt CO <sub>2</sub> eq	0.27	0.32	0.44	0.58	0.11	0.16	0.06	0.04	0.04	0.04	0.04	0.04	0.05	0.06
5.C.2	Open burning of waste	CO <sub>2</sub>	kt CO <sub>2</sub> eq	12.62	15.19	18.08	22.23	7.52	6.82	3.22	2.18	2.64	2.86	2.69	2.87	3.41	4.65
5.D.1	Domestic wastewater	CH <sub>4</sub>	kt CO <sub>2</sub> eq	61.1	62.7	62.4	49.3	50.3	50.1	50.7	50.5	52.3	52.2	50.4	51.0	50.3	51.1
5.D.1	Domestic wastewater	N <sub>2</sub> O	kt CO <sub>2</sub> eq	75.1	73.1	82.6	89.4	94.2	92.9	93.1	93.3	93.6	94.1	96.7	97.2	97.6	99.9
	<b>Total Waste</b>		<b>kt CO<sub>2</sub>eq</b>	<b>1552.1</b>	<b>1829.2</b>	<b>1492.8</b>	<b>1292.0</b>	<b>531.4</b>	<b>621.9</b>	<b>539.7</b>	<b>696.4</b>	<b>883.1</b>	<b>953.9</b>	<b>964.9</b>	<b>938.7</b>	<b>908.8</b>	<b>904.9</b>

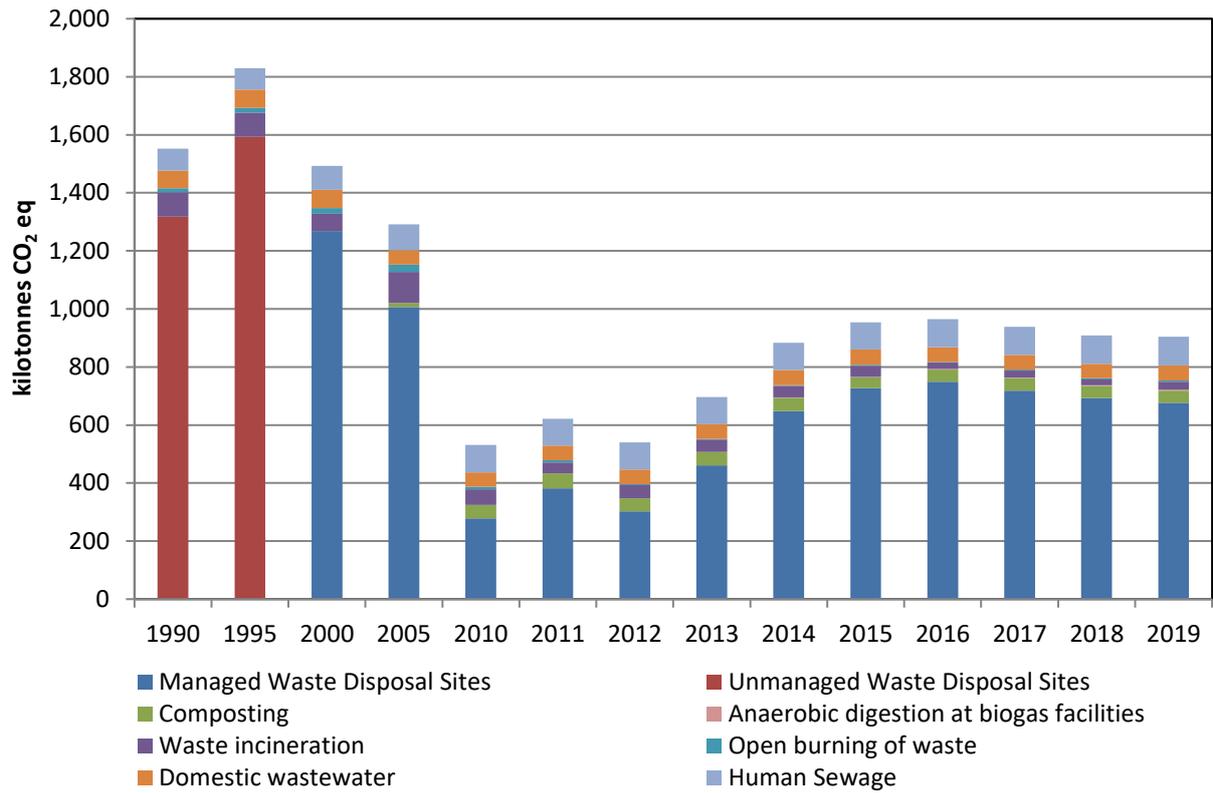


Figure 7.1 Total Emissions from Waste by Sector, 1990-2019

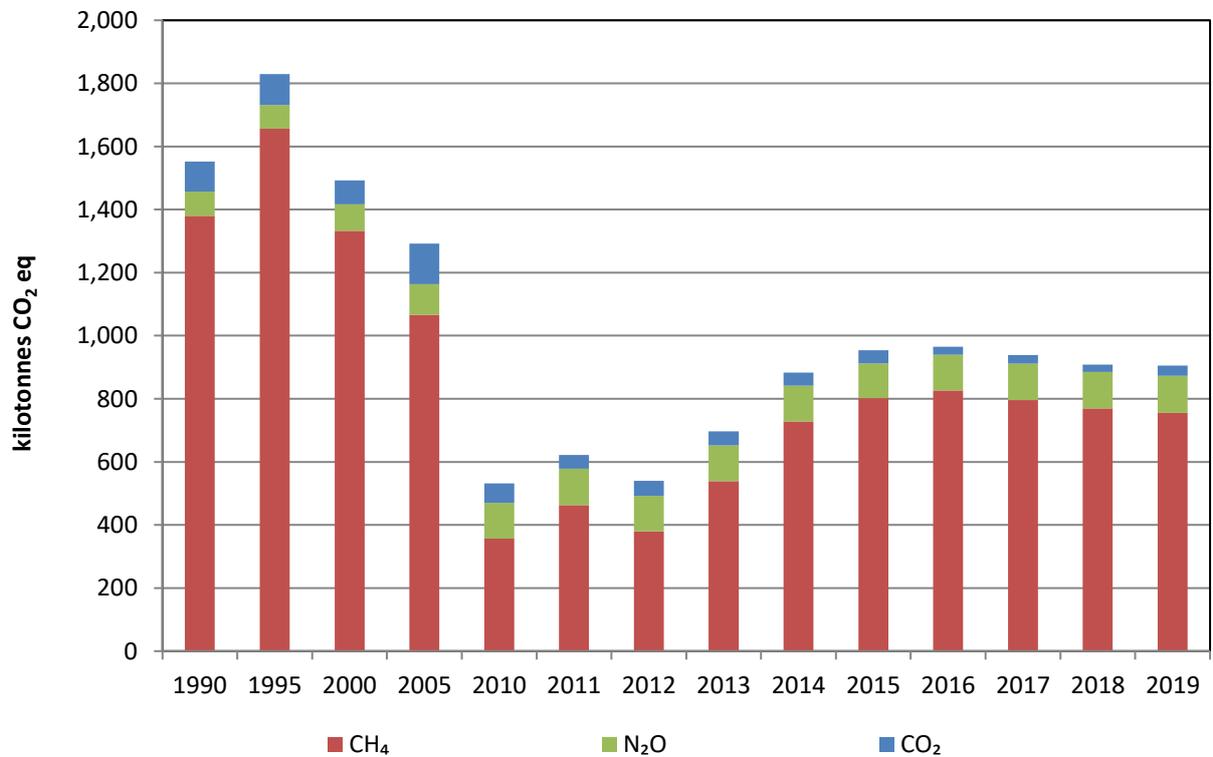


Figure 7.2 Total Emissions from Waste by Gas, 1990-2019

## 7.2 Emissions from Solid Waste Disposal (5.A)

The IPCC Level 3 emission source categories relevant under 5.A *Solid Waste Disposal* in 2019 are 5.A.1 *Managed Waste Disposal Sites* and 5.A.2 *Unmanaged Waste Disposal Sites*. Total CH<sub>4</sub> emissions from these activities amounted to 676.9 kt CO<sub>2</sub>eq in 2019.

### 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<sub>4</sub>). In addition to CH<sub>4</sub>, SWDS also produce biogenic carbon dioxide (CO<sub>2</sub>) and non-methane volatile organic compounds (NMVOCs) as well as smaller amounts of nitrous oxide (N<sub>2</sub>O), nitrogen oxides (NO<sub>x</sub>) 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<sub>4</sub> 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<sub>4</sub> and CO<sub>2</sub> 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<sub>4</sub> 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 time-frame 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).

Waste paper products are the key determinant of degradable carbon in landfills. The NWD shows a significant decline in the proportion of waste paper 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 2019. 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.

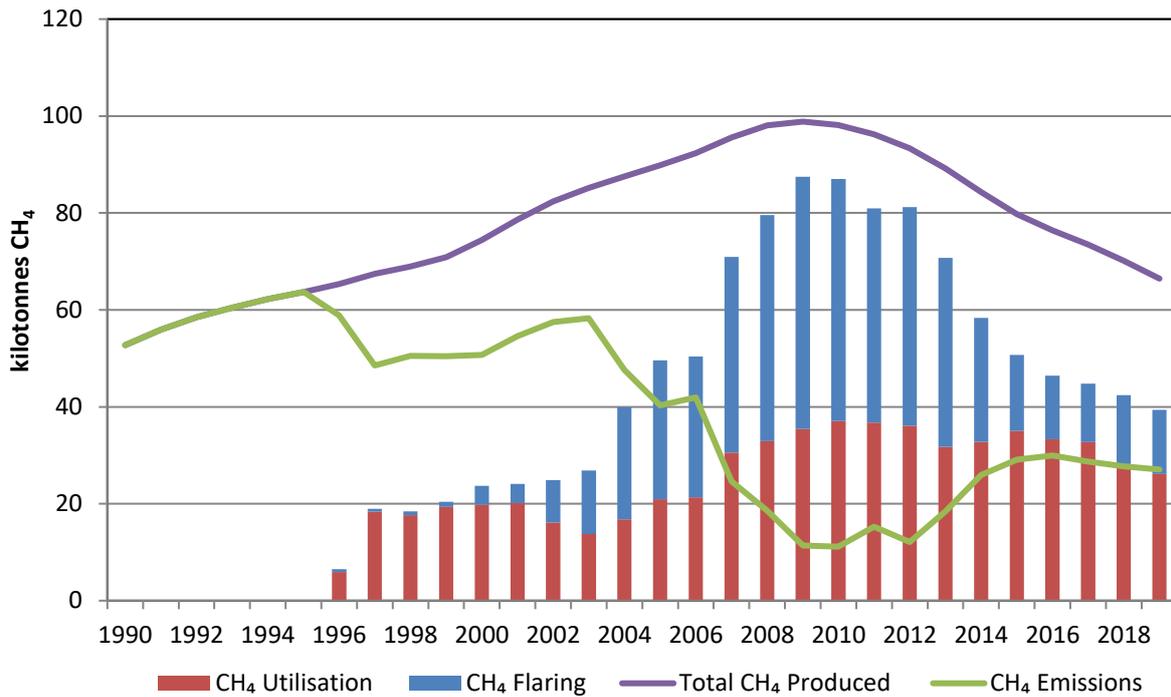
The default value of 0.5 is utilised for the fraction of DOC dissimilated ( $DOC_f$ )

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<sub>4</sub> 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 2019 found that there were 59 flares on 51 SWDS with 14 methane utilisation plants housing a total of 27 engines. The overall results of CH<sub>4</sub> production, utilisation and flaring are presented in Table 7.3.



**Figure 7.3 Methane Emissions from Solid Waste Disposal 1990-2019**

**Table 7.3. Methane Emissions from Solid Waste Disposal 1990-2019**

	Methane Generation (tonnes)	Methane Flaring (tonnes)	Methane Utilisation (tonnes)	Methane Recovery (tonnes)	Percent Methane Recovery (%)	Methane Emissions (tonnes)	Methane Emissions (kt CO <sub>2</sub> eq)
<b>1990</b>	52,723.00	-	-	-	0%	52,723.00	52.72
<b>1995</b>	63,710.36	-	-	-	0%	63,710.36	63.71
<b>2000</b>	74,400.15	3,855.11	19,818.49	23,673.60	32%	50,726.55	50.73
<b>2005</b>	89,865.44	28,638.38	20,947.12	49,585.50	55%	40,279.94	40.28
<b>2010</b>	98,123.39	49,886.65	37,090.88	86,977.53	89%	11,145.86	11.15
<b>2011</b>	96,212.33	44,205.15	36,744.73	80,949.88	84%	15,262.45	15.26
<b>2012</b>	93,335.39	45,121.03	36,102.70	81,223.72	87%	12,111.66	15.11
<b>2013</b>	89,169.69	38,988.32	31,742.57	70,730.89	79%	18,438.80	18.44
<b>2014</b>	84,277.04	25,538.51	32,814.48	58,352.99	69%	25,924.04	25.92
<b>2015</b>	79,755.03	15,619.44	35,058.52	50,677.96	64%	29,077.07	29.08
<b>2016</b>	76,375.49	13,076.51	33,316.55	46,393.06	61%	29,982.43	29.98
<b>2017</b>	73,506.45	12,043.13	32,747.10	44,790.24	61%	28,716.21	28.72
<b>2018</b>	70,115.29	14,240.19	28,166.73	42,406.92	60%	27,708.37	27.71
<b>2019</b>	66,434.59	13,236.95	26,122.55	39,359.50	59%	27,075.09	27.08

Table 7.3 and Figure 7.3 present the results for methane emissions from 5.A Solid Waste Disposal. These estimates of CH<sub>4</sub> 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<sub>4</sub> 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<sub>4</sub> generation. The utilisation of CH<sub>4</sub> remained generally constant up to 2006 since becoming established in 1996. The quantity of CH<sub>4</sub> 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<sub>4</sub> 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<sub>4</sub> generated and landfill gas management issues. Methane recovery through flaring and utilisation peaked in 2009.

*Table 7.4 Information related to Managed Waste Disposal (5.A.1)*

IPCC category	Category Description	Method used	CH <sub>4</sub> 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<sub>4</sub> generation, CH<sub>4</sub> flared and CH<sub>4</sub> utilised.

Despite continuous improvements in national data, the overall uncertainty associated with estimating CH<sub>4</sub> 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<sub>4</sub> generation which is combined with uncertainties of 30 per cent and 10 per cent for CH<sub>4</sub> 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 is no category-specific recalculation this year for 5.A.1.

### 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 0.67 over this period.

*Table 7.5 Information related to Unmanaged Waste Disposal Sites (5.A.2)*

IPCC category	Category Description	Method used	CH <sub>4</sub> 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 1990-2018 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<sub>4</sub> and N<sub>2</sub>O emissions from these activities amounted to 44.4 kt CO<sub>2</sub>eq in 2019.

## 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<sub>2</sub>). CH<sub>4</sub> 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<sub>4</sub> 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<sub>2</sub>O. 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<sub>4</sub> and N<sub>2</sub>O (e.g., Vesterinen, 1996).

In this submission, this category includes household, and for the first time, 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.

#### Equation 4.1;

$$CH_4 \text{ Emissions} = \sum (M_i * E_{i,CH_4}) * 10^3 - R$$

Where:

$CH_4 \text{ Emissions}$  = total CH<sub>4</sub> emissions in inventory year, kt CH<sub>4</sub>

$M_i$  = mass of organic waste treated by biological treatment type  $i$ , kt

$E_{i,CH_4}$  = EF for treatment (composting)  $i$ , g CH<sub>4</sub>/kg waste treated

$R$  = total amount of CH<sub>4</sub> recovered in inventory year, kt CH<sub>4</sub>

#### Equation 4.2;

$$N_2O \text{ Emissions} = \sum (M_i * E_{i,N_2O}) * 10^3$$

Where,

$E_{i,N_2O}$  = EF for treatment (composting)  $i$ , g N<sub>2</sub>O/kg waste treated.

Emission estimates are made for CH<sub>4</sub> and N<sub>2</sub>O 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 <sub>4</sub> Emission Factor	N <sub>2</sub> O Emission Factor	Emission Factor Reference
5.B.1	Composting	T1	10 g CH <sub>4</sub> /kg	0.6g N <sub>2</sub> O/kg	2006 IPCC Guidelines Table 4.1
5.B.2	Anaerobic digestion	T1	2 g CH <sub>4</sub> /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 2001–2018 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

Recalculations to emissions of on average 102 per cent from composting is a result of including commercial organic waste in this submission for all years from 2020 to 2019 for the first time.

### 7.3.1.6 Category-specific Planned Improvements

There are planned improvements for this category. The EPA’s Waste Statistics Team plan to improve estimates of material composted at treatment facilities and to examine also bio stabilisation of organic fines.

## 7.3.2 Anaerobic Digestion at Biogas Facilities (5.B.2)

### 7.3.2.1 Category Description

In this submission, estimates of methane emissions are quantified for Anaerobic digestion at biogas facilities for the first-time using data provided for 2017 and 2018 from 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<sub>4</sub> used to produce heat and/or electricity is reported in the Energy Sector while emissions of CH<sub>4</sub> from such facilities due to unintentional leakages during process disturbances or other unexpected events are reported here. Data for 2019 is assumed the same as 2018, as it is not yet available. Data for 2014 to 2016 is currently estimated by expert judgement and will be revised in future submissions after further consideration 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<sub>4</sub> in line with the 2006 IPCC guidelines and the CH<sub>4</sub> 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 2016 and 2017, and estimated for 2014, 2015 and 2019. Emissions from 1990 to 2013 are reported as Not Occurring.

**Equation 4.1;**

$$CH_4 \text{ Emissions} = \sum (M_i * E_{i,CH_4}) * 10^3 - R$$

Where:

$CH_4 \text{ Emissions}$  = total  $CH_4$  emissions in inventory year, kt  $CH_4$

$M_i$  = mass of organic waste treated by biological treatment type  $i$ , kt

$E_{i,CH_4}$  = 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 2014–2019 needs further improvement as data become available.

### 7.3.2.4 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.

### 7.3.2.5 Category-specific Recalculations

Estimates of  $CH_4$  are provided for the first time for the years 2014 to 2019.

### 7.3.2.6 Category-specific Planned Improvements

There are planned improvements for this category. The EPA's Waste Statistics Team plan to improve estimates of material digested at treatment facilities.

## 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 32.5 kt  $CO_2$  eq in 2019.

## 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<sub>2</sub>) 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 was 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<sub>2</sub> 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<sub>2</sub>

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<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O) 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 <sub>4</sub>	60 kg/kt waste (wet)	2006 IPCC Guidelines Table 5.3
				100% oxidation factor	2006 IPCC Guidelines Table 5.2
			N <sub>2</sub> O	20 g/t waste (wet)	2006 IPCC Guidelines Table 5.4
				100% oxidation factor	2006 IPCC Guidelines Table 5.2
			CO <sub>2</sub>	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 <sub>4</sub>	0.56 g/t (wet)	2006 IPCC Guidelines section 5.4.2
				100% oxidation factor	2006 IPCC Guidelines Table 5.2
			N <sub>2</sub> O	100 g/t waste (wet)	2006 IPCC Guidelines Table 5.46
				100% oxidation factor	2006 IPCC Guidelines Table 5.2
				100% fossil carbon (as % of total carbon)	2006 IPCC Guidelines Table 5.2
			CO <sub>2</sub>	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; McCoolle et al, 2009; McCoolle et al, 2010; McCoolle et al, 2011; McCoolle et al, 2012 ; McCoolle et al, 2013 and McCoolle 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;**

$$CO_2Emissions = \sum_i (AL_i * CL_i * OF_i) * 44/12$$

Where:

$CO_2Emissions$  = CO<sub>2</sub> 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<sub>2</sub>

### 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 were minor recalculations for 2017 and 2018 for *Open burning of waste, MSW(5.C.2)* due to revised activity data.

### 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. 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 <sub>4</sub>		6.5 kg/t waste (wet)	2006 IPCC Guidelines section 5.4.2
			58% oxidation factor	2006 IPCC Guidelines Table 5.2
	N <sub>2</sub> O		150 g/t waste (dry)	2006 IPCC Guidelines Table 5.6
			58% oxidation factor	2006 IPCC Guidelines Table 5.2
	CO <sub>2</sub>	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.

### 7.4.2.5 Category-specific Recalculations

The open burning of farm plastics was included in the inventory for the first time in this submission. This has resulted in an average recalculation of 3.7kt CO<sub>2</sub> eq across the time series as this new source was added in this submission. The activity data for open burning of household waste was also updated for 2016 and 2017 resulting in a recalculation of 35 per cent for these years.

### 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 2017 are *5.D.1 Domestic Wastewater* (CH<sub>4</sub>) and (N<sub>2</sub>O). Total CH<sub>4</sub> and N<sub>2</sub>O emissions from these activities amounted to 147.87 kt CO<sub>2</sub>eq in 2018.

### 7.5.1 Domestic Wastewater (5.D.1)

#### 7.5.1.1 Category Description

Wastewater can be a source of methane (CH<sub>4</sub>) when treated or disposed anaerobically. It can also be a source of nitrous oxide (N<sub>2</sub>O) emissions. Carbon dioxide (CO<sub>2</sub>) 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).

### 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 waste water treatment systems treating waste water 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<sub>4</sub> 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<sub>4</sub> 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 13 were operational for part or all of 2019.

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.

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<sub>4</sub> emissions from SWDS and is accounted for in *5.A Solid Waste Disposal*. The sludge applied to agricultural land contributes to N<sub>2</sub>O emissions from soils and is included in emission estimates for *3.D.1 Direct Emissions to Soil*. The total emissions of CH<sub>4</sub> from wastewater are estimated using equation 6.1 from the 2006 IPCC guidelines.

**Equation 6.1;**

$$CH_4 \text{ Emissions} = [ \sum (U_i * T_{i,j} * EF_j) ] (TOW - S) - R$$

Where:

$CH_4 \text{ Emissions}$  = CH<sub>4</sub> emissions in inventory year, kg CH<sub>4</sub>/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

$T_{ij}$  = 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<sub>4</sub> / kg BOD

$R$  = amount of CH<sub>4</sub> recovered in inventory year, kg CH<sub>4</sub>/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 ( $T_{ij}$ ) as follows;

1. Organically degradable material in wastewater at treatment plant with biogas facility (kg BOD y<sup>-1</sup>)
2. Organically degradable material in wastewater at treatment plant without biogas facility (kg BOD y<sup>-1</sup>)
3. Organically degradable material in wastewater in septic tanks (kg BOD y<sup>-1</sup>)

### 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<sub>4</sub> correction factor (MCF) based on the 2006 IPCC guidelines default value, has been revised down from 0.5 to 0.083. The CH<sub>4</sub> 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<sub>4</sub>/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<sub>4</sub>/kg BOD (Table 7.9)

$B_o$  = maximum CH<sub>4</sub> producing capacity, kg CH<sub>4</sub>/kg BOD (0.6 kg CH<sub>4</sub>/kg BOD)

$MCF_j$  = methane correction factor (fraction),  $(0.5 \cdot 2/12 = 0.083)$

The CH<sub>4</sub> 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<sub>4</sub>/kg BOD; based on a MCF of 0.03 (assumed some anaerobic) and a B<sub>0</sub> 0.6 kg CH<sub>4</sub>/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 <sub>4</sub>	0.05 kg CH <sub>4</sub> /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 <sub>4</sub>	0.018 kg CH <sub>4</sub> /kg BOD	2006 IPCC Guidelines Table 6.2, Monaghan et al. 2009
5.D.1	Sewage	T1	N <sub>2</sub> O	3.2 g N <sub>2</sub> O/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<sub>2</sub>O can be produced during these processes through nitrification and denitrification. N<sub>2</sub>O emissions are estimated using equation 6.7 and 6.8 of the 2006 IPCC guidelines. Parameter values and emission estimates of N<sub>2</sub>O are provided in Table 7.10.

**Equation 6.7;**

$$N_2O \text{ Emissions} = N_{EFFLUENT} \cdot EF_{EFFLUENT} \cdot 44/28$$

Where:

$N_2O \text{ emissions}$  = N<sub>2</sub>O emissions in inventory year, kg N<sub>2</sub>O/yr

$N_{EFFLUENT}$  = nitrogen in the effluent discharged to aquatic environments, kg N/yr

$EF_{EFFLUENT}$  = emission factor (0.005 kg N<sub>2</sub>O-N/kg N) for discharge to wastewater (Table 6.11),

The factor 44/28 is the conversion of kg N<sub>2</sub>O-N into kg N<sub>2</sub>O.

$N_{EFFLUENT}$  is estimated from equation 6.8.

**Equation 6.8;**

$$N_{EFFLUENT} = P \cdot Protein \cdot F_{NPR} \cdot F_{NON-CON} \cdot F_{IND-COM} - N_{SLUDGE}$$

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<sub>2</sub>O emissions from human sewage 1990-2019**

Year	Pop (million)	Days	Per capita protein consumption (g/day)	N fraction in protein (IPCC default)	Effluent EF kg N <sub>2</sub> O-N/kg-N (IPCC default)	Non-consumed protein (IPCC default)	Industrial co- discharge (IPCC default)	N <sub>2</sub> O * (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	115.0	0.16	0.005	1.1	1.25	0.300
2010	4.555	365	110.0	0.16	0.005	1.1	1.25	0.316
2011	4.575	365	108.0	0.16	0.005	1.1	1.25	0.312
2012	4.585	365	108.0	0.16	0.005	1.1	1.25	0.312
2013	4.593	365	108.0	0.16	0.005	1.1	1.25	0.313
2014	4.610	365	108.0	0.16	0.005	1.1	1.25	0.314
2015	4.635	365	108.0	0.16	0.005	1.1	1.25	0.316
2016	4.762	365	108.0	0.16	0.005	1.1	1.25	0.324
2017	4.785	365	108.0	0.16	0.005	1.1	1.25	0.326
2018	4.807	365	108.0	0.16	0.005	1.1	1.25	0.328
2019	4.922	365	108.0	0.16	0.005	1.1	1.25	0.335

\*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 no recalculations for this category for this year in this submission.

#### 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<sub>4</sub> 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 (1990-2018)**

2020 Submission		Units	1990	1995	2000	2005	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
5.A.1	Managed Waste Disposal Sites	kt CO <sub>2</sub> e	NO	NO	1,268.2	1,007.0	284.8	278.6	381.6	302.8	461.0	648.1	726.9	749.6	717.9	692.7
5.A.2	Unmanaged Waste Disposal Sites	kt CO <sub>2</sub> e	1,318.1	1,592.8	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
5.B.1	Treatment of solid waste- composting	kt CO <sub>2</sub> e	NO	NO	NO	13.8	21.1	21.0	22.9	22.4	22.7	19.3	20.7	19.9	25.6	25.6
5.B.2	Anaerobic digestion at biogas facilities	kt CO <sub>2</sub> e	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5.C.1	Waste Incineration-Biogenic	kt CO <sub>2</sub> e	0.02	0.02	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5.C.1	Waste Incineration-Fossil	kt CO <sub>2</sub> e	83.8	83.8	59.3	107.4	63.3	54.0	37.4	44.8	42.8	38.9	39.4	22.2	24.4	20.3
5.C.2	Open Burning of Waste-Biogenic	kt CO <sub>2</sub> e	0.6	0.7	1.1	1.6	0.1	0.1	0.4	0.1	0.1	0.0	0.0	0.0	0.0	0.0
5.C.2	Open Burning of Waste-Fossil	kt CO <sub>2</sub> e	13.3	16.1	19.1	23.5	7.2	7.9	7.2	3.4	2.3	2.8	3.0	2.8	3.0	3.6
5.D.1	Domestic Wastewater	kt CO <sub>2</sub> e	61.1	62.7	62.4	49.3	51.5	50.3	50.1	50.7	50.5	52.3	52.2	50.4	51.0	50.3
5.D.1	Domestic Wastewater	kt CO <sub>2</sub> e	75.1	73.1	82.6	89.4	93.8	94.2	92.9	93.1	93.3	93.6	94.1	96.7	97.2	97.6
5.D.2	Industrial Wastewater	kt CO <sub>2</sub> e	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
<b>Total Waste</b>		<b>kt CO<sub>2</sub>e</b>	<b>1,552.1</b>	<b>1,829.2</b>	<b>1,492.8</b>	<b>1,292.0</b>	<b>521.6</b>	<b>506.2</b>	<b>592.4</b>	<b>517.3</b>	<b>672.6</b>	<b>855.0</b>	<b>936.3</b>	<b>941.6</b>	<b>919.2</b>	<b>890.1</b>
2021 Submission		Units	1990	1995	2000	2005	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
5.A.1	Managed Waste Disposal Sites	kt CO <sub>2</sub> e	NO	NO	1,268.2	1,007.0	284.8	278.6	381.6	302.8	461.0	648.1	726.9	749.6	717.9	692.7
5.A.2	Unmanaged Waste Disposal Sites	kt CO <sub>2</sub> e	1,318.1	1,592.8	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
5.B.1	Treatment of solid waste- composting	kt CO <sub>2</sub> e	NO	NO	NO	13.8	21.1	46.2	52.4	44.8	46.5	46.5	37.2	41.6	43.7	42.0
5.B.2	Anaerobic digestion at biogas facilities	kt CO <sub>2</sub> e	NO	NO	NO	NO	NO	NO	NO	NO	NO	0.9	1.1	1.5	1.5	2.4
5.C.1	Waste Incineration-Biogenic	kt CO <sub>2</sub> e	0.02	0.02	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5.C.1	Waste Incineration-Fossil	kt CO <sub>2</sub> e	83.8	83.8	59.3	107.4	63.3	54.0	37.4	44.8	42.8	38.9	39.4	22.2	24.4	20.3
5.C.2	Open Burning of Waste-Biogenic	kt CO <sub>2</sub> e	0.6	0.7	1.1	1.6	0.1	0.1	0.4	0.1	0.1	0.0	0.0	0.0	0.0	0.0
5.C.2	Open Burning of Waste-Fossil	kt CO <sub>2</sub> e	13.3	16.1	19.1	23.5	7.2	7.9	7.2	3.4	2.3	2.8	3.0	2.8	3.0	3.6
5.D.1	Domestic Wastewater	kt CO <sub>2</sub> e	61.1	62.7	62.4	49.3	51.5	50.3	50.1	50.7	50.5	52.3	52.2	50.4	51.0	50.3
5.D.1	Domestic Wastewater	kt CO <sub>2</sub> e	75.1	73.1	82.6	89.4	93.8	94.2	92.9	93.1	93.3	93.6	94.1	96.7	97.2	97.6
5.D.2	Industrial Wastewater	kt CO <sub>2</sub> e	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
<b>Total Waste</b>		<b>kt CO<sub>2</sub>e</b>	<b>1,552.1</b>	<b>1,829.2</b>	<b>1,492.8</b>	<b>1,292.0</b>	<b>521.6</b>	<b>531.4</b>	<b>621.9</b>	<b>539.7</b>	<b>696.4</b>	<b>883.1</b>	<b>953.9</b>	<b>964.9</b>	<b>938.7</b>	<b>908.8</b>

**Table 7.11(b) Absolute and relative recalculations in the Waste Sector (1990-2018)**

<b>Absolute change</b>		<b>Units</b>	<b>1990</b>	<b>1995</b>	<b>2000</b>	<b>2005</b>	<b>2009</b>	<b>2010</b>	<b>2011</b>	<b>2012</b>	<b>2013</b>	<b>2014</b>	<b>2015</b>	<b>2016</b>	<b>2017</b>	<b>2018</b>	
5.A.1	Managed Waste Disposal Sites	kt CO <sub>2</sub> e	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	
5.A.2	Unmanaged Waste Disposal Sites	kt CO <sub>2</sub> e	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
5.B.1	Treatment of solid waste- composting	kt CO <sub>2</sub> e	-	-	-	-	0.00	25.18	29.51	22.40	23.75	27.18	26.54	21.75	18.06	16.33	
5.B.2	Anaerobic digestion at biogas facilities	kt CO <sub>2</sub> e	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
5.C.1	Waste Incineration-Biogenic	kt CO <sub>2</sub> e	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
5.C.1	Waste Incineration-Fossil	kt CO <sub>2</sub> e	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
5.C.2	Open Burning of Waste-Biogenic	kt CO <sub>2</sub> e	-	-	-	-	-	-	-	-	-	-	-	-	-0.00	0.00	
5.C.2	Open Burning of Waste-Fossil	kt CO <sub>2</sub> e	-	-	-	-	-	-	-	-	-	-	-	-	-0.00	0.01	
5.D.1	Domestic Wastewater	kt CO <sub>2</sub> e	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
5.D.1	Domestic Wastewater	kt CO <sub>2</sub> e	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
5.D.2	Industrial Wastewater	kt CO <sub>2</sub> e	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<b>Total Waste</b>		<b>kt CO<sub>2</sub>e</b>	-	-	-	-	-	<b>25.18</b>	<b>29.51</b>	<b>22.40</b>	<b>23.75</b>	<b>28.09</b>	<b>17.62</b>	<b>23.24</b>	<b>19.53</b>	<b>18.74</b>	
<b>Relative change</b>		<b>Units</b>															
5.A.1	Managed Waste Disposal Sites	kt CO <sub>2</sub> e	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0%
5.A.2	Unmanaged Waste Disposal Sites	kt CO <sub>2</sub> e	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5.B.1	Treatment of solid waste- composting	kt CO <sub>2</sub> e	-	-	-	-	0.0%	120.0%	128.8%	100.0%	104.5%	140.9%	80.0%	709.3%	70.4%	63.7%	
5.B.2	Anaerobic digestion at biogas facilities	kt CO <sub>2</sub> e	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
5.C.1	Waste Incineration-Biogenic	kt CO <sub>2</sub> e	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
5.C.1	Waste Incineration-Fossil	kt CO <sub>2</sub> e	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
5.C.2	Open Burning of Waste-Biogenic	kt CO <sub>2</sub> e	-	-	-	-	-	-	-	-	-	-	-	-	-0.8%	5.4%	
5.C.2	Open Burning of Waste-Fossil	kt CO <sub>2</sub> e	-	-	-	-	-	-	-	-	-	-	-	-	-0.1%	0.4%	
5.D.1	Domestic Wastewater	kt CO <sub>2</sub> e	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
5.D.1	Domestic Wastewater	kt CO <sub>2</sub> e	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
5.D.2	Industrial Wastewater	kt CO <sub>2</sub> e	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<b>Total Waste</b>		<b>kt CO<sub>2</sub>e</b>	-	-	-	-	-	<b>5.0%</b>	<b>5.0%</b>	<b>4.3%</b>	<b>3.5%</b>	<b>3.3%</b>	<b>1.9%</b>	<b>2.5%</b>	<b>2.1%</b>	<b>2.1%</b>	

## 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<sub>2</sub> and N<sub>2</sub>O Emissions

### 9.1 Description of Sources of Indirect Emissions in GHG Inventory

Parties may report indirect emissions of CO<sub>2</sub> from the atmospheric oxidation of CH<sub>4</sub>, CO and NMVOCs, and indirect emissions of N<sub>2</sub>O 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<sub>2</sub> equivalent emissions included in national totals. Ireland reports the indirect CO<sub>2</sub> 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<sub>2</sub> emissions from NMVOC accounted for 0.13 per cent (72.6 kt of CO<sub>2</sub> equivalent) and 0.18 per cent (106.1 kt of CO<sub>2</sub> equivalent) of total national emissions in 1990 and 2019, respectively. See Figure 9.1 below. The national total for Ireland includes indirect CO<sub>2</sub> emissions from 2.D.3, 2.G.4 and 2.H.2 categories and is fully consistent with the national total emissions reported in the first commitment period of 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.D.3.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.

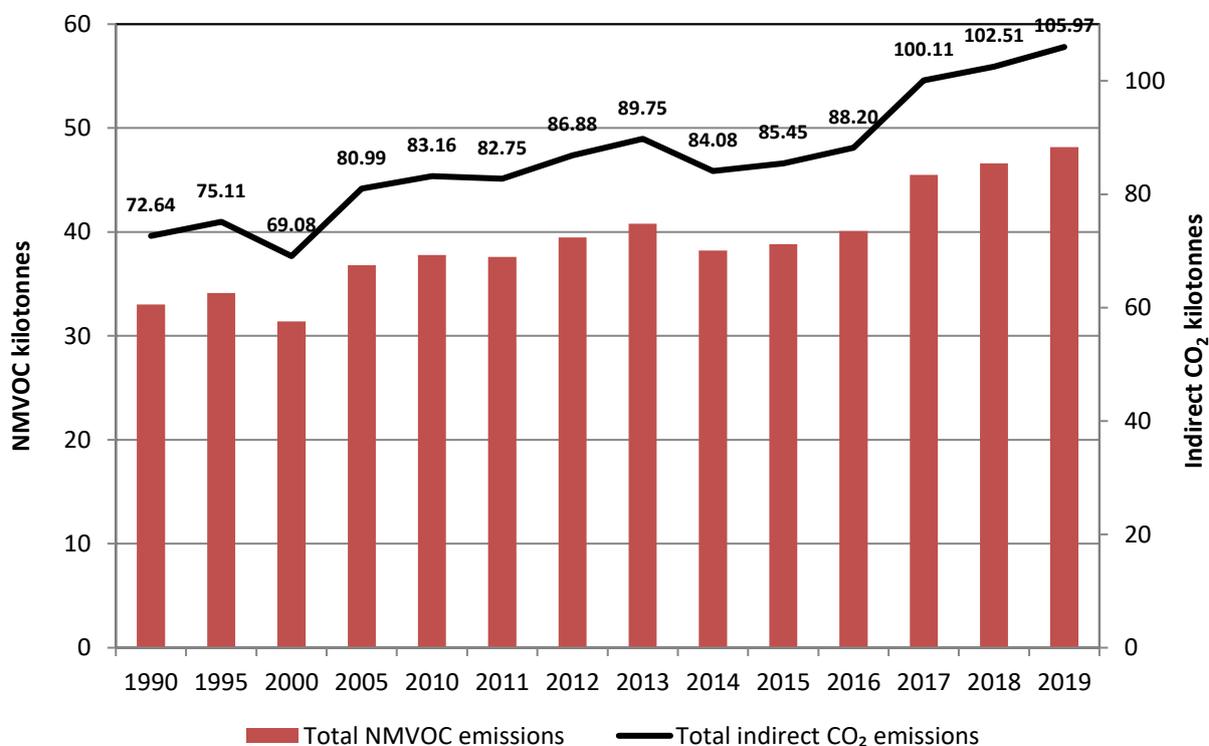


Figure 9.1 Total Indirect CO<sub>2</sub> emissions 1990-2019

## 9.2 Methodological Issues

Methodologies for estimating these NMVOC emissions can be found in the EEA/EMEP Emission Inventory Guidebook (EEA, 2016). The UNFCCC reporting format explicitly provides for the inclusion of CO<sub>2</sub> 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<sub>2</sub> from the combustion of fuels (Section 3.2), where the CO<sub>2</sub> 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<sub>2</sub> emission estimates are derived from NMVOCs by assuming that 60 per cent of the mass of NMVOCs is converted to CO<sub>2</sub>.

The activity data used for computing estimates of CO<sub>2</sub> 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 2019 used for reporting to the UNECE under the Convention on Long Range Transboundary Air Pollution (CLRTAP) (UNECE, 1999) and the National Emissions Ceilings 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 2021 (Duffy et al, 2021).

### 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 in this category are associated with revised activity data for animal feedstock production provided by the national statistics office. Recalculations focused on updating activity data as outlined in Ireland's Informative Inventory Report 2021 (Duffy et al, 2021).

### 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 2021 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 2021 submission CRF tables. The original and revised numerical values of the emissions estimates for the years 1990-2018, 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 1990-2018 included in the 2020 submission are outlined below (Figures 10.1 to 10.6).

### 10.2.1 Recalculations in Energy

The overall effect of recalculations on Energy sector emissions was an increase by 0.13 per cent on average per annum and 1,395.3 kt CO<sub>2</sub> eq in total in the 1990-2018 trend. The largest recalculation occurred in 2018, an increase of 1.2 per cent or 447.2 kt CO<sub>2</sub> eq. The reasons for the changes are outlined as follows;

- In this submission, there are extensive recalculation changes based on significant revisions to the historical energy balances going back as far as 1990. This is because SEAI (providers of national energy balance data) have incorporated a major new data set on business energy use for the first time. This is the Business Energy Use Survey (BEUS), first published by the Central Statistics Office (CSO) in December 2018. This valuable new data source provides a new basis for the breakdown of energy use in the commercial services, public services and industrial sectors, at a level of detail not previously possible. SEAI have revised the National Energy Balances from 1990 to 2018 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 2017 with the 2018 and 2019 splits based on the latest 2017 splits.

The following are some important points of note:

- Improved data allows more accurate allocation of final energy use in industry and services
- Revisions are extensive but no real change to overall type of fuel, i.e. does not affect total emissions
- No change to ETS / non-ETS split

The following are the individual sectors which have been affected as a result of the redistribution of fuel based on the new improved approach:

- In the Manufacturing Industry and Construction sector 1.A.2, there has been an extensive redistribution of oil and natural gas between the energy sub-sectors. 1990-1996, the oil use in this sector increased as a result of reallocating oil use within the commercial / services sector 1.A.4.a to 1.A.2. 1997-2018, there was a significant redistribution of oil from 1.A.2 to 1.A.4.a and 1.A.4.b. In turn, there was a significant redistribution of natural gas from 1.A.4.a to 1.A.2 from 2001 to 2018 (with the exception of 2004 and 2006, where the quantities in these two years were allocated to 1.A.4.a). Overall, there was an annual average reduction of approximately 3.6 per cent over the time series.
- In the Commercial/Institutional sector 1.A.4.a, there was a significant reallocation of oil and natural gas out of the sector over the entire time series from 1990-2018. 1990-1996, a portion of oil was redistributed from 1.A.4.a to both 1.A.2 and 1.A.4.b. 1997-2018, a substantial quantity of oil was moved into the residential sector 1.A.4.b. In turn, there was a significant redistribution of natural gas from 1.A.4.a to 1.A.2 from 2001 to 2018 (with the exception of 2004 and 2006, where the quantities in these two years were allocated to 1.A.4.a). Overall, there was an annual average reduction of approximately 16.2 per cent over the time series.
- In the Residential sector 1.A.4.b, there was a significant increase in the overall fuel use throughout the time series. 1990-1996, oil was reallocated from the Commercial / Services 1.A.4.a sector to the Residential sector. 1997-2001, the recalculated deficits of oil use for both 1.A.2 and 1.A.4.a are now allocated to the Residential sector 1.A.4.b. Overall, there is an annual average increase in emissions of 8.8 per cent over the time series 1990-2018.
- Other Transport (1.A.3.e.i pipeline transport) has been updated and as a result there is a recalculation for all years. The annual difference is less than 1.0 kt CO<sub>2</sub> eq or approximately 0.6 per cent per annum within this sub-sector. In previous years, the losses accounted for distribution losses whereas now, all transport losses are included (i.e. transmission and distribution).

The detailed results of the recalculations are given in CRF Tables 8s1 for the relevant years. The impact of the recalculations in the Energy sector between annual submissions in the 1990-2018 time series is outlined below in Figure 10.1.

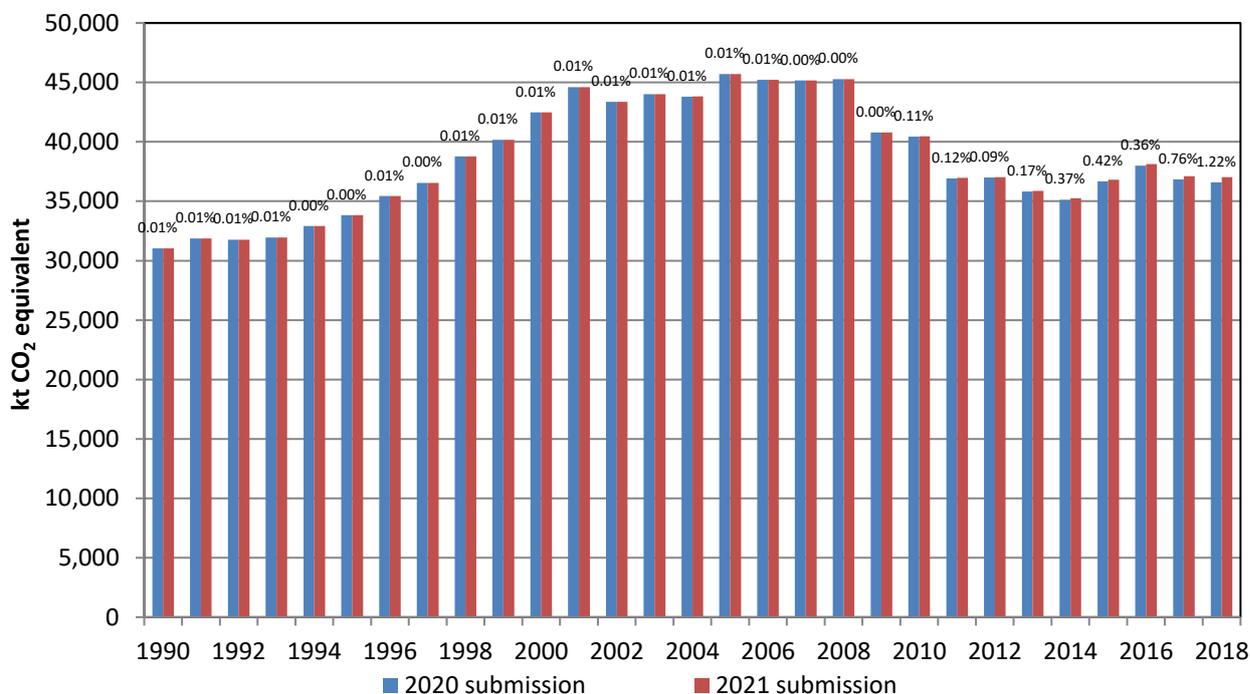


Figure 10.1 Impact of Recalculations in Energy between annual Submissions 1990-2018

## 10.2.2 Recalculations in Industrial Processes and Product Use

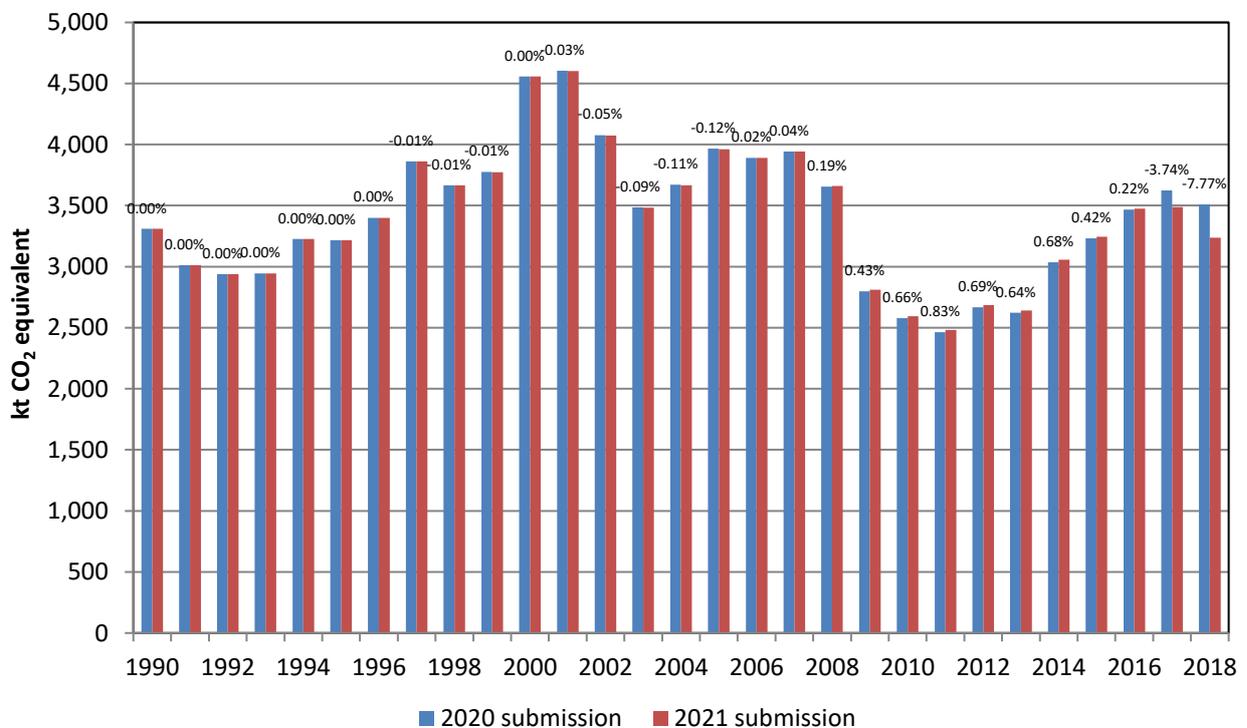
The overall impact of recalculations in the IPPU sector resulted in a 0.25 per cent decrease on average and a decrease of 288.5 kt CO<sub>2</sub> eq. in total in the 1990-2018 trend. The largest recalculations occurred in 2017 and 2018. The results of the recalculations are given in CRF Tables 8s1 and 8s4 for the relevant years.

The reasons for the recalculation between the two submissions were;

- A recalculation occurred in 2014, 2017 and 2018 due to a revision in the activity data for candles by the national statistics provider. These revised figures were submitted as part of the ESD review in June 2020.
- Revised activity data on F-gas bulk imports to Ireland for 2.F.1 Refrigeration and Air conditioning was received from data providers. This resulted in a 9.6 per cent decrease in 2017 and 26.2 per cent decrease in 2018 in this sub category. This indicates the effects of the F-gas regulation on the purchase of gases with high GWP in Ireland.
- A correction to the assumed recovery factor for Mobile Air conditioning in cars was made as information was received that recovery is not occurring for End of life vehicles in Ireland. This resulted in increased disposal emissions between 2-10 per cent.

- As a result of EPA surveys performed in 2020 to determine the rate of change over of MAC to low global warming potential (GWP) gases, the percentage of cars with low GWP gases was increased from 2015-2018. This has resulted in a decrease in emissions between 3-20 per cent for years 2015-2018.
- There was a recalculation in subcategory Other-Aerosols 2.F.4.b. due to the update of UK population proxy data used to calculate Irelands emissions. This population data was downloaded from the UK's Office of National Statistics (ONS) and linked to Aerosols and Other Sporting goods. A minor recalculation of 0.1-0.2 per cent is seen in Aerosols and Other sporting goods as a result.

The total impact of recalculations ranged from a decrease of 272.5 kt CO<sub>2</sub> eq in 2018 (7.8 per cent) to an increase of 20.6 kt CO<sub>2</sub> eq in 2014 (0.7 per cent).



*Figure 10.2 Impact of Recalculations in IPPU between annual Submissions 1990-2018*

### 10.2.3 Recalculations in Agriculture

The overall impact of recalculations in the Agriculture sector resulted in an increase of 1.4 per cent on average and 7,218.2 kt CO<sub>2</sub> eq. in total in the 1990-2018 trend. The largest decrease in emissions occurred in 1990, 1,069.6 kt CO<sub>2</sub> eq or 5.5 per cent and the largest increase occurred in 2018, 1,398.1 kt CO<sub>2</sub> eq or 7.0 per cent. The main recalculations are as follows;

- The EPA funded a review of methane emission models from cattle, originally developed in 2006. This review was undertaken by Teagasc (Ireland's national agriculture and food development authority). This updated model was used in the 2019 inventory and to re-

calculate all previous years in the time series to obtain a more accurate estimate of emissions from livestock. In addition, updated data on crude protein content in concentrate feeds and trends over time was obtained from a survey conducted by DAFM (Department of Agriculture, Food and Marine) in 2019 (previous data source was from a survey in 2003). Together these resulted in a 1.24 per cent increase in emissions from 3.A *Enteric fermentation* on average across time series.

- Manure management data has been updated to reflect current practices based on the National Farm Survey which is undertaken by Teagasc. Previous knowledge in this space was based on a survey undertaken in 2003, which was not fully reflective of current practice and had not captured the impact of the increased housing of cattle (other than dairy cows) in response to significant investment in housing as a result of national Nitrate Action Programmes. These surveys also include evidence of the use of low emission spreading techniques (LESS)
- Changes in the methane models, along with the updated crude protein content and manure management data resulted in recalculated CH<sub>4</sub> and N<sub>2</sub>O emissions estimates across all years in the time series. These resulted in average increases in annual emissions of 4.1 per cent in 3.B *Manure management*, and 0.84 per cent in 3.D *Agricultural soils*
- Revised estimates of emissions and removals for 4.B *Croplands* and 4.C *Grasslands* which are used as the activity data for direct N<sub>2</sub>O emissions from managed soils (3.D.a.1.5) also contributed to the increase (0.6 per cent) in emissions in 3.D.1 *Direct N<sub>2</sub>O Emissions From Managed Soils* on average.

The impact of the recalculations in the Agriculture sector between annual submissions in the 1990-2018 time series is outlined below in Figure 10.3.

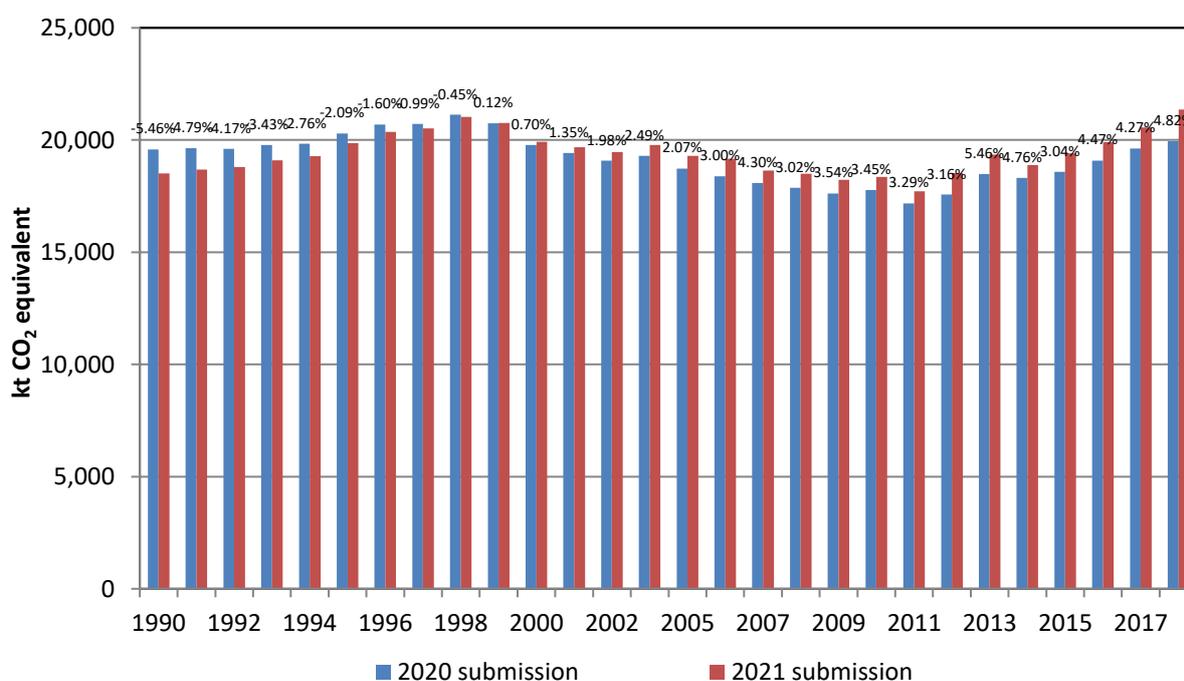


Figure 10.3 Impact of Recalculations in Agriculture between annual Submissions 1990-2018

## 10.2.4 Recalculations in LULUCF

### 10.2.4.1 Forest lands (4.A)

Recalculations for the forest land remaining forest land (CRF 4.A.1) category were due to revision of forest fire statistics for the years 1990 to 2013 and 2018 based on new forest fire statistics. The revision leads to higher emissions on 17 kt CO<sub>2</sub> eq on average per year across the timeseries. For land converted to forest land (CRF 4.A.2) harvest data for the period 2006 to 2018 was corrected in the CBM model following identification of a transcription error in the previous submission. The recalculation results in slightly different allocations of harvest from different species, or between clearfell and thinnings, but no differences in the total harvest over the period. The effect of the altered harvest influences stock changes in all C pools, but overall differences in removal was small (a change in net emissions of 0.9 to 13.1 per cent).

### 10.2.4.2 Cropland (4.B)

Recalculations in the Cropland category relate to the refinement of LPIS data into the analysis of areas of crop and temporary grassland with the addition of a further year of data on rotation patterns. This has led to recalculation of emissions and removals for all years in the reporting period. The net effect of this recalculation is a 72.9 per cent on change in emission and removals per year across the time series.

### 10.2.4.3 Grassland (4.C)

A revised assessment of land area statistics and management practices was undertaken for the Grassland category in this submission which refined the area statistics for both mineral and organic soils. The net effect of these recalculations is a 1.3 per cent on average increase in emissions across the time series.

### 10.2.4.4 Wetlands (4.D)

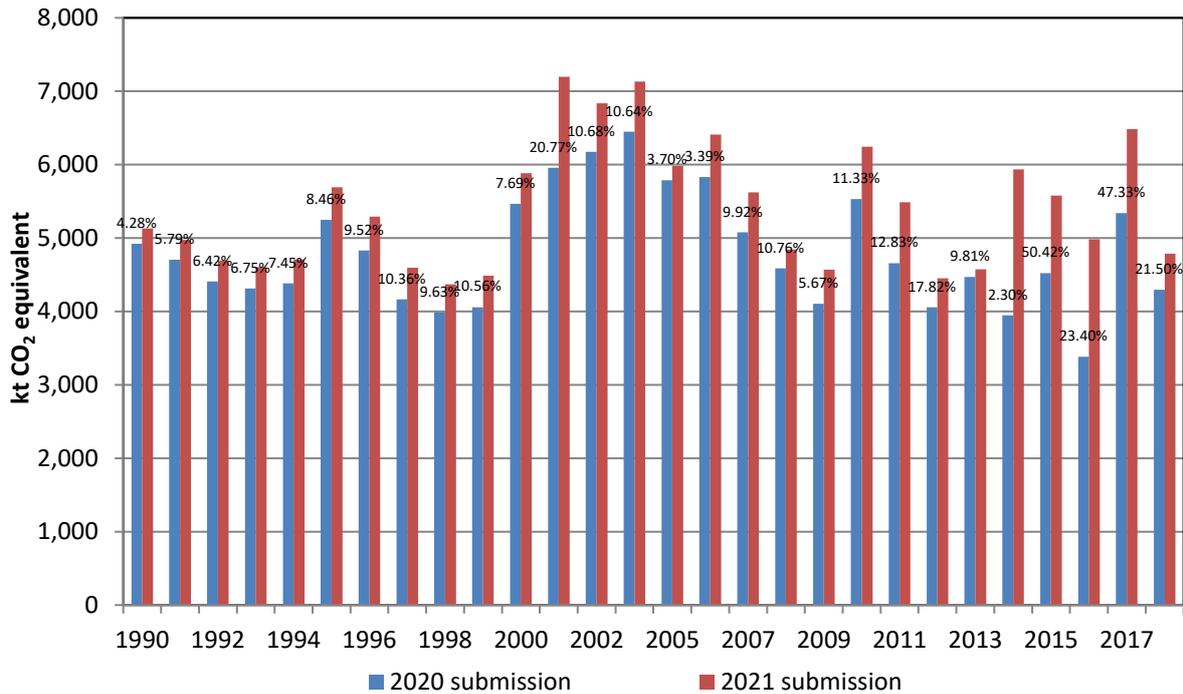
The main recalculation with the Wetland land use category is the correction of a transcription error associated with the estimation of onsite emissions from horticultural peat operations. The average recalculation across the timeseries is 20.9 per cent (433.2 kt CO<sub>2</sub> eq) increase in emissions with significant interannual variability.

### 10.2.4.5 Settlement (4.E)

Recalculations in Settlements were confined to the years 2016 to 2018 and were associated with minor revisions in the area of the other land categories that were converted to settlements. Recalculations were less than 1 per cent for each of the years identified.

### 10.2.4.6 Other Land (4.F)

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 revisions in estimates of land use area from the other land use categories. Given the low level of emissions from this land use category for most years, the absolute values of recalculations are small with 1.3 kt CO<sub>2</sub> eq on average increase evident across the timeseries.



**Figure 10.4 Impact of Recalculations in LULUCF between annual Submissions 1990-2018**

The net effect of the recalculations and additional information on recalculations is provided in CRF Table 8s2 for the relevant years.

### 10.2.5 Recalculations in Waste

The overall impact of recalculations in the Waste sector resulted in a 1.0 per cent increase on average and 208.1 kt CO<sub>2</sub> eq. in total in the 1990-2018 trend. Emissions in 2018 increased by 2.1 per cent. Additional information on recalculations is presented in CRF Table 8s3 for the relevant years.

The main recalculations between the two submissions are;

- Update of activity data for composting for the years 2010 to 2019 due to the inclusion of commercial waste for composting for the first time
- Estimates of CH<sub>4</sub> from anaerobic digestion at biogas facilities are provided for the first time for the years 2014 to 2019

The impact of the recalculations in the Waste sector between annual Submissions in the 1990-2018 time series is outlined below in Figure 10.5.

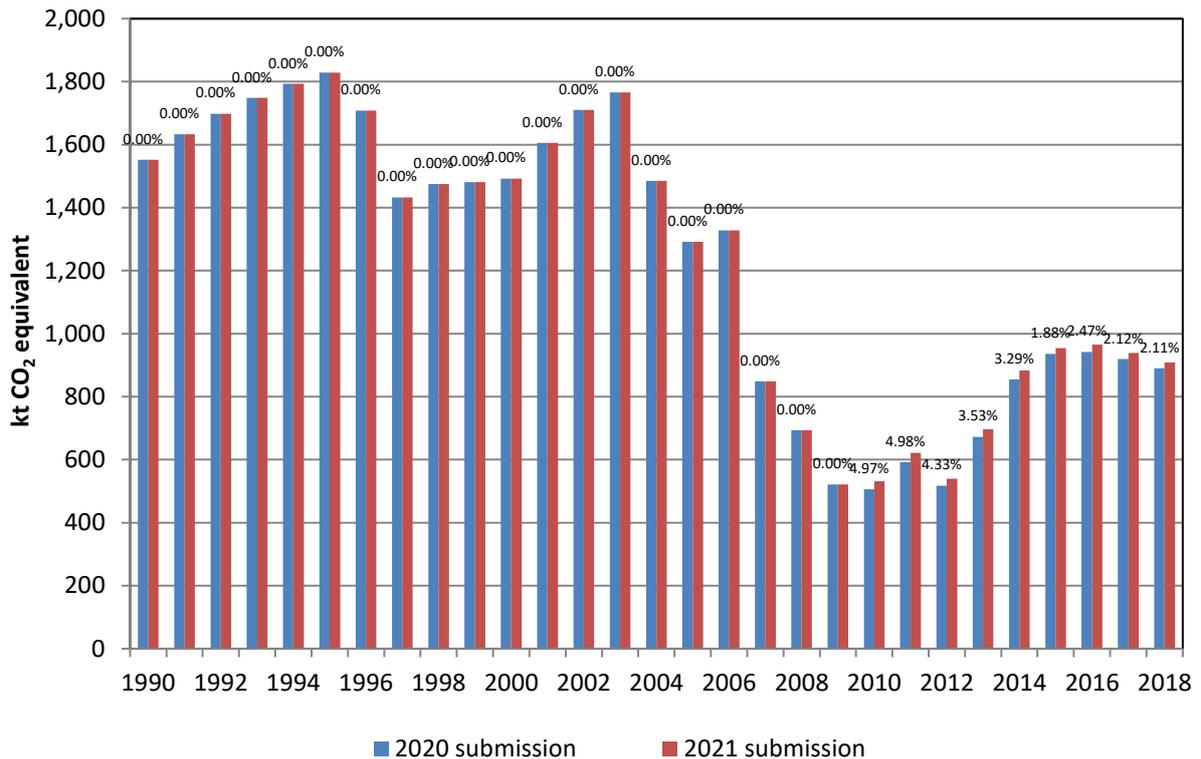
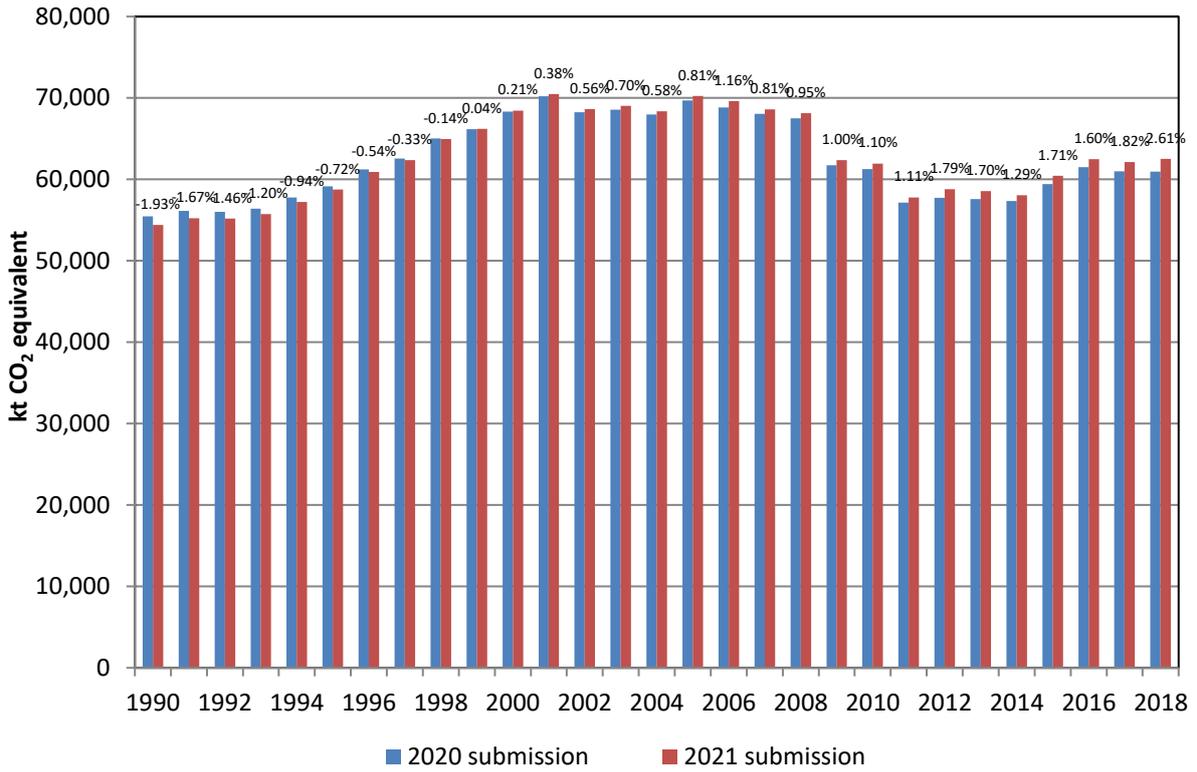


Figure 10.5 Impact of Recalculations in Waste between annual Submissions 1990-2018

### 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 1990-2018 according to greenhouse gas and the IPCC sectors, respectively. The overall effect on the total emissions (including indirect CO<sub>2</sub>, excluding LULUCF) shows decreases in estimates by 1.9 per cent (and 1,068.0 kt CO<sub>2</sub> eq.) in 1990 and an increase of 2.9 per cent (and 1,591.5 kt CO<sub>2</sub> eq.) in 2018. There is no significant impact on the trend in total emissions (Chapter Two).

Emissions decreased from 1990-1998 and increased in 20 years of the timeseries (1999-2018). On average emissions increased by 0.4 per cent per annum (Table 10.2 (c)). 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 1990-2018 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 1990-2018 included in the 2021 submission are outlined below (Tables 10.1 to 10.3 and Figure 10.6).



*Figure 10.6 Total Impact of Recalculations between annual Submissions 1990-2018*

Table 10.1. Changes in Methodological Descriptions compared to 2020 NIR

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	DESCRIPTION OF METHODS	RECALCULATIONS	REFERENCE
	Categories where the 2021 NIR includes major changes in methodological descriptions compared to the 2020 NIR	Sub-categories where changes are reflected in recalculations of previous year estimates	Reference to sub-category, gas, pages in the NIR, Annex
<b>Total (Net Emissions)</b>			
<b>1. Energy</b>			
A. Fuel Combustion (Sectoral Approach)	√	√	Methodological change to how the energy balance data was sourced, which is a significant improvement but has altered the distribution of fuels for 1.A.2, 1.A.4.a and 1.A.4.b for the entire time series 1990-2018.
1. Energy Industries			
2. Manufacturing Ind and Construction		√	Revised energy data. Chapter 3, Section 3.2.5.5
3. Transport			
4. Other Sectors		√	1.A.4.a and 1.A.4.b contains significant recalculations due to the improved data collection methodology.
5. Other			
B. Fugitive Emissions from Fuels			
1. Solid Fuels			
2. Oil and Natural Gas	√		Updated methodology for fugitive emissions from transmission, storage, distribution. Chapter 3, Section 3.3.2.2
C. CO <sub>2</sub> Transport and Storage			
<b>2. Industrial Processes and Product Use</b>			
A. Mineral Industry			
B. Chemical Industry			
C. Metal Industry			
D. Non-Energy Products from Fuels and Solvent Use			
E. Electronics Industry			
F. Product Uses as Substitutes for Ozone Depleting Substances		√	Updated assumptions on use of low GWP refrigerants used in Mobile air conditioning and recovery factor for End of life vehicles for 2.F.1 refrigeration and air conditioning. Chapter 4, Section 4.7.1.5
G. Other Product Manufacture and Use			
H. Other			
<b>3. Agriculture</b>			
A. Enteric Fermentation	√	√	Revised methane models applied across time series resulting in recalculations for categories 3A.1 and 3A.2 Revised AD for time series, Chapter 5, Section 5.2.1.1.5
B. Manure Management	√	√	Revised methane models applied across time series resulting in recalculations for categories 3B.1 and 3B.2 Revised AD for time series, Chapter 5, Section 5.3.2.5
C. Rice Cultivation			
D. Agricultural Soils		√	Revised AD for direct emissions and indirect emissions from soils, 3.D.1.5 and 3.D.2, Chapter 5, Sections 5.5.1.5 and 5.5.2.5
E. Prescribed Burning of Savannas			
F. Field Burning of Agricultural Residues			
G. Liming			

H. Urea Application			
I. Other			
<b>4. Land Use, Land-Use Change and Forestry</b>			
A. Forest Land		√	Recalibration of CFS-CBN model. Chapter 10, Section 10.2.4.1
B. Cropland		√	Refinement of LPIS data. Chapter 10, Section 10.2.4.2
C. Grassland		√	Revised land area statistics. Chapter 10, Section 10.2.4.3
D. Wetlands		√	Revised peat harvested data. Chapter 10, Section 10.2.4.4
E. Settlements		√	Revised planning permission statistics from CSO. Chapter 10, Section 10.2.4.5
F. Other Land		√	Revisions due to residual area approach for 4.F. Chapter 10, Section 10.2.4.6
G. Harvested Wood Products			
H. Other			
<b>5. Waste</b>			
A. Solid Waste Disposal			
B. Biological Treatment of Solid Waste	√	√	Composting AD changes for 2010-2018 in 5.B.1 and inclusion of emissions from 5.B.2 Anaerobic digestion
C. Incineration and Open Burning of Waste			
D. Wastewater Treatment and Discharge			
E. Other			
<b>6. Other</b>			
<b>Memo Items:</b>			
<b>International Bunkers</b>			
Aviation			
Marine			
<b>Multilateral Operations</b>			
<b>CO<sub>2</sub> Emissions from Biomass</b>			
<b>CO<sub>2</sub> captured</b>			
<b>Long-term storage of C in waste disposal sites</b>			
<b>N<sub>2</sub>O Indirect Emissions</b>			
<b>CO<sub>2</sub> Indirect Emissions</b>			

**Table 10.2. Recalculations by Gas 1990-2018 (a&b)**

**(a) Emissions by Gas 1990 –2018 reported in 2020 Submission (kt CO<sub>2</sub> eq)**

CO <sub>2</sub> emissions without net CO <sub>2</sub> from LULUCF	32,944.3	35,852.7	45,249.0	48,155.5	42,179.5	41,747.9	38,052.2	38,209.6	37,235.3	36,785.3	38,545.3	40,029.8	38,910.2	38,803.4
CO <sub>2</sub> emissions with net CO <sub>2</sub> from LULUCF	37,271.2	40,464.5	50,084.9	53,154.9	45,541.5	46,176.3	41,842.9	41,498.1	40,838.1	39,854.3	42,200.5	42,606.8	43,116.6	42,236.7
CH <sub>4</sub> emissions without CH <sub>4</sub> from LULUCF	14,760.7	15,000.5	14,338.2	13,581.9	12,322.6	12,070.1	12,037.6	12,336.9	12,672.9	12,966.8	13,290.1	13,678.8	13,991.9	13,985.0
CH <sub>4</sub> emissions with CH <sub>4</sub> from LULUCF	15,211.2	15,444.8	14,764.8	14,072.1	12,712.1	12,720.4	12,496.5	12,708.2	13,112.8	13,419.1	13,729.6	14,084.4	14,660.7	14,444.9
N <sub>2</sub> O emissions without N <sub>2</sub> O from LULUCF	7,728.7	8,084.7	7,958.1	6,762.0	6,092.5	6,345.6	5,938.7	6,097.9	6,536.8	6,356.3	6,355.0	6,465.8	6,749.0	6,953.7
N <sub>2</sub> O emissions with N <sub>2</sub> O from LULUCF	7,871.9	8,275.1	8,160.3	7,060.2	6,446.4	6,799.5	6,345.0	6,493.2	6,965.3	6,781.8	6,781.0	6,866.2	7,211.9	7,358.3
HFCs	0.6	45.3	270.3	861.1	1,019.0	1,034.2	1,067.0	1,060.5	1,092.0	1,174.9	1,159.5	1,239.3	1,266.1	1,100.4
PFCs	0.1	97.6	397.8	216.4	83.6	46.6	15.9	9.6	8.3	3.6	20.5	37.4	47.2	49.9
SF <sub>6</sub>	33.9	79.1	51.8	96.8	39.2	33.1	45.5	37.4	43.6	37.4	44.5	39.3	39.2	40.9
NF <sub>3</sub>	NO	4.4	49.2	28.4	NO	NO	NO	0.8	0.9	1.0	1.0	1.0	1.3	1.3
<b>Total (without LULUCF, with indirect)</b>	<b>55,468.3</b>	<b>59,164.3</b>	<b>68,314.3</b>	<b>69,702.1</b>	<b>61,736.4</b>	<b>61,277.5</b>	<b>57,156.9</b>	<b>57,752.7</b>	<b>57,589.7</b>	<b>57,325.3</b>	<b>59,415.9</b>	<b>61,491.4</b>	<b>61,004.9</b>	<b>60,934.5</b>
Total (with LULUCF, with indirect)	60,388.9	64,410.8	73,779.0	75,489.9	65,841.8	66,810.1	61,812.9	61,807.8	62,061.0	61,272.0	63,936.6	64,874.4	66,343.1	65,232.2

**(b) Recalculated Emissions by Gas 1990 –2018 reported in 2021 Submission (kt CO<sub>2</sub> eq)**

CO <sub>2</sub> emissions without net CO <sub>2</sub> from LULUCF	32,943.6	35,852.2	45,248.5	48,155.8	42,180.3	41,793.9	38,097.3	38,242.0	37,291.8	36,909.0	38,687.8	40,155.8	39,133.4	39,195.2
CO <sub>2</sub> emissions with net CO <sub>2</sub> from LULUCF	37,469.3	40,891.4	50,495.8	53,398.5	46,012.1	46,876.7	42,680.6	41,924.0	40,983.9	41,770.1	43,401.1	44,332.8	44,481.8	43,115.5
CH <sub>4</sub> emissions without CH <sub>4</sub> from LULUCF	13,752.1	14,556.7	14,386.9	14,019.7	12,827.1	12,576.7	12,523.8	13,155.8	13,439.1	13,512.0	14,037.6	14,423.1	14,825.5	15,139.3
CH <sub>4</sub> emissions with CH <sub>4</sub> from LULUCF	14,211.7	15,014.8	14,820.4	14,474.0	13,212.3	13,272.2	13,017.0	13,530.7	13,890.8	14,117.3	14,478.1	14,831.7	15,500.8	15,599.6
N <sub>2</sub> O emissions without N <sub>2</sub> O from LULUCF	7,670.1	8,105.7	8,054.6	6,891.8	6,197.7	6,451.0	6,026.8	6,264.7	6,680.6	6,409.6	6,471.1	6,575.7	6,909.6	7,253.9
N <sub>2</sub> O emissions with N <sub>2</sub> O from LULUCF	7,815.8	8,298.9	8,258.5	7,178.9	6,551.3	6,915.1	6,435.9	6,660.5	7,110.8	6,879.9	6,895.7	6,974.1	7,371.6	7,659.3
HFCs	0.6	45.2	270.0	855.5	1,028.5	1,048.1	1,084.3	1,075.0	1,106.3	1,190.0	1,169.5	1,242.9	1,158.7	845.5
PFCs	0.1	97.6	397.8	216.4	83.6	46.6	15.9	9.6	8.3	3.6	20.5	37.4	47.2	49.9
SF <sub>6</sub>	33.9	79.1	51.8	96.8	39.2	33.1	45.5	37.4	43.6	37.4	44.5	39.3	39.2	40.9
NF <sub>3</sub>	NO	4.4	49.2	28.4	NO	NO	NO	0.8	0.9	1.0	1.0	1.0	1.3	1.3
<b>Total (without LULUCF, with indirect)</b>	<b>54,400.3</b>	<b>58,740.9</b>	<b>68,458.7</b>	<b>70,264.3</b>	<b>62,356.4</b>	<b>61,949.4</b>	<b>57,793.6</b>	<b>58,785.1</b>	<b>58,570.6</b>	<b>58,062.6</b>	<b>60,432.0</b>	<b>62,475.1</b>	<b>62,114.9</b>	<b>62,526.0</b>
Total (with LULUCF, with indirect)	59,531.4	64,431.4	74,343.4	76,248.5	66,927.0	68,191.9	63,279.0	63,238.0	63,144.6	63,999.3	66,010.2	67,459.2	68,600.5	67,312.0

*(c) Percentage Change in Emissions by Gas 1990-2018*

CO <sub>2</sub> emissions without net CO <sub>2</sub> from LULUCF	0.00%	0.00%	0.00%	0.00%	0.00%	0.11%	0.12%	0.08%	0.15%	0.34%	0.37%	0.31%	0.57%	1.01%
CO <sub>2</sub> emissions with net CO <sub>2</sub> from LULUCF	0.53%	1.06%	0.82%	0.46%	1.03%	1.52%	2.00%	1.03%	0.36%	4.81%	2.84%	4.05%	3.17%	2.08%
CH <sub>4</sub> emissions without CH <sub>4</sub> from LULUCF	-6.83%	-2.96%	0.34%	3.22%	4.09%	4.20%	4.04%	6.64%	6.05%	4.20%	5.62%	5.44%	5.96%	8.25%
CH <sub>4</sub> emissions with CH <sub>4</sub> from LULUCF	-6.57%	-2.78%	0.38%	2.86%	3.94%	4.34%	4.16%	6.47%	5.93%	5.20%	5.45%	5.31%	5.73%	7.99%
N <sub>2</sub> O emissions without N <sub>2</sub> O from LULUCF	-0.76%	0.26%	1.21%	1.92%	1.73%	1.66%	1.48%	2.73%	2.20%	0.84%	1.83%	1.70%	2.38%	4.32%
N <sub>2</sub> O emissions with N <sub>2</sub> O from LULUCF	-0.71%	0.29%	1.20%	1.68%	1.63%	1.70%	1.43%	2.58%	2.09%	1.45%	1.69%	1.57%	2.21%	4.09%
HFCs	0.00%	-0.14%	-0.14%	-0.65%	0.93%	1.34%	1.61%	1.36%	1.31%	1.29%	0.86%	0.29%	-8.49%	-23.16%
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%	0.00%	0.00%
SF <sub>6</sub>	0.00%	0.00%	0.00%	-0.03%	0.00%	0.00%	-0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
NF <sub>3</sub>	NO	0.00%	0.00%	0.00%	NO	NO	NO	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
<b>Total (without LULUCF, with indirect)</b>	<b>-1.93%</b>	<b>-0.72%</b>	<b>0.21%</b>	<b>0.81%</b>	<b>1.00%</b>	<b>1.10%</b>	<b>1.11%</b>	<b>1.79%</b>	<b>1.70%</b>	<b>1.29%</b>	<b>1.71%</b>	<b>1.60%</b>	<b>1.82%</b>	<b>2.61%</b>
Total (with LULUCF, with indirect)	-1.42%	0.03%	0.77%	1.00%	1.65%	2.07%	2.37%	2.31%	1.75%	4.45%	3.24%	3.98%	3.40%	3.19%

*(d) Actual Change in Emissions by Gas 1990-2018 (kt CO<sub>2</sub> eq)*

CO <sub>2</sub> emissions without net CO <sub>2</sub> from LULUCF	-0.72	-0.46	-0.49	0.26	0.78	45.99	45.08	32.38	56.46	123.69	142.44	125.96	223.23	391.76
CO <sub>2</sub> emissions with net CO <sub>2</sub> from LULUCF	198.13	426.97	410.93	243.68	470.54	700.42	837.64	425.94	145.82	1915.87	1200.57	1726.08	1365.16	878.86
CH <sub>4</sub> emissions without CH <sub>4</sub> from LULUCF	-1008.63	-443.80	48.72	437.86	504.54	506.54	486.29	818.88	766.25	545.13	747.45	744.25	833.60	1154.35
CH <sub>4</sub> emissions with CH <sub>4</sub> from LULUCF	-999.57	-430.03	55.65	401.99	500.30	551.85	520.45	822.50	778.03	698.25	748.46	747.30	840.15	1154.77
N <sub>2</sub> O emissions without N <sub>2</sub> O from LULUCF	-58.62	20.95	96.57	129.73	105.18	105.44	88.13	166.75	143.78	53.33	116.15	109.91	160.65	300.21
N <sub>2</sub> O emissions with N <sub>2</sub> O from LULUCF	-56.10	23.74	98.22	118.62	104.93	115.62	90.88	167.38	145.47	98.10	114.67	107.85	159.67	301.04
HFCs	0.00	-0.06	-0.37	-5.60	9.44	13.91	17.23	14.42	14.35	15.10	9.98	3.58	-107.49	-254.85
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	0.00	0.00
SF <sub>6</sub>	0.00	0.00	0.00	-0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NF <sub>3</sub>	NO	0.00	0.00	0.00	NO	NO	NO	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<b>Total (without LULUCF, with indirect)</b>	<b>-1067.98</b>	<b>-423.37</b>	<b>144.43</b>	<b>562.23</b>	<b>619.94</b>	<b>671.87</b>	<b>636.72</b>	<b>1032.43</b>	<b>980.85</b>	<b>737.25</b>	<b>1016.03</b>	<b>983.70</b>	<b>1109.98</b>	<b>1591.47</b>
Total (with LULUCF, with indirect)	-857.54	20.62	564.43	758.67	1085.20	1381.79	1466.20	1430.24	1083.67	2727.32	2073.68	2584.81	2257.49	2079.81

*Table 10.3 Recalculations by IPCC Sector 1990-2018*

*(a) Emissions by IPCC Sector 1990 –2018 reported in 2020 Submission (kt CO<sub>2</sub> eq)*

SOURCE AND SINK CATEGORIES	1990	1995	2000	2005	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
1. Energy	31,022.1	33,824.9	42,485.8	45,711.7	40,798.4	40,427.9	36,925.9	36,998.8	35,816.8	35,114.7	36,665.9	37,998.1	36,840.0	36,582.9
2. Industrial Processes and Product Use	3,309.2	3,217.3	4,558.5	3,967.4	2,799.3	2,577.8	2,462.2	2,668.5	2,623.2	3,037.2	3,232.7	3,467.1	3,623.8	3,508.5
3. Agriculture	19,585.0	20,292.8	19,777.2	18,731.0	17,617.1	17,765.6	17,176.3	17,568.0	18,477.2	18,318.4	18,581.0	19,084.7	19,621.9	19,953.1
5. LULUCF	4,920.6	5,246.5	5,464.7	5,787.7	4,105.3	5,532.5	4,656.0	4,055.1	4,471.2	3,946.7	4,520.6	3,382.9	5,338.2	4,297.7
5. Waste	1,552.1	1,829.2	1,492.8	1,292.0	521.6	506.2	592.4	517.3	672.6	855.0	936.3	941.6	919.2	890.1
6. Other	NO													
<b>Total (excl. LULUCF, with indirect)</b>	<b>55,468.3</b>	<b>59,164.3</b>	<b>68,314.3</b>	<b>69,702.1</b>	<b>61,736.4</b>	<b>61,277.5</b>	<b>57,156.9</b>	<b>57,752.7</b>	<b>57,589.7</b>	<b>57,325.3</b>	<b>59,415.9</b>	<b>61,491.4</b>	<b>61,004.9</b>	<b>60,934.5</b>

*(b) Recalculated Emissions by IPCC Sector 1990 –2018 reported in 2021 Submission (kt CO<sub>2</sub> eq)*

SOURCE AND SINK CATEGORIES	1990	1995	2000	2005	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
1. Energy	31,023.7	33,825.1	42,491.7	45,716.9	40,799.3	40,473.4	36,970.5	37,031.5	35,878.3	35,245.6	36,820.8	38,135.8	37,120.0	37,030.0
2. Industrial Processes and Product Use	3,309.2	3,217.4	4,558.3	3,962.6	2,811.3	2,594.7	2,482.6	2,686.8	2,639.9	3,057.8	3,246.3	3,474.7	3,488.3	3,236.0
3. Agriculture	18,515.4	19,869.2	19,915.9	19,292.8	18,224.2	18,349.9	17,718.5	18,527.2	19,356.0	18,876.0	19,410.9	19,899.8	20,567.8	21,351.2
4. LULUCF	5,131.1	5,690.5	5,884.7	5,984.2	4,570.6	6,242.4	5,485.5	4,452.9	4,574.1	5,936.8	5,578.3	4,984.0	6,485.7	4,786.0
5. Waste	1,552.1	1,829.2	1,492.8	1,292.0	521.6	531.4	621.9	539.7	696.4	883.1	953.9	964.9	938.7	908.8
6. Other	NO													
<b>Total (excl. LULUCF, with indirect)</b>	<b>54,400.3</b>	<b>58,740.9</b>	<b>68,458.7</b>	<b>70,264.3</b>	<b>62,356.4</b>	<b>61,949.4</b>	<b>57,793.6</b>	<b>58,785.1</b>	<b>58,570.6</b>	<b>58,062.6</b>	<b>60,432.0</b>	<b>62,475.1</b>	<b>62,114.9</b>	<b>62,526.0</b>

*(c) Percentage Change in Emissions by Sector 1990-2018*

SOURCE AND SINK CATEGORIES	1990	1995	2000	2005	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
1. Energy	0.01%	0.00%	0.01%	0.01%	0.00%	0.11%	0.12%	0.09%	0.17%	0.37%	0.42%	0.36%	0.76%	1.22%
2. Industrial Processes and Product Use	0.00%	0.00%	0.00%	-0.12%	0.43%	0.66%	0.83%	0.69%	0.64%	0.68%	0.42%	0.22%	-3.74%	-7.77%
3. Agriculture	-5.46%	-2.09%	0.70%	3.00%	3.45%	3.29%	3.16%	5.46%	4.76%	3.04%	4.47%	4.27%	4.82%	7.01%
4. Land use, land-use change and forestry	4.28%	8.46%	7.69%	3.39%	11.33%	12.83%	17.82%	9.81%	2.30%	50.42%	23.40%	47.33%	21.50%	11.36%
5. Waste	0.00%	0.00%	0.00%	0.00%	0.00%	4.97%	4.98%	4.33%	3.53%	3.29%	1.88%	2.47%	2.12%	2.11%
6. Other	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
<b>Total (excl. LULUCF, with indirect)</b>	<b>-1.93%</b>	<b>-0.72%</b>	<b>0.21%</b>	<b>0.81%</b>	<b>1.00%</b>	<b>1.10%</b>	<b>1.11%</b>	<b>1.79%</b>	<b>1.70%</b>	<b>1.29%</b>	<b>1.71%</b>	<b>1.60%</b>	<b>1.82%</b>	<b>2.61%</b>

*(d) Actual Change in Emissions by Sector 1990-2018*

SOURCE AND SINK CATEGORIES	1990	1995	2000	2005	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
1. Energy	1.6	0.2	6.0	5.2	0.9	45.5	44.6	32.6	61.5	130.9	154.9	137.7	280.0	447.2
2. Industrial Processes and Product Use	0.0	0.1	-0.2	-4.8	12.0	16.9	20.4	18.3	16.8	20.6	13.6	7.6	-135.4	-272.5
3. Agriculture	-1069.6	-423.6	138.7	561.8	607.0	584.3	542.1	959.1	878.9	557.6	829.9	815.1	945.9	1398.1
4. Land use, land-use change and forestry	210.4	444.0	420.0	196.4	465.3	709.9	829.5	397.8	102.8	1990.1	1057.6	1601.1	1147.5	488.3
5. Waste	0.0	0.0	0.0	0.0	0.0	25.2	29.5	22.4	23.8	28.1	17.6	23.2	19.5	18.7
6. Other	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
<b>Total (excl. LULUCF, with indirect)</b>	<b>-1067.98</b>	<b>-423.37</b>	<b>144.43</b>	<b>562.23</b>	<b>619.94</b>	<b>671.87</b>	<b>636.72</b>	<b>1032.43</b>	<b>980.85</b>	<b>737.25</b>	<b>1016.03</b>	<b>983.70</b>	<b>1109.98</b>	<b>1591.47</b>

## 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 fifth 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 provisional main findings in the 2018 annual inventory review report and Ireland's response to those findings. It may be stated therefore that the inventory material being submitted in 2020 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. 525/2013 of the European Parliament and of the Council and the Kyoto Protocol. 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. 525/2013 and its Implementing Regulation No. 749/2014 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.

**PART II**  
**SUPPLEMENTARY INFORMATION**  
**REQUIRED UNDER ARTICLE 7.1**  
**OF THE KYOTO PROTOCOL**

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# Chapter 11 Emissions and Removals from LULUCF Activities under Article 3, paragraphs 3 and 4, of the Kyoto Protocol

## 11.1 General Information

### 11.1.1 Introduction

The major item of supplementary information required under Article 7.1 of the Kyoto Protocol, as outlined in annex II of decision 2/CMP.8, is the estimation of anthropogenic emissions by sources and removals by sinks from land use land-use change and forestry activities under Article 3 paragraph 3, forest management (FM) under Article 3 paragraph 4 and any other activities that a Party has elected under Article 3 paragraph 4 of the Kyoto Protocol (KP).

Ireland **has elected** to account (at the end of the commitment period) for the optional activities Cropland Management (CM) and Grazing land Management (GM) under Article 3 paragraph 4. Ireland has **not** elected to account for optional activities; Wetland Drainage and Rewetting, or Revegetation under Article 3 paragraph 4. The approaches employed for data collection and the methodologies used to derive the estimates for Article 3.3 and FM, CM and GM Article 3.4 activities are described in Chapter 6, since the same approaches and time series are used for both Convention and KP reporting. The estimates of emissions and removals for these activities are compiled in supplementary CRF tables similar to those used for submitting the GHG inventory under the Convention as described in Chapter 6 of this NIR. Ireland has elected to account for KP activities at the end of the commitment period.

The reported net removals of CO<sub>2</sub> in 2019 on 330.60 kha of lands subject to afforestation/reforestation since 1990 is estimated at 3,875.2 kt CO<sub>2</sub> eq while there were net emissions of 266.5 kt CO<sub>2</sub> eq on a deforested area of 20.65 kha (Table 11.2 and 11.4). The overall forest sink for Article 3.3 forest increased from 3,310.3 kt CO<sub>2</sub>eq in 2013 to 3,608.7 kt CO<sub>2</sub>eq in 2019, primarily due to an increase in the area under afforestation and increased productivity as the forest matures.

Reported removals in 2019 on 446.05 kha of land under forest management is estimated to be 1,212.7 kt CO<sub>2</sub> eq, of which are associated with long term storage of C in harvested wood products.

Reported net-net removals in 2019, relative to the 1990 base year, on 740.00 kha of land under cropland management is estimated to be 80.7 kt CO<sub>2</sub>eq. This is mainly due to changes in the patterns of utilisation of cropland and temporary grassland.

Reported net-net removals, relative to the 1990 base year, on 4,222.55 kha of land in 2019 under grazing land management is estimated to be 331.8 kt CO<sub>2</sub> eq. This is mainly due to apparent changes in the patterns of utilisation of improved grassland and rough grazing.

Carbon dioxide emissions in *KP B.3 Grazing Land Management*, *KP A.1 Afforestation/Reforestation and KP B.1 Forest Management* and CH<sub>4</sub> emissions from *KP B.3 Grazing Land Management* are key categories in 2019 when Article 3, paragraph 3 and paragraph 4, activities are included in key category analysis as outlined in section 1.6.2 of this report. Drainage of organic grassland soils for agricultural production is the driver for reported emissions of CO<sub>2</sub> and CH<sub>4</sub> from *KP B.3 Grazing Land Management*. Details of the key category analysis as it pertains to *KP* activities is presented in Table 11.3.

### 11.1.2 Institutional Arrangements

The inventory for Article 3, paragraph 3 and Article 3, paragraph 4 Forest Management, activities is prepared by FERS Ltd, a consultant working to COFORD/DAFM (Council for Forest Research and Development) which in turn delivers the information to the inventory agency under an agreed Memorandum of Understanding (Table 1.1). The reporting system adopts an activity-based approach using the tier 3 CFS CBM model to report on Article 3.3 activities and forest management activities under article 3.4. To ensure consistency in reporting for *Lands converted to Forest Land* in the LULUCF inventory under the Convention (Chapter 6) and Afforestation and Reforestation under Kyoto Protocol, the same time series and methodological approach using the CBM model has been developed and reported (see Chapter 6).

The inventory for Article 3.4 CM and GM activities are prepared by the inventory agency at the EPA's OES. The reporting system adopts an activity-based approach using Tier 1 assessment of changes in land use on lands associated with CM and GM. To ensure consistency with reporting under Cropland and Grassland land use categories in LULUCF under the Convention, the same time series and methodological approach as reported in Chapter 6 is used.

Table 11.1 shows the reported activities and pools. The definition of carbon pools are presented in Table 6.4 section 6.3.2.6.

Table 11.1 Reported Activities and Pools (CRF Table NIR-1)

Activity	CHANGE IN CARBON POOL REPORTED <sup>(1)</sup>							GREENHOUSE GAS SOURCES REPORTED <sup>(2)</sup>								
	Above-ground biomass	Below-ground biomass	Litter	Dead wood	Soil		HWP <sup>(4)</sup>	Fertilization <sup>(5)</sup>	Drained, rewetted and other soils <sup>(6)</sup>		Nitrogen mineralization in mineral soils <sup>(8)</sup>	Indirect N <sub>2</sub> O emissions from managed soil <sup>(5)</sup>	Biomass burning <sup>(9)</sup>			
					Mineral	Organic <sup>(3)</sup>			CH <sub>4</sub> <sup>(7)</sup>	N <sub>2</sub> O			N <sub>2</sub> O	CO <sub>2</sub> <sup>(10)</sup>	CH <sub>4</sub>	N <sub>2</sub> O
<b>Article 3.3 activities</b>																
<b>Afforestation and reforestation</b>	R	R	R	R	R	R	R	IE	R	R	NO	IE	R	R	R	
<b>Deforestation</b>	R	R	R	R	R	R	IO	IE	R	R	R	IE	NO	NO	NO	
<b>Article 3.4 activities</b>																
<b>Forest management</b>	R	R	R	R	R	R	R	IE	R	R	NO	IE	R	R	R	
<b>Cropland management</b>	R	IE	NO	NO	R	NO			NO		IE		NO	R	R	
<b>Grazing land management</b>	R	IE	NO	NO	R	R			R		IE		NO	R	R	
<b>Revegetation</b>	NA	NA	NA	NA	NA	NA		NA	NA	NA	NA	NA	NA	NA	NA	
<b>Wetland drainage and rewetting</b>	NA	NA	NA	NA		NA		NA	NA	NA		NA	NA	NA	NA	

R indicates the reported carbon pools and emissions from biomass burning;

IE (included elsewhere) is used to show that emissions from fertilisation of soils and indirect N<sub>2</sub>O emissions are included under Agriculture

HWP from lands reported under deforestation, which originated from the deforestation event at the time of the land-use change are accounted for on the basis of instantaneous oxidation (IO).

NA : Mineral soils are shown not to be "a source", so are not reported.

NO: Mineralisation losses in mineral soils do not occur since there are no changes in mineral soil carbon stocks for AR and FM, CO<sub>2</sub> emissions from Biomass burning under Cm and GM are assumed to be transient, and taken up in subsequent regrowth of vegetation.

Table 11.2 Land Transition Matrix (CRF Table NIR-2) for inventory year 2019

	ARTICLE 3.3 ACTIVITIES		ARTICLE 3.4 ACTIVITIES					Other <sup>(6)</sup>	Total area at the end of the previous inventory year <sup>(7)</sup>
	Afforestation and reforestation	Deforestation	Forest management <sup>(5)</sup>	Cropland management (if elected)	Grazing land management (if elected)	Revegetation (if elected)	Wetland drainage and rewetting (if elected)		
	(kha)								
<b>Article 3.3 activities</b>									
Afforestation and reforestation	327.05	0.04							327.09
Deforestation		20.53							20.53
<b>Article 3.4 activities</b>									
Forest management		0.09	446.05						446.14
Cropland management <sup>(3)</sup> (if elected)	NO		NO	740.00	NA	NA	NA		740.00
Grazing land management <sup>(3)</sup> (if elected)	3.19		NO	NO	4222.55	NO	NO		4225.74
Revegetation <sup>(3)</sup> (if elected)	NA		NA	NA	NA	NA	NA		NA
Wetland drainage and rewetting <sup>(3)</sup> (if elected)	NA		NA	NA	NA	NA	NA		NA
Other <sup>(4)</sup>	0.35	NO	NO	NO	NO	NA	NA	1351.94	1352.29
<b>Total area at the end of the current inventory year</b>	330.60	20.65	446.05	740.00	4222.55	NO,NA	NO,NA	1351.94	7111.79

Areas and changes in areas between the previous and the current inventory year

Table 11.3 Key Categories for Article 3.3 and A.4 Activities (CRF Table NIR-3)

KEY CATEGORIES OF EMISSIONS AND REMOVALS	Gas	CRITERIA USED FOR KEY CATEGORY IDENTIFICATION			Comments <sup>(4)</sup>
		Associated category in UNFCCC inventory <sup>(1)</sup> is key (indicate which category)	Category contribution is greater than the smallest category considered key in the UNFCCC inventory <sup>(2)</sup> (including LULUCF)	Other <sup>(3)</sup>	
Specify key categories according to the national level of disaggregation used <sup>(1)</sup>					
B.3 Grazing Land Management	CO <sub>2</sub>	4.C.1 Grassland remaining grassland	Yes	NA	Level
A.1 Afforestation/Reforestation	CO <sub>2</sub>	4.A.2 Land converted to forest land	Yes	NA	Level
B.1 Forest Management	CO <sub>2</sub>	4.A.1 Forest land remaining forest land	Yes	NA	Level
B.3 Grazing Land Management	CH <sub>4</sub>	4.C.1 Grassland remaining grassland	Yes	NA	Level

Table 11.4 Information Table on Reporting of emission/removals for Activities under Article 3, paragraphs 3 and 4 for the second commitment period of the Kyoto Protocol

Year	A.1. KP_AR			A.2.KP_D			B.1.KP_FM			B.2.KP_CM			B.3.KP_GM		
	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O
1990							-411.73	NA	NA	23.63	0.0019	4.9x10 <sup>-5</sup>	6737.34	9.78	0.01
2013	-4488.31	1.04	0.29	851.01	0.28	0.69	-1590.45	2.03	0.28	42.36	NO	NO,IE	6287.97	9.81	0.01
2014	-4203.86	1.05	0.29	45.76	0.33	0.69	-916.37	1.98	0.28	4.51	NO	NO,IE	6437.93	10.99	0.04
2015	-4379.15	1.03	0.30	1132.00	0.43	0.68	-1268.34	1.88	0.28	-5.82	NO	NO,IE	6276.79	9.75	0.01
2016	-4453.58	1.01	0.31	150.66	0.48	0.67	-830.71	1.78	0.28	-38.95	NO	NO,IE	6273.72	9.72	1.5x10 <sup>-3</sup>
2017	-4225.60	1.58	0.32	74.21	0.48	0.66	-577.63	3.04	0.29	-39.11	NO	NO,IE	6441.59	10.90	0.03
2018	-4090.74	1.19	0.33	71.35	0.48	0.65	-998.04	2.08	0.28	-125.20	5.7x10 <sup>-4</sup>	1.5x10 <sup>-5</sup>	6395.94	10.27	0.01
2019	-4000.96	1.09	0.33	65.87	0.48	0.63	-1341.01	1.79	0.28	-104.39	5.4x10 <sup>-4</sup>	1.4x10 <sup>-5</sup>	6400.87	10.05	4.5x10 <sup>-3</sup>

**Table 11.5 Annex II of decision 2/CMP8 checklist and cross references**

<b>Paragraphs reference in Annex II</b>	<b>Reference in NIR</b>	<b>Comment</b>
1	All of Ch6 and 11	All reporting requirement below. Definitions in section 11.1.3
2(a)	All of Ch6 and 11	Methodologies used in Ch6 and Ch11
2(b) and 5(b)	Section 11.1.4 and 11.1.5	
2(c)and 5(c)	Section 11.1.5.1	
2(d)	Section 11.1.5 and 11.1.5 KP CRF tables	Elected activities since 2013
2(e)	Section 11.3	
2(f) i-vi	Section 11.4	Only required when accounting at end of commitment period
2 (g)	KP CRF tables	
2(g)i and vii	KPCRf tables, sections 6, 6.3.7 and 11.6 and 11.6.3	Tables 6.25 (domestic consumption) Tables 11.11 (harvest fraction for 3.3 AR and 3.4 FM activities) Tables 6.6, 6.13, and 6.19 (Harvest from AR, D and FM lands)
2(g)ii	Section 6.3.7.1 and 11.6.2	Eqs 6.3.11 and 6.3.12
2(g) iii	Section 11.5	TAR of FMRL ( <a href="http://unfccc.int/resource/docs/2011/tar/irl01.pdf">unfccc.int/resource/docs/2011/tar/irl01.pdf</a> )
2 (g) iv and v	Sections 11.6.4 and 11.6.5	Table 11.11 and KP CRF tables
2 (g) vi	Section 11.6.6	
3 a, b, and c	Section 11.6.7	
4 (a) and 5(a)	Section 11.1.6	
4 (b)	Section 11.2.3.1	
5 (d)	Not relevant	All forests are managed
5 (e) and (f)	Section 11.5	
5 (g)	Not relevant	No equivalent areas

### 11.1.3 Definitions and Application

For the definition of different carbon (C) pools please refer to sections 6.1 and 6.3.2.6. Also see Table 11.1 for reporting of different C pools.

#### Forest definition

The definition of forest is the same as that adopted for the LULUCF inventory under the Convention. Forest land has a minimum area 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. 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.

The forest definition is applied to the NFI when land cover and use is determined (see section 6.3.2.3). The classification of forest roads, open forest areas within forest boundaries are undertaken at the plot level based on established permanent sample plots established under the NFI.

### **Consistency of forest definition with those used under other reporting obligations**

The generic FAO forest definition is different to national specific forest definitions or those developed under the Marrakesh Accords. The current national forest definition (see previous page) has been adopted since 2006, since the completion of the first NFI. The FAO Global Forests Assessment Report 2015 for Ireland uses the same definition as used for Kyoto reporting (<http://www.fao.org/3/a-az242e.pdf>). However, the national forest definition reported to the FAO before 2006 was different to the currently used definition (<http://www.fao.org/forestry/8417-071e8f7472987413b443e217d2ff4130e.pdf>).

### **Forest management**

Ireland considers that all areas meeting the forest definition are managed through forestry operations (timber resource utilisation) or for other reasons such as conservation, control of invasive species, pests or diseases. Therefore, activities under FM include all areas which meet the forest definition and

were first established before the 1<sup>st</sup> of January 1990, or are pre-existing semi-natural forests before 1<sup>st</sup> of January 1990.

### **Natural disturbances**

Ireland applies the same definition for natural disturbance as that outlined in the annex of decision 2/CMP.7 paragraph 1a. Ireland considers that wildfires, insect and disease outbreaks, extreme weather and or geological disturbances are outside the control of or are not influenced by policy in Ireland. Ireland may wish to apply the provisions to exclude emissions from natural disturbances for the accounting for afforestation and reforestation (AR) under Article 3, paragraph 3, of the Kyoto Protocol and FM under Article 3, paragraph 4, of the Kyoto Protocol during the second commitment period in accordance with decision 2/CMP.7, annex, paragraph 33 (see section 11.4).

### **Carbon equivalent forest conversion (CEFC)**

Ireland has not identified any land which qualifies for CEFC as outlined in the decision 2/CMP.7, annex, paragraph 37.

### **Cropland Management**

The definition of cropland is the same as that adopted for the LULUCF inventory under the Convention. This is consistent with the definition contained in decision 16/CMP.1. *“Cropland management” is the system of practices on land on which agricultural crops are grown and on land that is set aside or temporarily not being used for crop production.* The following activities are also relevant to the CM:

- Non-forest woodland and hedgerows, including boundary features, associated with identified croplands are included in the definition of CM. However, assessment of these has not been included in this submission (section 6.4.1);
- CM includes areas identified as temporary grassland, with a history of cultivation for crops in the period 1990-2019;
- The CM area includes tree stands (not classified as forests) in agricultural production systems;
- CM excludes recreational areas in urban parks and gardens, which have been used for recreational/private vegetable growing.
- The Land Parcel Information System requires parcels mapping for submission by land managements to be accurate to within 0.1 hectares. An annual audit by DAFM is undertaken based on inspection of a random selection of parcels each year. Therefore, Cropland Management has a minimum area of 0.1 ha.

Ireland considers all areas which have been identified as being utilised for crop cultivation in the period 1990-2019 as subject to Cropland Management activity. In any given year, these include areas under crops and areas under temporary grasslands. Those areas previously reported under CM which have been converted to other land uses (e.g. Settlements) will also continue to be reported under CM.

### **Grazing land Management**

The definition of Grazing land Management is the same as that adopted for Grassland for the LULUCF inventory under the Convention. This is consistent with the definition contained in decision 16/CMP.1, *“Grazing land management” is the system of practices on land used for livestock production aimed at manipulating the amount and type of vegetation and livestock produced*”. The following caveats are relevant to the definition:

- Non-forest woodland and hedgerows, including boundary features, associated with identified grasslands are included in the definition of GM, however, assessment of these has not been included in this submission (section 6.5.1);
- GM excludes areas identified as temporary grassland, with a history of cultivation for crops in the period 1990-2019;
- GM excludes recreational areas such as urban parks, sporting facilities and gardens.
- The Land Parcel Information System requires parcels mapping for submission by land managements to be accurate to within 0.1 hectares. An annual audit by DAFM is undertaken based on inspection of a random selection of parcels each year. Therefore, Grazing land Management has a minimum area of 0.1 ha.

Ireland considers grassland areas which have identified as utilised as agricultural land in the period since 1<sup>st</sup> Jan 1990 as areas under Grazing land management, unless explicitly identified under reported Art 3.3 or Art 3.4 activities. Therefore, areas of land which had a history of crop cultivation, but are currently under grass are reported under CM and excluded from GM.

#### 11.1.4 The geographical location of the boundaries of the areas that encompass activities under Article 3, paragraphs 3 and 4

The following information is provided to assist in review for compliance under annex II to Decision 2/CMP.8. para. 2b. The definition of reporting boundaries and their geographical locations for afforestation, deforestation and forest management areas are reported within the entire territory of Ireland, with further sub division of species strata within internal national boundaries. The national boundary is used as the basis for the random systematic grid sample used in the National Forest Inventory (NFI, see Section 6.3.2.3).

The definition of reporting boundaries and their geographical locations for cropland management and grazing land management areas are reported within the entire territory of Ireland, with further sub division of management type and soil type strata within the national boundaries. The national boundary is used as the basis for data collation for the Land Parcel Information System and Central Statistics Office analysis of Utilised Agricultural Area (see Section 6.4.1 and 6.5.1).

#### 11.1.5 Classification hierarchy and continuity of accounting reported activities over time

Activities under forest management (FM Art 3.4) are distinguished from AR lands based on the year of afforestation as derived from the IFORIS system and the NFI (sections 6.3.2.2 and 6.3.2.3). This system identifies units of land subject to activities under Article 3, paragraph 3, of the Kyoto Protocol which would otherwise be included in land subject to forest management or elected activities under Article 3, paragraph 4, of the Kyoto Protocol under the provisions of decision 2/CMP.8, annex, paragraph 5c. The hierarchy used for assigning land areas to specific activities ensures that all areas reported under afforestation or forest management activities cannot decrease unless converted to deforestation land (see CRF Table NIR2).

Activities under cropland management (CM Art 3.4) and grazing land management (GM Art 3.4) are distinguished based on land parcel histories derived from the Land Parcel Information System, and the CORINE land cover database (section 6.4.3 and 6.5.1). The hierarchy used for assigning land areas to

specific activities ensures that all areas reported under CM or GM cannot decrease unless converted to Art 3.3 Afforestation land, or swapping between CM and GM. (see CRF Table KP NIR2). From Figure 6.1, it can be seen that the hierarchy ensures no double counting of areas of elected or mandatory activities

This means that in all cases once land is accounted for under activities under Article 3, paragraph 3 and forest management, cropland management or grazing land management under Article 3, paragraph 4 reporting shall continue throughout subsequent and contiguous commitment periods (see CRF table NIR 2, para 2(d) in annex II of decision 2/CMP.8).

#### 11.1.5.1 The information on identifiable units of land under mandatory activities and spatial assessment units.

The NFI is the primary data source used to identify areas under ARD and FM (section 6.3.2.2 and 6.3.2.3, Chapter 6). The primary classification of forest land in the NFI uses approach 3 as defined in Chapter 3, Section 3.3 of the 2006 IPCC Guidelines for Agriculture, Forestry and Other Land Uses for the representation of land areas for Article 3.3 activities and FM. The spatial assessment unit used in the NFI and for reporting is the area of permanent sample plots (0.05ha). The same assessment unit is used to determine AR, D and FM areas and these are not larger than 1ha in accordance with paragraph 2(c) in the annex to decision 2/CMP.8.

The NFI used information from the IFORIS system (section 6.3.2.2) to identify forest lands afforested after the 31<sup>st</sup> of December 1989. This enables the inventory to distinguish between activities under AR and those occurring under FM.

A secondary classification of identified forest land is carried out at the plot inventory phase in the NFI. This secondary classification is done to verify that the forest definition was correctly applied and interpreted during the photo interpretation in phase 1 and to further classify forest areas into areas under planted forest areas, temporary un-stocked forest areas, open areas with forest boundaries (e.g., rides, roads etc.). Forest stand attributes from the NFI were also collected to classify forest age, rotation stage (i.e. thicket, pre thinning, thinning cycle or rotation cycle), and management status so that inventory plots could be disaggregated into appropriate KP forest categories.

The hierarchical classification system used to define land use areas (see Figure 6.1 in section 6.2.2.1) and the level 2 classification of forest lands ensured that land areas are not double counted, and that CSC is calculated based on the spatial assessment unit for all activities.

Activities under ARD or FM are reported within the entire territory of Ireland, with further sub division into species/forest type strata (Annex 3.4B, Tables 3.4.B.1-1 and 3.4.B.2) within internal national boundaries.

In years when NFI inventory data is not available (i.e. before the 1<sup>st</sup> or after the last NFI) afforestation areas are tracked on a spatially explicit basis (IPCC Approach 3, see section 6.3.2.5) while deforestation areas are identifiable but not spatially explicit (IPCC Approach 2, see section 6.3.2.4) for years before the 1<sup>st</sup> or after the last NFI. Both approaches can detect a land use change at a resolution consistent with the forest definition area of 0.1 ha. For deforestation activities, (CRF Tables 4(KP-I)A.1.2) areas are stratified according to land use activities converted from forest area. This is consistent with forests converted to other land uses in LULUCF Convention reporting (CRF Tables 4 B, C, D and E).

### 11.1.5.2 The information on identifiable units of land under elected activities and spatial assessment units

The Land Parcel Information System (LPIS) is the primary data source used to identify areas under CM and GM (section 6.4.1 and 6.4.3).

The primary classification of cropland and grazing land uses approach 3 as defined in, section 3.3 Chapter 3 of the 2006 IPPC guidelines for AFOLU for the representation of land areas. The classification is based on the explicit spatial boundaries of land parcels with a tolerance of 0.1 ha for each parcel. The same assessment unit is used to determine AR, D and FM areas and these are not larger than 1 ha in accordance with paragraph 3 in the annex to decision 2/CMP.7.

The Land Parcel Information Systems is maintained by the DAFM, and is compatible and spatially consistent with the IFORIS system (section 6.3.2.2). This enables the inventory to distinguish between activities under AR and conversion of CM and GM lands to AR. It also allows tracking of deforestation D to cropland and grassland land uses, which are reportable under Art 3.3 D.

The hierarchical classification system used to define land use areas (section 6.2.2.1) and the level 2 classification of forest lands ensure that land areas are not double counted and that CSC are calculated based on the spatial assessment unit for all activities.

Activities under CM or GM are reported within the entire territory of Ireland.

At present, the analysis of the conversion of CM and GM to other land-uses, e.g. Settlement, is not spatially explicit. However, whilst the conversion to an alternative land use is captured, through adjustments in the land parcel data, the new-land use is not spatially explicit. Work is underway to address this through the development of a spatial land use map as discussed in Chapter 6.

### 11.1.6 Information that demonstrates elected activities are directly human induced and have occurred since 1990

#### **Article 3.3 activities (para. 4a of 2/CMP.8)**

Reforestation activities do not occur in Ireland and the relevant activities under Article 3.3 are limited to afforestation and deforestation. All afforested areas are a result of direct planting and establishing forest areas under guidelines of the Forest Service Grant and Premiums Scheme since the beginning of 1990 (Forest Service, 2003). The afforestation grant and premiums scheme was introduced under Council Regulation (EEC) No. 2080/92 to support afforestation of agricultural land as part of accompanying measures to reform the Common Agricultural Policy. The afforestation grant and premiums dataset capture all areas afforested following successful grant application. All afforestation areas recorded by the Forest Service are verified using a strict control and referrals process, following a post establishment site visit by a forestry inspector (Forest Service 2003).

All deforestation areas are derived from legally-binding licence applications under the Forestry Act, 2014. These provisions fulfil the requirement to demonstrate that afforestation (i.e. planting of non-forest land with trees for development of the forest sector) and deforestation began on or after 1 January 1990 and are directly human-induced, which is necessary for the accounting of emissions and removals for activities under Article 3.3. These datasets were primarily digitised using the 1:12560 and 1:2500 Ordnance Survey Ireland (OSI) raster maps (see section 6.3.2.5).

#### **Article 3.4 Forest management (para. 5a of 2/CMP.8)**

All forest areas are managed (see definition) and these are distinguished from ARD activities based on year of initial establishment (see 11.1.5). Areas under forest management can be categorised into the following:

1. *Land owned by the State forestry company- Coillte.* These areas [ca. 89 per cent of the total FM area] are subject to forest management plans (FMPs), forest inventory and routine application for felling licences under the Forestry Act 2014. These management plans are updated every 5 years to ensure that future timber demands are met. This information is used for timber forecasting and securing timber sales. Other management activities carried out include pest and disease control, crop nutrition, biodiversity management, nutrient loading and runoff management, riparian woodland management etc. The Coillte FMP 2011-2015 for each forest region can be downloaded from:  
[http://www.coillte.ie/coillteforest/plans/previous\\_business\\_area\\_unit\\_bau\\_strategic\\_plans\\_and\\_forest\\_management\\_plans\\_2011\\_2015/business\\_area\\_unit\\_bau\\_strategic\\_plans\\_2011\\_2015/](http://www.coillte.ie/coillteforest/plans/previous_business_area_unit_bau_strategic_plans_and_forest_management_plans_2011_2015/business_area_unit_bau_strategic_plans_2011_2015/)
2. *Private grant aided afforestation from 1985-1989:* These areas of forest were established before 1990 under the Forest Service Grant and Premiums Scheme. The application procedure for the scheme requires a detailed forest management plan for a 20-year period. In addition, the Forestry Act 2014 requires management plans for clearfell, thinning and replanting operations, which are submitted when applying for felling licences.
3. *Private grant aided forests since 1920:* These represent very small areas of existing forests which were grand aided under various other small schemes before 1985. Evidence of forest management activities for these lands include:
  - a) The 1975 private forest survey provided detailed management plans for all private forests.
  - b) The Forestry Act 2014 requires management plans for clearfell, thinning and replanting operations, which are submitted when applying for felling licences.
  - c) The Forestry Act 2014 aims to promote the development of forests and forest-related activities and industries in such a way that forests provide an economically, environmentally and socially sustainable yield of forest goods and services, while maintaining and enhancing their biological diversity. There are numerous sections in the act, which refer to specific management plans. For example, section 10(1) “The Minister may, by notice in writing, require an owner of a forest to submit a forest management plan in respect of his or her forest to ensure that afforestation, felling, restocking, forest road works and other forestry related activities (including amenity and recreation uses of forestry) are being carried out in accordance with good forest practice”.
4. *Existing forests before 1920:* These include old estate forests and semi-natural forests/woodlands in existence before 1920. Specific forest management activities include those outlined under item 3 above and include:
  - a) Management guidelines for the ‘Woodlands of Ireland’ (<http://www.woodlandsofireland.com/>) with the objective to generate awareness of native woodlands amongst policy makers and the public and to develop projects and

sustainable management strategies aimed at ensuring the future viability of native woodlands.

- b) Existing semi natural woodland grants also require submission of detailed management plans on application for grant aid.

### **Article 3.4 Cropland Management**

All areas subject to CM activities are managed (see definition), in private ownership, and these are distinguished from GM activities based on history of land parcel use since 2000 as derived from the LPIS. The data which forms the basis of the analysis of CM is collected as an integral and mandated component of the Farm payments systems under the EU Common Agriculture Policy, which is under the administration of the Department of Agriculture, Food and Marine. In order to satisfy the regulatory controls under the CAP, all aspects of the farm payments system are subjected to rigorous auditing, including the mapping and spatial attribute data from the LPIS.

Areas under cropland management can be categorised into the following:

1. *Croplands under continuous tillage*

These are land parcels which are identified as having been declared as tillage crops in all years since 2000, and with the assumption that these parcels were managed in a similar manner since 1990. It is reasonable to assume these lands are in long term equilibrium with respect to carbon pools. These lands tend to be in the direct ownership of the land manager/farmer.

2. *Croplands under regular rotation with temporary grassland*

These are land parcels which are identified as having declared as tillage crops in many of the years since 2000, and with the assumption that these parcels were managed in a similar manner since 1990. These lands tend to be in the direct ownership of the land manager/farmer. However, a significant proportion may be subject to short term leasing arrangements, whereby the land manager can vary, with switching in land use for short periods, and little consideration of the long-term sustainable management of the land. These lands are not in in long term equilibrium with respect to carbon pools.

3. *Lands under crops occasionally or infrequently, generally under grassland*

These lands have spent far longer periods under grass than under crops during their recent histories. It is very likely that these lands are subject to very short-term leasing arrangements between livestock and tillage farmers. Their carbon pools are likely close to the long-term equilibrium condition of permanent grasslands.

4. *Croplands converted to Settlement*

Conversion of agricultural land to Settlement is relatively common in rural and suburban settings. These lands remain reportable under Art 3.4 activities.

### **Article 3.4 Grazing land Management**

All areas subject to GM activities are managed (see definition) and these are distinguished from CM activities based on a history of permanent grassland. Areas under grazing land management can be categorised into the following:

1. *Grasslands identified as permanent grasslands*

Grazing land is subdivided into improved grasslands, consisting of lands reported as managed as pasture, silage and hay.

Unimproved grasslands, consisting of lands reported as managed as rough grazing.

Un utilised grasslands, consisting of unmanaged but accessible grasslands, which have been identified as in agricultural use at some stage since 1990.

## 2. Grasslands converted to Settlement

Conversion of agricultural land to Settlement is relatively common in rural and suburban settings. These lands remain reportable under Art 3.4 activities.

## 11.2 Methodologies and description of data

For detailed description of sources of activity data and methods used please refer see sections 6.3.1, 6.3.2, 6.3.3, 6.4.1, 6.4.2, 6.4.3, 6.5.1 and 6.5.2 and Annex 3.4). Harvested wood product CSC is estimated using the same methodology as outlined in section 6.3.7. However, harvest inflows into HWP for afforested land in the 1<sup>st</sup> commitment period (2008-2012) and all deforested lands are excluded (assumed to be instantly oxidised) from HWP estimates as specified by paragraphs 2g (iv and v) of annex II to decision 2.CMP.8 (see section 11.6.4 and 11.6.5). This differs from the approach adopted under Convention reporting.

### 11.2.1 Afforestation

See Sections 6.3.2.5 and 6.3.3 and Annex 3.4 for methodology. For detailed data on areas and CSCs (excluding HWP) over the time series see Tables 6.5 and Figure 6.13.

### 11.2.2 Forest management

See Sections 6.3.2 and 6.3.3 and Annex 3.4 for methodology. For detailed data on areas and CSCs (excluding HWP) over the time series see Table 6.6 and Figure 6.11.

### 11.2.3 Deforestation

#### 11.2.3.1 Information on how harvesting or forest disturbance that is followed by the re-establishment of a forest is distinguished from deforestation.

Ireland provides information on how lands subject to harvest or disturbance followed by re-establishment is distinguished from deforestation as required under paragraph 4b of annex II to the decision 2/CMP.8. A forest area is classified as deforested when there is clear indication of a specific land use change for that area or if clearfelled areas have not been replanted within a period of 5 years. Whilst different methodologies have been used to detect deforestation over time (Sections 6.3.2.4 and 6.3.6), this definition of deforestation has been applied consistently in developing the 1990 to 2019 area time-series.

The NFI 2012 and 2017 enabled the detection of all deforestation events including illegal deforestation and failure to replant felled areas within 5 years. ***If a clearfelled area has not been planted with a successive crop within one NFI cycle (i.e. 5 years), the area is classified under deforestation.*** These areas are to be reported for the year deforestation is detected. Under the felling licence rules all replanted forests must be inspected after 5 years to ensure a 95 per cent survival rate. The forest is then considered to be successfully established for the next rotation.

### 11.2.3.2 Deforestation Information

See sections 6.3.6 and Annex 3.4A for methodology. For detailed data on areas and CSCs over the time series see Tables 6.17 and 6.18.

Information for deforested areas supplied with the limited felling license application/or from the NFI provides details of the species, areas, volume of timber clear felled and an indication of the applicable land use transition categories (see CRF 4(KP-I)A.2):

Forest land to Grassland (**F-GL**)

Forest land to Cropland (**F-CL**), this does not occur.

Forest land to Wetland (**F-WL**)

Forest land to Settlement (**F-S**)

Forest land to Other land (**F-OL**), these include land not classified above such as quarries, windfarms

Biomass, litter and deadwood pools for deforestation land were assumed to be immediately oxidised in the year deforestation occurs (see Chapter 6). The changes in biomass and deadwood C pools stock for these deforested lands converted to other land uses in the subsequent years is assumed to be zero and reported as NO. This is because all forest C pools have been oxidised in the previous year.

### 11.2.4 Cropland management

See sections 6.4.1 to 6.4.4. For detailed data on areas over the time series see Figures 6.23 and 6.25.

### 11.2.5 Grazing land management

See sections 6.5.1 to 6.5.4. For detailed data on areas over the time series see Figure 6.30.

### 11.2.6 Direct and indirect emissions from N fertilisation

Direct and indirect emissions of N<sub>2</sub>O from N fertiliser application are included under Agriculture (3.D.a.2).

### 11.2.7 N<sub>2</sub>O and CH<sub>4</sub> from drained and rewetted organic soils

See sections 6.3.4.5, 6.3.4.6, 6.3.5.5 and 6.3.5.6. Note that CO<sub>2</sub> emissions from drained organic soils are reported as IE in CRF tables 4(KP-I) A.1, A.2 and B.1

### 11.2.8 N<sub>2</sub>O losses from mineralization of soils due C loss associated with land use change

For afforestation activities, this does not occur (NO) because CSC in afforested mineral soils is not a source (see CRF 4(KP-II)3).

For deforestation to settlement and other land, CSC in mineral soils are reported and N<sub>2</sub>O emission are reported using tier 1 approaches (see 6.3.6.1.)

### 11.2.9 Biomass burning from Forest ARD and FM Fires

Areas of forest subjected to wild fires were obtained from Forest Service statistics (see section 6.3.4.4 and Table 6.8). These areas were assumed to be proportionally distributed between the Kyoto

Protocol forestry categories afforestation/reforestation and forest management. For example, in 2008 the AR area in Table 11.1 represented 36 per cent of the total forest area, so it was assumed that 36 per cent of areas experiencing wild fires in 2008 are in the AR category. This determines the area for estimating biomass burned under AR and FM (see Table 6.8), reported in CRF Table 4(KP II)4. The same assumptions are applied to years subsequent to 2008.

#### 11.2.10 Biomass burning from CM Fires

Areas of cropland subjected to wild fires were extrapolated from (see section 6.4.8) remote sensing detection of fires from the NASA FIRMS database.

#### 11.2.11 Biomass burning from GM Fires

Areas of grazing land subjected to controlled fires were extrapolated from (see section 6.5.4 and Figure 6.33) remote sensor detection of fires from the NASA FIRMS database.

### 11.3 Justification for Omitting a Carbon Pool

All carbon pools are estimated for forested and deforested land.

#### 11.3.1 Cropland management Dead Organic Matter Carbon Pools

Based on the decision tree in Section 2.9.4.1 of the 2013 KP Supplement to the 2006 IPCC Guidelines, and Section 5.2.2.4, Vol 4 of the 2006 Guidelines, changes in Litter and Dead Matter carbon pools are assumed to be stable.

Changes in biomass associated with transitions between grassland and croplands within the CM cohort are estimated. Changes in the biomass of hedgerows, and other non-forest wood features, have not been estimated.

Biomass changes due to changes in the area of perennial woody crops are based on the analysis of the dominant crops, apple orchards and Christmas trees. In the case of Christmas trees, there is evidence that the market for trees is stable or increasing slightly over time, and as such the biomass associated with this crop is stable or increasing (section 6.4.7).

The area of apple orchard decreased in the early 1990s, but has been in near equilibrium in recent years as shown in Figure 6.21.

Hedgerows are an integral part of the CM landscape. However, there is very limited long-term monitoring data as to conditions and extent of these features. The EPA has funded a research project to pilot an analysis of historic and contemporary remote sensing data to establish a robust time series of changes in these landscapes. There is conflicting evidence as to the current trends in hedgerow and wooded area management within CM. Measures under planning guidelines, the Rural Environment scheme, Green Low-Carbon Agri-Environment Scheme (GLAS), its antecedents and other policies, the maintenance, of existing hedgerows and establishment of new hedgerow has been encouraged. For example, under REPS 3 and 4 and AEOS 1 and 2 rural environmental protection schemes (see Figure 11.6), support was provided for establishment of approximately 10,000 km of new hedgerow (Teagasc Newsletter, Sep 2013<sup>13</sup>). However, the National Forest Inventory detected a decrease in hedgerow area of 4,548 ha between 2006 and 2012, albeit with a very large uncertainty. At present it is not

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<sup>13</sup> [http://www.teagasc.ie/publications/2013/2865/Environment\\_Newsletter\\_September2013.pdf](http://www.teagasc.ie/publications/2013/2865/Environment_Newsletter_September2013.pdf)

possible to provide a robust time series of hedgerows, and therefore it has not been possible to produce an estimate of biomass changes associated with their management.

### 11.3.2 Grazing land management Carbon Pools

Based on the decision tree in Section 2.10.4.1 of the 2013 KP Supplement to the 2006 IPCC Guidelines, and Section 6.2.2.1, Vol 4 of the 2006 2006 Guidelines, changes in Litter and Dead Organic Matter carbon pools are assumed to be in equilibrium and there is no requirement to estimate carbon stock changes in these pools, as a Tier 1 approach.

Biomass changes due to the transition between different grazing land management types are interpreted as “not a source”. The main transitions which have occurred are:

- An increase in the intensive management of improved grasslands, which will tend to increase the productivity of the grazing land. However, this additional productivity is removed by harvesting for fodder or grazing. As such, any apparent increase in biomass is short lived. Averaged over the year, it is more likely than not to result in a slight increase in biomass, due to increased productivity. Therefore, the transition can reasonably be considered “not a source”.
- An increase in the area of land reverting from rough grazing to unutilised (not in use) grassland is inferred from the activity data. With the removals of grazing animals from rough grazing areas, there is likely an increase in the biomass on these lands. However, this has not been quantified. However, it is reasonable to consider the transition to be “not a source” with respect to biomass.

Hedgerows are an integral part of the GM landscape. However, there is very limited long-term monitoring data as to condition and extent of these features. The EPA has funded a research project to pilot an analysis of historic and contemporary remote sensing data to establish a robust time series of changes in these landscapes. There is conflicting evidence as to the current trends in hedgerow and wooded area management within GM. See section 11.3.3 for a more detailed discussion of available data. At present it is not possible to provide a robust time series of hedgerows, and therefore it has not been possible to produce an estimate of biomass changes associated with management of these

Ireland considers that all emissions/removals from Article 3.3 activities are directly human induced, since they are activities resulting from silvicultural intervention. No factoring out of indirect human-induced activities is considered in this submission due to a cited poor understanding of these influences (see Ainsworth and Long, 2005).

For FM, it is considered that the use of a forward looking baseline or FMRL factors out any non-human induced induction of emissions or removals such as N deposition, CO<sub>2</sub> fertilisation or age class legacies (see reviews carried out under 2.CMP6 and the 2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol).

For CM and GM, Ireland considers emissions and removals to be dominated by, and indistinguishable from, the influence of management decisions and therefore all changes in in emissions and removals to be directly human induced. By using Tier 1, emission factors, possible changes in the emissions and removals associated with direct impact of climate change or the fertilization effect of increased CO<sub>2</sub> levels are not included in the estimates. At this time, climate change impacts have not invalidated the use of temperate zone Tier 1 emission factors for Ireland<sup>14</sup>, with an observed increase in temperature

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<sup>14</sup> Met Eireann, May 2012, Meteorological Note No. 14, A Summary of Climate Averages for Ireland 1981-2010

of 0.5°C between climate averages for 1961-1990 and 1981 -2010. Precipitation has been observed to increase slightly over the same period. Therefore, Ireland remains in the “temperate, moist” climate zone. Therefore, “factoring out” is inherent, and estimates of emissions and removals are only driven by evaluation of human impacts on the activities.

## 11.4 Natural disturbances

Ireland wishes to indicate that it may apply the provisions to exclude emissions from natural disturbances for the accounting for afforestation and reforestation under Article 3, paragraph 3, of the Kyoto Protocol and forest management under Article 3, paragraph 4, of the Kyoto Protocol during the second commitment period in accordance with decision 2/CMP.7, annex, paragraph 33a. A national system needs to be developed to track the exact location of areas subject to fires, if the natural disturbance provision is to be applied. Ireland cannot apply the provision until this capacity has been developed.

### 11.4.1 Calculation of background and margin

Emissions from wild fires may be excluded, if “triggered”, under the natural disturbance provision for both Article 3, paragraph 3, and Article 3, paragraph 4 activities. The calibration data to calculate the background level and margin includes the period 1990-2009, but has been extended to 2012 to account for most recent data (Table 11.6a and 11.6b). Wildfires have only been recorded in AR lands since 2008 and are assumed not to occur before 2008. The background and margin estimates are based on the 2015 KP submission and not the most recent fire statistics (see Table 6.8 of Ch 6).

**Table 11.6a Total emissions form wild fires and area specific emissions from disturbances for the calibration period for FM**

Year	Wildfires (kt CO <sub>2</sub> eq.)	Insect/diseases	extreme weather	geological disturbances	other	Area (ha)
1990	113					389
1991	73					250
1992	47					161
1993	94					324
1994	108					372
1995	148					508
1996	164					565
1997	90					309
1998	47					163
1999	39					133
2000	97					334
2001	194					666
2002	45					153
2003	275					944
2004	160					550
2005	58					200
2006	58					200
2007	65					225
2008	51					175
2009	28					98
2010	185					636
2011	69					237
2012	17					60

**Table 11.6b Total and area specific emissions from disturbances for the calibration period for AR**

Year	Wildfires (kt CO <sub>2</sub> eq.)	Insect /diseases	extreme weather	geological disturbances	other	Area (ha)
2008	17					99
2009	10					57
2010	64					377
2011	24					139
2012	6					35

The default method for estimating the background and margin for the natural disturbance provision is applied to the calibration data for both FM and AR disturbances using default approaches (Box 2.3.6 2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol). The final background and margin is derived at step VI, as outlined in the 2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol (see Table 11.7).

**Table 11.7 Calculation steps used to derive the background and harvest for FM and AR for the second commitment period (see Box 2.3.6 of 2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol for detailed methods)**

**kt CO<sub>2</sub> eq. for FM**

Background/margin	I step	II step	III step	IV step	V step	VI step
Arithmetic mean	97	89	84	79	74	69
standard deviation	64	52	48	43	39	33
background+margin	225	193	179	164	151	136

**kt CO<sub>2</sub> eq. for AR**

Background/margin	I step	II step	III step	IV step	V step	VI step
Arithmetic mean	23.95	23.95	23.95	23.95	23.95	23.95
standard deviation	23.33	23.33	23.33	23.33	23.33	23.33
background+margin	70.62	70.62	70.62	70.62	70.62	70.62

### 11.4.2 Trigger test for implementation of the natural disturbance provision

The reported emissions from wild fires under AR lands for 2019 were 4.1 kt CO<sub>2</sub> eq, which is lower than the background plus margin (70.6 kt CO<sub>2</sub>) presented in table 11.7. For 2017, Ireland can trigger the election of the natural disturbance provision (i.e. trigger test in CRF table 4(KP-1) A1.1). However, Ireland cannot track the geolocation of burned areas as outlined in para 2f(vi) in annex II of 2.CMP/8). Therefore, emissions to be excluded from the 2017 inventory are reported as “NE” in CRF Table 4(KP-1) A1.1)

The reported emissions from wild fires in lands under FM activities are also lower than the background and margin presented in Table 11.7. As for AR areas in 2017, Ireland cannot track the geolocation of burned areas for FM areas in 2017 as outlined in para 2f(vi) in annex II of 2.CMP/8.). Therefore, emission to be excluded from the 2017 inventory are reported as “NE” in CRF table 4(KP-1) B1.3. Inventory improvement plans are underway to develop a spatial tracking system for wildfires (see planned improvements section 6.3.8). All reporting requirements relating to the election of the natural disturbance provision should only be provided when accounting (see annex II para.2f of 2/CMP8). Ireland has elected to account at the end of the commitment period.

### 11.4.3 Exclusion of emissions from salvage logging

Salvage logging does not occur in lands subjected to forest fires. This is consistent with the assumption that all biomass and DOM is immediately oxidised when subjected to wild fire (see section 6.3.4.4 in Ch 6).

Ireland does not include disturbance event emissions associated with windthrow damage under the natural disturbance provision because all timber in windthrown areas is assumed to be recovered by salvage logging. Therefore, salvage logging will be excluded from natural disturbance emissions, should the provision be triggered (see para 2f(vi) in annex II of 2.CMP/8.). Emissions associated with windthrow (i.e. biomass, litter, deadwood etc.) are captured in the NFI inventory and included under ARD or FM CSCs. Insect and disease infestations currently result in minimal emissions and are assumed to be captured by the inventory as reflected by the NFI permanent sample plot data.

## 11.5 FMRL, FM CAP and technical corrections

Ireland's forest management reference level (FMRL) as inscribed in the appendix to the annex to decision 2/CMP.7 is -142.07 kt CO<sub>2</sub> equivalent, see table 11.9 below. The forest management CAP (FM CAP) for the second commitment period as describes in paragraph 13 of the annex to 2/CMP.7 is 15,708.78 kt CO<sub>2</sub> (see CRF KP accounting table).

Ireland has performed recalculations for the historic time series and will apply a technical correction when accounting for the second commitment period. The requirement to apply a recalculation is based on conditions as outlined in the IPCC 2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol (IPCC 2013 GPG KP-LULUCF):

- Use of new models to derive the reported CSC in the inventory year 2017. The same new model has been applied to the activity data used for the forest management reference level (FMRL) inscribed in the annex to 2/CMP.7. The CFS-CBM model is now used for the basis for CSC changes in biomass, litter, deadwood and soil pools. The FMRL submission (see 2/CMP7) used CARBWARE version 4.5 (Black et al., 2012).
- Mineral soil CSC is now included in the FM inventory.
- There have been a range of methodological changes for estimation of CO<sub>2</sub>, N<sub>2</sub>O and CH<sub>4</sub> emissions from organic and mineral soils as outlined in the 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands (IPCC Wetland supplement 2013). These include offsite DOC emissions of C, N<sub>2</sub>O and CH<sub>4</sub> emissions due to drainage of organic soils.
- In accordance with Decision 2/CMP.6, Ireland's FMRL submission included a description of the domestic policies adopted and implemented no later than December 2009 and explain how these policies have been considered in the construction of the FMRL. Ireland confirms that the construction of the FMRL does not include assumptions about changes to domestic policies adopted and implemented after December 2009. However, Ireland has obtained new historical data for:
  - FM areas due to new deforestation data based on the repeat NFI in 2012 (See Table 11.8).
  - New historical harvest rates from FM areas before 2009 based on new national forest inventory (NFI) data (highlighted in bold in Table 11.8).

These data have been used to recalculate the historical and projected time series and a technical correction will be applied **when accounting** for FM activities.

New historical activity data (prior to 2009) and new methods for HWP estimations have been applied. Therefore, HWP pools emission reductions have been recalculated for the whole time series. The new methods include differentiation of domestic harvests from deforestation and those originating from FM lands remaining as FM land (IPCC 2013 GPG KP-LULUCF). The allocation of harvest volume to timber assortments was derived from the All Ireland Roundwood Forecast 2011-2028 (Phillips, 2011). The allocation of timber assortment to semi-finished harvested wood products was based on original regression equations use in the FMRL submission.

There is generally good agreement between the level of projected harvest used in construction of the FMRL and the reported harvest in the GHG inventory (Table 11.8), for the year 2013-2016. From 2017

onwards, the level of harvest reported in the inventory is lower compared to the projected harvest used in the FMRL. The decline in harvest from areas under FM is associated with a higher harvest from AR lands from 2017 onwards.

*Table 11.8 A comparison of previous activity data for 1990-2009 used for the FMRL submission and the new data used in the 2019 inventory*

Year	Area (Kha)		Harvests (M m <sup>3</sup> )	
	FM 2019 inventory	FMRL submission	FM 2019 (this submission)	FMRL submission
1990	465.25	481.35	1.68	<b>1.787</b>
1991	465.27	479.91	1.77	<b>1.837</b>
1992	465.22	476.96	2.08	<b>2.156</b>
1993	465.20	479.4	2.10	<b>2.003</b>
1994	465.18	480.7	2.29	<b>2.220</b>
1995	464.85	474.14	2.38	<b>2.424</b>
1996	464.51	463.2	2.46	<b>2.520</b>
1997	464.18	461.33	2.32	<b>2.398</b>
1998	463.84	463.32	2.64	<b>2.493</b>
1999	463.51	466.75	2.78	<b>2.842</b>
2000	462.66	462.14	3.01	<b>2.940</b>
2001	461.79	456.02	2.84	<b>2.700</b>
2002	460.94	450.85	2.91	<b>2.911</b>
2003	460.08	458.81	3.00	<b>2.951</b>
2004	459.22	456.45	2.85	<b>2.818</b>
2005	458.37	454.35	2.94	<b>2.775</b>
2006	456.37	477.21	2.17	<b>2.803</b>
2007	454.77	444.52	2.54	<b>2.160</b>
2008	452.77	446.94	2.01	<b>2.056</b>
2009	451.97	447.29	2.18	<b>2.392</b>
2010	451.17		2.65	1.833
2011	449.57		2.62	2.061
2012	449.57		2.64	2.314
2013	447.97		2.43	2.390
2014	447.97		2.23	2.104
2015	447.17		2.08	2.402
2016	446.37		2.53	2.558
2017	446.24		2.47	2.704
2018			2.63	2.870
2019			2.05	3.026
2020				3.182

The corrected time series (FMRLcorr) was re-estimated using the original assumptions in projected harvest and FM areas (Table 11.9). Projected areas for organic soils and fire assumptions were based on the original FMRL submission.

**Table 11.9: The corrected FMRL (FMRLcorr) time series from 2013-2020**

	Units	Year								Average
		2013	2014	2015	2016	2017	2018	2019	2020	
Area	kHa	445.58	445.16	444.73	444.3	443.88	443.45	443.02	442.59	
AB_gain	kt C	2614.43	2631.72	2641.26	2647.72	2647.48	2643.68	2632.62	2630.59	<b>2636.19</b>
AB_loss		-	-	-2324.44	2389.54	-2453.35	-2515.65	2594.14	2642.08	<b>2428.03</b>
AB_net		320.37	420.74	316.81	258.18	194.13	128.03	38.48	-11.49	<b>208.16</b>
Bggain		778.86	781.08	782.02	781.86	780.16	775.36	769.67	767.84	<b>777.11</b>
BG_loss		-737.95	-719.45	-743.59	-756.62	-769.34	-782.06	-796.56	-801.45	<b>-763.38</b>
BG_net		40.91	61.62	38.43	25.24	10.82	-6.70	-26.89	-33.62	<b>13.73</b>
Litter_Net		18.66	-2.01	21.72	30.70	47.56	62.26	65.81	70.49	<b>39.40</b>
DW_net		-96.59	-104.82	-64.97	-40.38	-27.28	-20.88	12.12	4.96	<b>-42.23</b>
Mineral Soils		-6.46	-6.74	-5.55	-4.94	-4.71	-4.73	-4.02	-4.14	<b>-5.16</b>
Organic Soils		-142.08	-141.83	-141.94	-141.86	-132.74	-141.24	-132.49	-132.36	<b>-138.32</b>
<b>Total C</b>		<b>134.82</b>	<b>226.96</b>	<b>164.49</b>	<b>126.95</b>	<b>87.78</b>	<b>16.75</b>	<b>-46.99</b>	<b>-106.16</b>	<b>75.58</b>
<b>Total CO2</b>		<b>-494.34</b>	<b>-832.18</b>	<b>-603.13</b>	<b>-465.49</b>	<b>-321.88</b>	<b>-61.40</b>	<b>172.30</b>	<b>389.24</b>	<b>-277.11</b>
Fires		kt CO <sub>2</sub> eq	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00
Drainage	128.18		128.06	127.94	127.81	127.69	127.57	127.44	127.32	<b>127.75</b>
<b>Total excl HWP</b>	<b>-501.46</b>		<b>-249.29</b>	<b>-156.63</b>	<b>485.61</b>	<b>717.40</b>	<b>821.02</b>	<b>971.16</b>	<b>-65.96</b>	<b>252.73</b>
<b>HWP</b>	<b>-576.70</b>		<b>-501.33</b>	<b>-628.48</b>	<b>-758.65</b>	<b>-823.18</b>	<b>-940.32</b>	<b>1036.70</b>	<b>1103.95</b>	<b>-796.16</b>
<b>Total incl HWP</b>	<b>-930.86</b>		<b>1193.45</b>	<b>-1091.67</b>	<b>1084.33</b>	<b>-1005.36</b>	<b>-862.15</b>	<b>-724.95</b>	<b>-575.39</b>	<b>-933.52</b>

**Table 11.10 Summary of the mean FMRL recalculated (FMRLcorr) values for different pools in 2013-2020, compared to the mean FMRL 2013-2020 and reported mean FM emission/removal for 2013-2019**

	FMRLcorr (mean 2013-2020)	FMRL (2/CMP6) submission (mean 2013-2020)	FM Reported (mean 2013-2018)
Biomass (kt C)	221.89	-2.64	388.15
Litter	39.40	45.6	19.08
Deadwood	-42.23	60.21	-82.90
Mineral soils	-5.16	NE	-7.31
Organic soils	-138.32	-94.75	-123.68
<b>Sub-total C-CO<sub>2</sub></b>	<b>-277.11</b>	<b>-30.87</b>	<b>-708.92</b>
Fires CO <sub>2</sub> eq	12	12	84.20
N <sub>2</sub> O and CH <sub>4</sub> drainage CO <sub>2</sub> eq	127.75	10.91	127.53
<b>HWP CO<sub>2</sub> eq</b>	<b>-796.16</b>	<b>-134.09</b>	<b>-441.13</b>
<b>Total</b>	<b>-933.52</b>	<b>-142.07</b>	<b>-938.33</b>

Major reasons for the difference between the corrected estimate of FMRL (FMRLcorr) and the original FMRL include:

- CBM is a dynamic model which provides more accurate estimates of biomass, litter and deadwood CSC over time. The CARBWARE model (version 4.5) assumed that younger age classes (i.e. those less than 7 years old) exhibited a zero CSC. The new version estimates harvest biomass losses based on NFI plot data instead of yield tables, which were used in the FMRL submission. Therefore, the mean net biomass emission for the time series is larger when the FMRLcorr and FMRL values are compared (Table 11.0).
- CBM provides a better estimate of Litter and deadwood pools, including fragmentation and transfer between DOM pools (Table 6.13 in section 6.3.4.9), which were not considered in the CARBWARE model (version 4.5) (Table 11.10).
- Higher CO<sub>2</sub> and non-CO<sub>2</sub> emissions from soils in the FMRLcorr due to the new Wetland supplement methodology (Table 11.10).
- Larger removals from the HWP pool in the FMRLcorr due to new methods applied and the higher historical harvest up to 2009, based on new data. The allocation of HWP feedstock to FMRLcorr was also higher than the FMRL submission due to a change in methodology used. This resulted in a larger HWP for the FMRLcorr time series (Table 11.9).
- Differences between the FMRLcorr and reported FM emissions and removals (Table 11.10) are primarily due to a difference in the level of harvest for the period 2013-2019. However, the expected harvest in article 3.3 AR land was slightly higher than expected over the same period. The HWP removals in FM were lower than the FMRLcorr due to a lower feedstock from harvest.

## 11.6 Harvested wood products

Ireland reports and accounts for domestically produced harvested wood products (HWP) using the first order decay approach (tier 2). The same approach is used for reporting under the convention (see section, see 6.3.7.1). However, these estimates exclude harvest emissions accounted AR activities in the 1st commitment period as set out under see para 2g(iv) of annex II to decision 2.CMP.8. This means that all inflows into the HWP pool under AR in the first commitment period are accounted for on the basis of instantaneous oxidation (IO, see CRF Table 4(KP-1)C for inventory years 2008-2012). The HWP estimated are not adjusted for FM because this was not elected for the 1<sup>st</sup> commitment period (see CRF Table 4(KP-1)C). All harvests from deforestation are accounted for on the basis of instantaneous oxidation IO (see CFR Table 4(KP-1)C).

### 11.6.1 Information on activity data for the harvested wood products categories used for estimating the harvested wood products pool removed from domestic forests, for domestic consumption and for export

Ireland derives HWP feedstock from domestically produced products (excluding imported HWP), such as sawnwood (SW), wood-based panel (WBP), paper and paper board (PPB) from FAO/EUROSTAT data using Eq 2.8.1 and 2.8.2 of the 2013 Revised Supplementary Methods and Good Practice Guidance

Arising from the Kyoto Protocol. This uses the data shown in CRF Gs4 and  $f_{irw}$  and  $f_{pulp}$  ratios to derive the volume of SW, WBP and PPB (see Table 6.25).

#### 11.6.2 Information on half-lives used in estimating the emissions and removals for these categories in accordance with decision 2/CMP.7, annex, paragraph 29 or 30

The half-lives used for HWP are the default values as indicated in section 6.3.7.1.

#### 11.6.3 Information on whether emissions from harvested wood products originating from forests prior to the start of the second commitment period have been included in the accounting (see para 2g(iii) of annex II to decision 2.CMP.8).

Ireland uses HWP C inflows dating back to 1900 based on methods outlined in section 6.3.7.1.

#### 11.6.4 Information on how emissions from the harvested wood products pool that have been accounted for during the first commitment period on the basis of instantaneous oxidation have been excluded from the accounting for the second commitment period; (see para 2g(iv) of annex II to decision 2.CMP.8).

Harvests accounted on the basis of instantaneous oxidation under AR activities in the first commitment period represented 1 to 4 per cent of the total harvest over the period 2008-2012 (see Table 11.11). The emissions are excluded from accounting for the second commitment period by applying a corrected AR fraction ( $f_{ARcorr}$ ) of zero to calculate HWP feedstocks under AR activities for the period 2007 to 2012 (see table 11.5). This means that only harvest for 2007 and from 2013 onwards are used as HWP feedstock under AR activities (CRF Table 4(KP-1)C).

#### 11.6.5 Information showing that harvested wood products resulting from deforestation have been accounted on the basis of instantaneous oxidation; (see para 2g(v) of annex II to decision 2.CMP.8).

The estimation of the annual fraction of harvest originating from the different forest activities (i.e. forest remaining forest ( $f_{FM}$ ), land converted to forest ( $f_{AR}$ ) and deforested ( $f_D$ ) harvest) are derived using Eq. 2.8.3 in Chapter 2 of the 2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol (see Table 11.11). The input information for the different activities (j) are derived from harvest data shown in Table 6.18 and in the CRF table 4(KP-1)C). All harvests for deforested land are assumed to be immediately oxidised by applying a  $f_D$  corrected ratio of zero ( $f_{Dcorr}$ , Table 11.11), so CSC in the CRF under HWP are reported as instantaneous oxidation (IO) under in CRF table 4(KP-1)C).

*Table 11.11 The estimated fractions of HWP feedstock originating from different forest activities under Article 3.3 and 3.4*

*The fDcorr fraction are the adjusted fraction to zero to account for harvest as instantaneous oxidation (2g(v) of annex II to 2/CMP.8) and exclusion of harvest from AR lands for the 1<sup>st</sup> commitment period (i.e. fAR=0 for 2008-2102) as outlined in para 2g(iv) of annex II to decision 2.CMP.8*

	fAR	fARcorr	fD	fDcorr	fFM
1990	NO	NO	1.94E-03	IO	0.998
1995	NO	NO	0.02	IO	0.98
2000	NO	NO	0.05	IO	0.95
2005	NO	NO	0.05	IO	0.95
2006	NO	NO	0.27	IO	0.73
2007	0.03	0.03	0.12	IO	0.85
2008	IO	IO	0.09	IO	0.90
2009	IO	IO	0.07	IO	0.84
2010	IO	IO	0.03	IO	0.92
2011	IO	IO	0.03	IO	0.90
2012	IO	IO	0.03	IO	0.93
2013	0.07	0.07	0.13	IO	0.80
2014	0.28	0.28	7.12E-04	IO	0.72
2015	0.19	0.19	0.16	IO	0.65
2016	0.18	0.18	0.02	IO	0.80
2017	0.20	0.20	4.54E-03	IO	0.80
2018	0.29	0.29	4.36E-03	IO	0.71
2019	0.36	0.36	3.80E-03	IO	0.64

NO indicates no harvest, IO indicated that the harvest for AR land for the 1st commitment period and all deforestation harvests are accounted as IO and not included in the HWP inflow for the second commitment period

### 11.6.6 Information showing that carbon dioxide emissions from harvested wood products in solid waste disposal sites, where these emissions are separately accounted for, and from wood harvested for energy purposes have been accounted on the basis of instantaneous oxidation;

Ireland does not report emissions of CO<sub>2</sub> from biogenic sources from landfills in the waste sector. The emissions associated with instantaneous oxidation of wood used for energy have been excluded from the HWP estimates. This is done using the term  $f_{IRW}$  in Eq 2.8.1 and 2.8.2 of the IPCC Supplementary guidance 2013 (see table 6.24 and section 6.3.7.1). The  $f_{IRW}$  estimate is based on industrial roundwood inflows from domestic harvest, which exclude wood used for energy purposes. The ratio of the industrial roundwood to total roundwood volumes, published in FAO/EUROSTAT, decreases from 0.98 in 1990 to 0.86 by 2019. This decrease is consistent with an increase utilisation of timber for energy purposes in Ireland.

## 11.6.7 Factoring out indirect effects of age class legacy, elevated CO<sub>2</sub> and N deposition of article 3.4 forest management (para 3 of 2/CMP.8)

The FMRL is considered to factor out indirect effects of elevated CO<sub>2</sub>, N deposition and age class legacy when accounting for these activities because of the use of a projected reference level (see <https://www.unfccc.int/resource/docs/2011/tar/irl01.pdf>).

## 11.7 Uncertainty Analysis

The IPCC tier 1 approach is applied to estimate uncertainties for the Article 3.3 activities described in this chapter using the methods for combining uncertainties given in 3.2.3.1 of Chapter 3 Vol 1 of the 2006 IPCC guidelines (see equations 6.3.5 and 6.3.6).

For detailed characterisation of individual uncertainties refer to sections 6.3.4.8 (FM), 6.3.5.8 (AR), 6.3.6.4 (D) and 6.3.7.2 (HWP). Note that the uncertainty estimates for HWP in AR lands is different due to the exclusion of feedstock for 2008-2012.

*Table 11.12 Uncertainty estimates of Article 3.3 and 3.4 activity estimates.*

Activity	CRF table	Combined uncertainty in year (±%)						
		2013	2014	2015	2016	2017	2018	2019
<b>AR</b>	4(KP-I)A.1	18.0	18.6	18.5	18.6	19.0	19.9	20.5
	4(KP-I)C	24.24	24.24	24.24	24.28	24.27	24.27	24.64
	4(KP-II)2	94.2	93.8	94.0	94.0	94.0	94.0	94.0
	4(KP-II)4	52.2	52.2	52.2	52.2	52.2	52.2	52.2
<b>Total</b>		<b>18.5</b>	<b>18.0</b>	<b>18.9</b>	<b>18.5</b>	<b>19.4</b>	<b>19.4</b>	<b>19.3</b>
<b>D</b>	4(KP-I)A.2	49.2	181.9	51.9	67.9	116.8	121.4	129.6
	4(KP-II)2	164.7	173.6	188.2	194.3	193.3	192.4	191.9
	4(KP-II)3	66.0	66.0	66.0	66.0	66.0	66.0	66.0
	<b>Total</b>		<b>51.3</b>	<b>165.0</b>	<b>49.2</b>	<b>104.9</b>	<b>140.8</b>	<b>141.9</b>
<b>FM</b>	4(KP-I)A.1	50.4	87.9	53.1	54.4	58.4	79.2	46.6
	4(KP-I)C	24.3	24.4	24.6	24.6	24.5	24.6	24.8
	4(KP-II)2	78.5	78.5	78.5	78.5	78.5	78.5	78.5
	4(KP-II)4	59.4	59.4	59.4	59.4	59.4	59.4	59.4
<b>Total</b>		<b>43.8</b>	<b>64.1</b>	<b>47.3</b>	<b>38.5</b>	<b>55.5</b>	<b>57.6</b>	<b>44.5</b>
<b>CM</b>	4(KP-I) B.2	72.15	72.15	72.15	72.15	72.15	72.15	72.15
<b>GM</b>	4(KP-I) B.3	90.83	72.15	90.83	90.83	90.83	90.83	90.83

## 11.8 Quality Assurance and Quality Control (QA\QC)

The same QA/QC procedures were carried out for KP LULUCF as reported for forest lands under section 6.10.1. The entire compilation for this submission for both LULUCF (Chapter 6) and forest activities under Article 3.3 and 3.4 of the Kyoto Protocol (Chapter 11) were reviewed externally by an independent consultant, qualified as a UNFCCC expert reviewer for LULUCF/KP-LULUCF in March 2012 and in the Autumn 2017. This provides an important element of quality assurance for this submission. Following the findings of this independent peer review, both chapter 6 and 11 of this report have been substantially improved to provide additional transparency and consistency between Convention and KP reporting for LULUCF.

The same QA/QC elements are carried out for KP-LULUCF as for LULUCF, but additional validation information was gathered to provide evidence that pools that are not reported are demonstrated not to be a source (see section 11.3).

## 11.9 Recalculations in KP LULUCF

Recalculations for the Article 3.3. ARD and 3.4 FM (CRF 4(KP) Recalculations also see sections 6.3.4.9, 6.3.5.9, 6.3.6.5, 6.3.7.3) are due to:

- Correction to levels of harvest in AR land since 2006 (see section 6.3.5.9 Chapter 6);
- New forest fire statistics (see section 6.3.7.3 Chapter 6).

Other Recalculations for the 2019 submission are

**Cropland Management:** - Refinement of the analysis of the LPIS spatial dataset; Further information on these recalculations is presented in section 6.4.11.

**Grazing land Management:** - Revised assessment of land area statistics and management practices. Revised area of organic soils. Further information on these recalculations is presented in section 6.5.7.

## Chapter 12 Information on Accounting of Kyoto Units

### 12.1 Background Information

Ireland's Standard Electronic Format report for the 2020 reported year (second commitment period), which contains the information required in paragraph 11 of the annex to decision 15/CMP.1 and adhering to the guidelines of the SEF has been submitted to the UNFCCC Secretariat electronically.

Information on Kyoto Protocol units for the 2020 reported year (second commitment period):

RREG1\_IE\_2020\_2\_2.xlsx

The contents of the SEF report (R1) can also be found in Appendix 1 – *SIAR Supplementary Information* of this document.

The contents of the reports can also be found in annex 6 of this document.

### 12.2 Summary of Information Reported in the SEF Tables

Information on Kyoto Protocol units for the 2020 reporting period (second commitment period):

There were ZERO AAUs in Ireland's domain of the Union Registry at the end of the year 2020.

There was 6,773,042 CERs in the registry at the end of 2020: all of which were held in the entity holding accounts.

There was 74,964 ERUs in the registry at the end of 2020; all of which were held in the entity holding accounts.

There were 636,919 t-CERs in the registry at the end of 2020; all of which were held in the entity holding accounts.

There were ZERO RMUs in the registry at the end of 2020.

The registry did not contain any I-CERs.

There were no units in the Article 6 issuance and conversion accounts; no units in the Article 3.3 and Article 3.4 issuance account and no units in the Article 12 afforestation and reforestation accounts.

The total amount of the units in the registry corresponded to 7,484,925 tonnes CO<sub>2</sub> eq.

Ireland's assigned amount for the second commitment period is 343,519,892 kt CO<sub>2</sub> eq as indicated in [FCCC/IRR/2016/IRL](#) *Report on the review of the report to facilitate the calculation of the assigned amount for the second commitment period of the Kyoto Protocol of Ireland of 20 July 2017*.

*Table 12.1 Information on the SEF tables*

Annual Submission Item	Reported for 2020
<p>15/CMP.1 annex I.E paragraph 11: Standard electronic format (SEF)</p>	<p>Ireland's Standard Electronic Format report for the 2020 reporting period (second commitment period) which contains the information required in paragraph 11 of the annex to decision 15/CMP.1 and adhering to the guidelines of the SEF has been submitted to the UNFCCC Secretariat electronically.</p> <p>RREG1_IE_2020_2_2.xlsx</p> <p>The contents of the SEF reports (R1) can also be found in Appendix 1 – <i>SIAR Supplementary Information</i> of this document.</p> <p>The contents of the report can also be found in annex 6 of this document.</p>

### 12.3 Discrepancies and notifications

For the 2020 reporting period, there were no discrepant transactions, one CDM notification, no non-replacements and no invalid units in 2020. Accordingly, no changes were made to address discrepancies and one action was taken for the 2020 reporting period (Table 12.2).

*Table 12.2 Discrepancies and notifications*

Annual Submission Item	Reported for 2020
<p>15/CMP.1 annex I.E paragraph 12: List of discrepant transactions</p>	<p>No discrepant transactions, pursuant of 15/CMP.1 annex I.E paragraph 12, occurred for the 2020 reporting period (second commitment period).</p> <p>The contents of the Report R2 can also be found in the Appendix 1 – <i>SIAR Supplementary Information</i> of this document.</p> <p>Refer to Separate Electronic Attachments for the 2020 reporting period (second commitment period):</p> <p>RREG2_IE_2020_1</p>
<p>15/CMP.1 annex I.E paragraph 13 &amp; 14: List of CDM notifications</p>	<p>One CDM notification was received for the 2020 reporting period pursuant of 15/CMP.1 annex I.E paragraphs 13 &amp; 14.</p> <p>The contents of the Report R3 can also be found in Appendix 1 – <i>SIAR Supplementary Information</i> of this document.</p> <p>Refer to Separate Electronic Attachments for the 2020 reporting period (second commitment period):</p> <p>RREG3_IE_2020_4</p>

Annual Submission Item	Reported for 2020
<p>15/CMP.1 annex I.E paragraph 15: List of non-replacements</p>	<p>No non-replacements occurred for the 2020 reporting period, pursuant of 15/CMP.1 annex I.E paragraph 15.</p> <p>The contents of the Report R4 can be found in Appendix 1 – <i>SIAR Supplementary Information</i> of this document.</p> <p>Refer to Separate Electronic Attachments for the 2020 reporting period (second commitment period):</p> <p>RREG4_IE_2020_4</p>
<p>15/CMP.1 annex I.E paragraph 16: List of invalid units</p>	<p>No invalid units exist for the 2020 reporting period as at 31 December 2020, pursuant of 15/CMP.1 annex I.E paragraph 16.</p> <p>The contents of the Report R5 can also be found in Appendix 1 – <i>SIAR Supplementary Information</i> of this document.</p> <p>Refer to Separate Electronic Attachments for the 2020 reporting period (second commitment period):</p> <p>RREG5_IE_2020_1</p>
<p>15/CMP.1 annex I.E paragraph 17 Actions and changes to address discrepancies</p>	<p>No actions were taken or changes made to address discrepancies for the 2020 reporting period.</p>

## 12.4 Publicly Accessible Information

The public has access via the registry website to information on registry account types and account holders, information regarding Article 6 projects (currently no Article 6 projects in Ireland), information on transactions and the list of account holders authorised to hold Kyoto units in their account (Table 12.3).

*Table 12.3 Publicly Accessible Information*

Annual Submission Item	Reported for 2020
<p>15/CMP.1 annex I.E Publicly accessible information</p>	<p>There was no change regarding publicly accessible information during 2020.</p> <p>The following information is publicly accessible and is available via the homepage of Ireland’s domain on the Union Registry – <a href="https://unionregistry.ec.europa.eu/euregistry/IE/public/reports/publicReports.xhtml">https://unionregistry.ec.europa.eu/euregistry/IE/public/reports/publicReports.xhtml</a></p> <p>See also the EPA website: <a href="http://www.epa.ie/climate/emissionstradingoverview/union%20registry/publicreports">http://www.epa.ie/climate/emissionstradingoverview/union%20registry/publicreports</a></p> <p>In accordance with the requirements of Annex E to Decision 13/CMP.1, all required information for a Party with an active Kyoto registry is provided with the exceptions as outlined below.</p>
	<p><b>Account Information (Paragraph 45)</b></p> <p>In line with the data protection requirements of Regulation (EC) No 45/2001 and the GDPR Regulation (EU) 2016/679 and in accordance with Article 110 and Annex XIV of Commission Regulation (EU) No 389/2013, the information on account representatives, account holdings, account numbers, all transactions made and carbon unit identifiers, held in the EUTL, the Union Registry and any other KP registry (required by paragraph 45) is considered confidential.</p> <p>The most up-to-date account information may be accessed via the homepage of Ireland’s domain on the Union Registry <a href="https://unionregistry.ec.europa.eu/euregistry/IE/public/reports/publicReports.xhtml">https://unionregistry.ec.europa.eu/euregistry/IE/public/reports/publicReports.xhtml</a></p> <p>See also the EPA website: <a href="http://www.epa.ie/climate/emissionstradingoverview/union%20registry/publicreports">http://www.epa.ie/climate/emissionstradingoverview/union%20registry/publicreports</a></p>
	<p><b>JI projects in Ireland (Paragraph 46)</b></p> <p>Note that no Article 6 (Joint Implementation) projects are reported as conversion to an ERU under an Article 6 project, as this did not occur in the specified period.</p>

Annual Submission Item	Reported for 2020
	<p><b>Holding and transaction information of units (Paragraph 47)</b></p> <p>Holding and transaction information is provided on a holding type level, due to more detailed information being declared confidential.</p> <p>The detailed information on transactions is considered confidential according to Article 110 of Commission Regulation (EU) No 389/2013:</p> <p><i>Information, including the holdings of all accounts, all transactions made, the unique unit identification code of the allowances and the unique numeric value of the unit serial number of the Kyoto units held or affected by a transaction, held in the EUTL, the Union Registry and any other KP registry shall be considered confidential except as otherwise required by Union law, or by provisions of national law that pursue a legitimate objective compatible with this Regulation and are proportionate.</i></p> <p>The most up-to-date account information may be accessed via the homepage of Ireland’s domain on the Union Registry  <a href="https://unionregistry.ec.europa.eu/euregistry/IE/public/reports/publicReports.xhtml">https://unionregistry.ec.europa.eu/euregistry/IE/public/reports/publicReports.xhtml</a></p> <p>See also the EPA website:  <a href="http://www.epa.ie/climate/emissionstradingoverview/union%20registry/publicreports">http://www.epa.ie/climate/emissionstradingoverview/union%20registry/publicreports</a></p>
<p>15/CMP.1 annex I.E Publicly accessible information</p>	<p><u>Paragraph 47c</u> For the 2020 reporting period: Ireland does not host JI projects.</p> <p><u>Paragraph 47e</u> For the 2020 reporting period: Ireland does not perform LULUCF activities and therefore does not issue RMUs.</p> <p><u>Paragraph 47g</u> For the 2020 reporting period: No ERUs, CERs, AAUs and RMUs have been cancelled on the basis of activities under Article 3, paragraphs 3 and 4 to date.</p> <p><u>Paragraph 47h</u> For the 2020 reporting period: No ERUs, CERs, AAUs and RMUs have been cancelled following determination by the Compliance Committee that the Party is not in compliance with its commitment under Article 3, paragraph 1 to date.</p> <p><u>Paragraph 47j</u> For the 2020 reporting period: No ERUs, CERs, AAUs and RMUs have been retired to date</p>

Annual Submission Item	Reported for 2020
	<p><b>Paragraph 47k</b></p> <p>Ireland requests to carry over up to 7,816,073 AAUs; 5,255,000 CERs and 74,964 ERUs from the first to the second commitment period of the Kyoto Protocol.</p> <p>Ireland did complete a carryover of 5,255,000 CERs and 74,964 ERUs from the first to the second commitment period of the Kyoto Protocol in December 2016.</p> <p>Reference should also be made to the final report on the individual review of the report upon expiration of the additional period for fulfilling commitments (true-up period) for the first commitment period of the Kyoto Protocol of Ireland.</p> <p>The report is available on the UNFCCC webpage together with the true-up period assessment report (TUPAR) and the true-up period report submission by Ireland:  <a href="http://unfccc.int/kyoto_protocol/reporting/true-up_period_reports_under_the_kyoto_protocol/items/9049.php">http://unfccc.int/kyoto_protocol/reporting/true-up_period_reports_under_the_kyoto_protocol/items/9049.php</a></p>
	<p><b>Entities authorised to hold Kyoto Units (Paragraph 48)</b></p> <p>In line with the data protection requirements of Regulation (EC) No 45/2001 and the GDPR Regulation (EU) 2016/679 and in accordance with Article 110 and Annex III of the Commission Regulation (EU) no 389/2013, the legal entity contact information (required by paragraph 48) is considered confidential.</p> <p>The most up-to-date account information may be accessed via the homepage of Ireland's domain on the Union Registry  <a href="https://unionregistry.ec.europa.eu/euregistry/IE/public/reports/publicReports.xhtml">https://unionregistry.ec.europa.eu/euregistry/IE/public/reports/publicReports.xhtml</a></p> <p>See also the EPA website:  <a href="http://www.epa.ie/climate/emissionstradingoverview/union%20registry/publicreports">http://www.epa.ie/climate/emissionstradingoverview/union%20registry/publicreports</a></p>

## 12.5 Calculation of the Commitment Period Reserve

For the 2020 reporting period (second commitment period):

The commitment period reserve was calculated in accordance with the annex to decision 18/CP.7, the annex to decision 11/CMP.1 and decision 1/CMP.8, paragraph 18.

Ireland's commitment period reserve is 309,167,903 kt CO<sub>2</sub> eq for the second commitment period as outlined in Table 3 of the Report [FCCC/IRR/2016/IRL](#) *Report on the review of the report to facilitate the calculation of the assigned amount for the second commitment period of the Kyoto Protocol of Ireland of 20 July 2017*.

## 12.6 Accounting for Activities under Article 3, paragraphs 3 and 4

For the second commitment period, Ireland intends to account for each activity under Article 3, paragraphs 3 and 4, of the Kyoto Protocol, for the entire commitment period.

## Chapter 13 Changes in National System

### 13.1 Changes in National System since previous submission

Ireland's national system is described in section 1.3 of Chapter 1.

There has been no changes in the national inventory arrangements since the previous annual inventory submission in April 2020.

## Chapter 14 Changes in National Registry

### 14.1 Introduction

The national registry of Ireland is described in the initial report under the Kyoto Protocol ([FCCC/IRR/2007/IRL](#)). Ireland's national registry was established initially for the implementation of Directive 2003/87/EC (EP and CEU, 2003) on emissions trading. The registry software was purchased from the Department of the Environment, Food and Rural Affairs in the UK and has been developed in consultation with other Member States that also purchased this software as part of the GRETA group. 2012 saw the transition from the national registry using the GRETA registry software to the Consolidated System of EU Registries (CSEUR).

The following changes to the national registry of IRELAND have occurred in 2020.

These changes are summarised in this chapter and further details are provided in electronic form as Appendix 1 *SIAR Supplementary Information* to the NIR.

### 14.2 Information on Changes in National Registry

Reporting Item	Description
15/CMP.1 annex II.E paragraph 32.(a) Change of name or contact	No change of name or contact occurred during the reporting period.
15/CMP.1 annex II.E paragraph 32.(b) Change regarding cooperation arrangement	No change of cooperation arrangement occurred during the reporting period.
15/CMP.1 annex II.E paragraph 32.(c) Change to database structure or the capacity of national registry	There has been a new EUCR release (Version 11.5) after Version 8.2.2 (the production version at the time of the last Chapter 14 submission). Due to the new release, some changes were applied to the database. The updated database model is provided in <b>Annex A</b> - this is provided in electronic form as Appendix 1 <i>SIAR Supplementary Information</i> to the NIR. No change was required to the application backup plan or to the disaster recovery plan. No change to the capacity of the national registry occurred during the reporting period.
15/CMP.1 annex II.E paragraph 32.(d)	The changes that have been introduced with Version 11.5 compared with Version 8.2.2 of the national registry (the production version at the time of the last Chapter 14 submission)

Reporting Item	Description
Change regarding conformance to technical standards	<p>are presented in <b>Annex B</b>. This is provided in electronic form as Appendix 1 <i>SIAR Supplementary Information</i> to the NIR.</p> <p>Each release of the registry is subject to both regression testing and tests related to new functionality. These tests also include thorough testing against the DES and are carried out prior to the relevant major release of the version to Production (see <b>Annex B</b>).</p> <p>No other change in the registry's conformance to the technical standards occurred for the reporting period.</p>
15/CMP.1 annex II.E paragraph 32.(e) Change to discrepancies procedures	No change of discrepancies procedures occurred during the reporting period.
15/CMP.1 annex II.E paragraph 32.(f) Change regarding security	The use of soft tokens for authentication and signature was introduced for the registry end users.
15/CMP.1 annex II.E paragraph 32.(g) Change to list of publicly available information	<p>No change to the list of publicly available information occurred during the reporting period. The following information is publicly accessible and is available via the homepage of Ireland's domain on the Union Registry –</p> <p><a href="https://unionregistry.ec.europa.eu/euregistry/IE/public/reports/publicReports.xhtml">https://unionregistry.ec.europa.eu/euregistry/IE/public/reports/publicReports.xhtml</a></p> <p>See also the EPA website:</p> <p><a href="http://www.epa.ie/climate/emissionstradingoverview/union%20registry/publicreports">http://www.epa.ie/climate/emissionstradingoverview/union%20registry/publicreports</a></p> <p>In accordance with the requirements of Annex E to Decision 13/CMP.1, all required information for a Party with an active Kyoto registry is provided with the exceptions as outlined below.</p>
	<p><b>Account Information (Paragraph 45)</b></p> <p>In line with the data protection requirements of Regulation (EC) No 45/2001 and the GDPR Regulation (EU) 2016/679 and in accordance with Article 110 and Annex XIV of Commission Regulation (EU) No 389/2013, the information on account representatives, account holdings, account numbers, all</p>

Reporting Item	Description
	<p>transactions made and carbon unit identifiers, held in the EUTL, the Union Registry and any other KP registry (required by paragraph 45) is considered confidential.</p> <p>The most up-to-date account information may be accessed via the homepage of Ireland's domain on the Union Registry –</p> <p><a href="https://unionregistry.ec.europa.eu/euregistry/IE/public/reports/publicReports.xhtml">https://unionregistry.ec.europa.eu/euregistry/IE/public/reports/publicReports.xhtml</a></p> <p>See also the EPA website:</p> <p><a href="http://www.epa.ie/climate/emissionstradingoverview/union%20registry/publicreports">http://www.epa.ie/climate/emissionstradingoverview/union%20registry/publicreports</a></p>
	<p><b>JI projects in Ireland (Paragraph 46)</b></p> <p>Note that no Article 6 (Joint Implementation) projects are reported as conversion to an ERU under an Article 6 project, as this did not occur in the specified period.</p>
	<p><b>Holding and transaction information of units (Paragraph 47)</b></p> <p>Holding and transaction information is provided on a holding type level, due to more detailed information being declared confidential.</p> <p>The detailed information on transactions is considered confidential according to Article 110 of Commission Regulation (EU) No 389/2013:</p> <p><i>Information, including the holdings of all accounts, all transactions made, the unique unit identification code of the allowances and the unique numeric value of the unit serial number of the Kyoto units held or affected by a transaction, held in the EUTL, the Union Registry and any other KP registry shall be considered confidential except as otherwise required by Union law, or by provisions of national law that pursue a legitimate objective compatible with this Regulation and are proportionate.</i></p> <p>The most up-to-date information may be accessed via the homepage of Ireland's domain on the Union Registry –</p> <p><a href="https://unionregistry.ec.europa.eu/euregistry/IE/public/reports/publicReports.xhtml">https://unionregistry.ec.europa.eu/euregistry/IE/public/reports/publicReports.xhtml</a></p>

Reporting Item	Description
	<p>See also the EPA website:</p> <p><a href="http://www.epa.ie/climate/emissionstradingoverview/union%20registry/publicreports">http://www.epa.ie/climate/emissionstradingoverview/union%20registry/publicreports</a></p>
	<p><u>Paragraph 47c</u></p> <p>For the 2020 reporting period:</p> <p>Ireland does not host JI projects.</p> <p><u>Paragraph 47e</u></p> <p>For the 2020 reporting period:</p> <p>Ireland does not perform LULUCF activities and therefore does not issue RMUs</p> <p><u>Paragraph 47g</u></p> <p>For the 2020 reporting period:</p> <p>No ERUs, CERs, AAUs and RMUs have been cancelled on the basis of activities under Article 3, paragraphs 3 and 4 to date.</p> <p><u>Paragraph 47h</u></p> <p>For the 2020 reporting period:</p> <p>No ERUs, CERs, AAUs and RMUs have been cancelled following determination by the Compliance Committee that the Party is not in compliance with its commitment under Article 3, paragraph 1 to date.</p> <p><u>Paragraph 47j</u></p> <p>For the 2020 reporting period:</p> <p>No ERUs, CERs, AAUs and RMUs have been retired to date</p> <p><u>Paragraph 47k</u></p> <p>Ireland requests to carry over up to 7,816,073 AAUs; 5,255,000 CERs and 74,964 ERUs from the first to the second commitment period of the Kyoto Protocol.</p>

Reporting Item	Description
	<p>Ireland did complete a carryover of 5,255,000 CERs and 74,964 ERUs from the first to the second commitment period of the Kyoto Protocol in December 2016.</p> <p>Reference should also be made to the final report on the individual review of the report upon expiration of the additional period for fulfilling commitments (true-up period) for the first commitment period of the Kyoto Protocol of Ireland.</p> <p>The report is available on the UNFCCC webpage together with the true-up period assessment report (TUPAR) and the true-up period report submission by Ireland:</p> <p><a href="http://unfccc.int/kyoto_protocol/reporting/true-up_period_reports_under_the_kyoto_protocol/items/9049.php">http://unfccc.int/kyoto_protocol/reporting/true-up_period_reports_under_the_kyoto_protocol/items/9049.php</a></p>
	<p><b>Entities authorised to hold Kyoto Units (Paragraph 48)</b></p> <p>In line with the data protection requirements of Regulation (EC) No 45/2001 and the GDPR Regulation (EU) 2016/679 and in accordance with Article 110 and Annex III of the Commission Regulation (EU) no 389/2013, the legal entity contact information (required by paragraph 48) is considered confidential.</p> <p>The most up-to-date account information may be accessed via the homepage of Ireland’s domain on the Union Registry –</p> <p><a href="https://unionregistry.ec.europa.eu/euregistry/IE/public/reports/publicReports.xhtml">https://unionregistry.ec.europa.eu/euregistry/IE/public/reports/publicReports.xhtml</a></p> <p>See also the EPA website:</p> <p><a href="http://www.epa.ie/climate/emissionstradingoverview/union%20registry/publicreports">http://www.epa.ie/climate/emissionstradingoverview/union%20registry/publicreports</a></p>
<p>15/CMP.1 annex II.E paragraph 32.(h)</p> <p>Change of Internet address</p>	<p>No change to the registry internet address during the reporting period.</p>
<p>15/CMP.1 annex II.E paragraph 32.(i)</p> <p>Change regarding data integrity measures</p>	<p>No change of data integrity measures occurred during the reporting period.</p>

Reporting Item	Description
15/CMP.1 annex II.E paragraph 32.(j) Change regarding test results	No change occurred during the reporting period.
The previous Annual Review Recommendations	No recommendations relevant to registry operations in <a href="#">FCCC/ARR/2020/IRL</a> of 17 February 2021.

## Chapter 15 Minimisation of Adverse Impacts under Article 3, paragraph 14

### 15.1 Introduction

There are no changes to the information provided in this submission relating to Article 3, paragraph 14.

Article 3, paragraph 14, of the Kyoto Protocol requires that Annex I Parties shall strive to meet their commitments under Article 3, paragraph 1 of the Kyoto Protocol in such a way as to minimize adverse social environmental and economic impacts on developing country Parties, particularly those Parties identified in Article 4, paragraphs 8 and 9, of the Convention. Information on how commitments under Article 3, paragraph 14, are being implemented is to be prioritised under a number of actions as set down in section H of the annex to guidelines for the preparation of supplementary information required under Article 7, paragraph 1, of the Kyoto Protocol (Decision 15/CMP.1). These requirements are addressed in this chapter. There has been no change to the information provided since the previous inventory submission.

### 15.2 Context

As a Member State of the European Union, Ireland's commitments under the Kyoto Protocol are being implemented under Decision 2005/166/EC, governing joint fulfilment under Article 4, and Decision 280/2004/EC, which covers specific emissions monitoring and reporting requirements. In this context, the minimization of adverse impacts on developing countries is also largely dictated by the European Commission's policy on climate change and by its policies and programmes affecting developing countries. Regulation at the European level also controls or influences market conditions, fiscal incentives, tax and duty exemptions and subsidies in all economic sectors in Member States.

The impact assessment of new policy initiatives has been established in the European Union, which allows their potential adverse social, environmental and economic impacts on various stakeholders, including developing country Parties, to be identified and limited at an early stage within the legislative process. Impact Assessment Guidelines specifically address impacts on third countries and also issues related to international relations. This provides a framework in which Member States like Ireland can also ensure a high level of protection of the environment and contribute to the integration of environmental considerations into the preparation and adoption of specified plans and programmes with a view to promoting sustainable development.

### 15.3 Specific Elements

*a) The progressive reduction or phasing out of market imperfections, fiscal incentives, tax and duty exemptions and subsidies in all greenhouse-gas-emitting sectors, taking into account the need for energy price reforms to reflect market prices and externalities*

Ireland's electricity market has been deregulated and the levy supporting the use of peat for electricity generation under a Public Service Agreement has been discontinued. Tax incentives contributed to the development of Ireland's most recent gas field off the west coast but such incentives will be severely curtailed for any similar developments in the future under new legislation. Reforms of the Common Agricultural Policy have resulted in changes to subsidies in agriculture, which are now linked

to environmental, food safety and animal welfare standards. The EU Emissions Trading Scheme is a market-based emissions control measure which applies to major combustion and process emission sources of CO<sub>2</sub> and a carbon tax is being introduced for fossil fuel use outside the ETS.

*b) Removing subsidies associated with the use of environmentally unsound and unsafe technologies*

Environmentally unsound and unsafe technologies may be regarded as technologies that would not conform to the concept of sustainable development and the objective and principles of the UNFCCC. The EC has addressed this issue by developing legislation to ensure that the price for coal produced in Member States is not lower than the price of coal of similar quality available from third countries and by phasing out subsidies on fossil fuel production and consumption by 2010. No environmentally unsound or unsafe technologies are in operation in Ireland.

*c) Cooperating in the technological development of non-energy uses of fossil fuels, and supporting developing country Parties to this end*

The Irish Government is represented on the energy and environment strands of the Seventh Framework Programme (FP7) for Research and Technological Development (RTD). This representation includes the FP7 Energy Programme Committees that focuses on developing and agreeing the annual work programme and strategic vision for the FP7 Energy Work programme 2007–2013. Much of the focus of this (energy theme) initiative is on energy mitigation through supporting technological development and transfer through joint collaborations and calls with emerging economies including India, Russia and Brazil.

The International Energy Agency (IEA) is the energy forum and think-tank for 26 OECD countries. The Irish Government is a Party to four Renewable Energy Implementing Agreements of the IEA on Bioenergy, Ocean, Wind and RE Technology Deployment (RETD). Ireland provides national delegates to the executive committees of the Implementing Agreements and nominates and supports country experts to a number of tasks. The Government also sits on the Committee for Energy research and technology (CERT). Ireland is a member of the EU Expert Group on Technology, which supports the EC in climate negotiations. This expert group is focused on the transfer of technology to reduce the impacts of climate change and on supporting developing countries to this end.

*d) Cooperating in the development, diffusion, and transfer of less-greenhouse-gas-emitting advanced fossil-fuel technologies, and/or technologies, relating to fossil fuels, that capture and store greenhouse gases, and encouraging their wider use; and facilitating the participation of the least developed countries and other non-Annex I Parties in this effort*

The EU collaborates with other Annex I and Non-Annex I Parties (Brazil, Saudi Arabia, China, Colombia, India, Korea, Mexico and South Africa) in the Carbon Sequestration Leadership Forum (CSLF). The CSLF is a ministerial-level international climate change initiative that is focused on the development of improved cost-effective technologies for the capture transport and long-term safe storage of CO<sub>2</sub>. The mission of the CSLF is to facilitate the development and deployment of such technologies via collaborative efforts that address key technical, economic, and environmental obstacles. The CSLF will also promote awareness and champion legal, regulatory, financial, and institutional environments conducive to such technologies.

Ireland began its support to the Renewable Energy and Energy Efficiency Partnership (REEEP) in 2005. Following the decision by the Irish Government in 2007 to offset all its carbon emissions from official travel, REEEP was chosen as its implementing partner. REEEP is a Public-Private partnership and was launched by the United Kingdom along with other partners at the Johannesburg World Summit on

Sustainable Development in August 2002. By providing opportunities for concerted collaboration among its partners, REEEP aims to accelerate the marketplace for renewable energy and energy efficiency. Funding from Ireland is being prioritised for projects in its programme countries of Ethiopia, Lesotho, Mozambique, Tanzania, Uganda, Zambia and Malawi.

Ireland provides development assistance in line with the priorities expressed by partner countries. To date requests for assistance in the area of technology are primarily in connection with water supply, transport infrastructure and agriculture. An innovative programme in Ethiopia carries out operational participatory research with farmers, extension workers and government officials to identify, develop, and disseminate new agricultural technologies. Some of the successful technologies are based on traditional practices, for example soil conservation techniques. Other new technologies are related to new crop varieties and irrigation. In addition to ODA, private companies also provide technology and advice to developing countries, particularly in the energy sector. Due to the range of funding sources no precise figure is available for funding attributed to technology development and transfer. Ireland's support to REEEP is worth mentioning again here as an example of Ireland's support for technology transfer. REEEP brings the private and public sectors together to facilitate the financing, development and transfer of renewable energy technologies. Ireland believes that this type of public-private collaboration is essential for the development of appropriate and environmentally sound technologies and to facilitate their application and use in developing countries.

*e) Strengthening the capacity of developing country Parties identified in Article 4, paragraphs 8 and 9, of the Convention for improving efficiency in upstream and downstream activities relating to fossil fuels, taking into consideration the need to improve the environmental efficiency of these activities*

The EU contributes to strengthening the capacities of countries engaged in the export of fossil fuels through the work of the Energy Expert Group of the Gulf Cooperation Council (GCC), in particular under the working sub-group on energy efficiency. As part of the EU's research programme, a project called "EUROGULF" was launched with the objective of to analyse The European Commission's planned e-network on clean energy technologies, is aiming to promote research and technical development of clean energy technologies in the GCC countries.

Ireland currently holds the Programme Chair of Renewable Energy and Energy Efficiency Partnership, a Type 2 International NGO. The Renewable Energy and Energy Efficiency Partnership (REEEP) is a global partnership that works to reduce the barriers in policy, regulatory and financial structures that bar and limit the uptake of renewable-energy and energy-efficiency technologies and projects. This Partnership focuses on deployment of projects in sub-Saharan Africa, Asia and Latin America. Ireland is actively involved in the partnership, alongside energy-related organisations from Australia, Austria, Canada, Germany, Italy, Spain, the Netherlands, New Zealand, Norway, the UK, the USA and the European Commission.

Ireland is a founding member of the UNEP SEFI Public Finance Alliance, or 'SEF Alliance'. This is a member-driven coalition of public and publicly backed organisations that finance sustainable-energy markets in various countries, including emerging and developing economies. . Members use the platform to exchange best practices, pool resources, launch joint projects and assist other governments in establishing new or similar financing models. The SEF Alliance is under the remit of the Sustainable Energy Finance Initiative (SEFI) of the United Nations Environment Programme (UNEP) but is governed directly by its members and pursues activities according to their interests. In 2008, the Alliance published Public Finance for Climate Change Mitigation, which provided an overview of mechanisms being used by the public sector to help scale up the climate mitigation markets, with a particular focus on the clean energy sector. In 2008, the SEF Alliance also published a Public Venture

Capital Study which examined current clean-energy venture financing, focusing on the role of public sector-sponsored venture capital.

*f) Assisting developing country Parties which are highly dependent on the export and consumption of fossil fuels in diversifying their economies*

Ireland supports a range of EU activities aimed at reducing dependence on the consumption of fossil fuels, in particular those EU support programmes for the promotion of renewable energies and energy efficiency in developing countries. Renewable energy cooperation with Mediterranean and Gulf countries which led to the Mediterranean Solar Plan, endorsed in 2008 with the objective of installing 20 GW of new generation capacity in solar and other renewable energy sources around the Mediterranean Sea by 2020. Another objective is to create a sub-regional electricity market between Morocco, Tunisia and Algeria and to progressively integrate it with the electricity market of the EU. Important initiatives which target energy efficiency and renewable energy projects in South America, Africa and Asia include the Africa, Caribbean and the Pacific (ACP-E) Energy Facility, the Latin America Investment Facility (LAIF), the Euro-Solar Programme in Latin America and the Global Energy Efficiency and Renewable Energy Fund (GEEREF).

## Glossary

<b>Annex 1 Parties</b>	Countries listed in Annex I to the United Nations Framework Convention on Climate Change
<b>Base year</b>	The year or period under the Kyoto Protocol on which quantified emission limitation or reduction commitments in the commitment period are based.
<b>BOD</b>	Biochemical Oxygen Demand
<b>CARBWARE</b>	A forest model to calculate carbon stock change and growth increment for Irish forests
<b>CFCs</b>	Chlorofluorocarbons
<b>CH<sub>4</sub></b>	Methane
<b>CHP</b>	Combined Heat and Power.
<b>CMMS</b>	Cattle Movement and Monitoring System
<b>CO</b>	Carbon Monoxide
<b>CO<sub>2</sub></b>	Carbon Dioxide
<b>CO<sub>2</sub> equivalent</b>	The equivalent mass as CO <sub>2</sub> of other greenhouse gases converted on the basis of their global warming potential (GWP)
<b>COFORD</b>	National Council for Forest Research and Development
<b>Commitment Period</b>	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
<b>COP</b>	Conference of the Parties
<b>CORINAIR</b>	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.
<b>CRF</b>	Common Reporting Format
<b>DAF</b>	Department of Agriculture and Food
<b>DAFM</b>	Department of Agriculture, Food and the Marine
<b>DCCAE</b>	Department of Communications, Climate Action and Environment
<b>DCENR</b>	Department of Communications, Energy and Natural Resources
<b>DEHLG</b>	Department of Environment Heritage and Local Government
<b>DNDC</b>	DeNitrification-DeComposition, is a computer simulation model of carbon and nitrogen biogeochemistry in agri-ecosystems
<b>EMEP</b>	European Monitoring and Evaluation Programme, a co-operative programme for monitoring and evaluation of the long-range transmissions of air pollutants in Europe
<b>Emission</b>	(of a greenhouse gas). The release of greenhouse gases into the atmosphere.
<b>Enteric Fermentation</b>	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 <sub>4</sub> as a by product
<b>EUROSTAT</b>	Statistical Agency of the European Union
<b>FAO</b>	Food and Agriculture Organisation of the United Nations
<b>FFS</b>	Farm Facilities Survey
<b>FIPS</b>	Forest Inventory and Planning System
<b>Fluorinated Gases</b>	HFCs, PFCs, SF <sub>6</sub> and NF <sub>3</sub>

<b>Fossil Fuel</b>	Peat, coal, oil and natural gas and associated derivatives
<b>FTA</b>	Fraction of BOD in sludge that degrades anaerobically
<b>GDP</b>	Gross Domestic Product
<b>Gg</b>	Gigagram (10 <sup>9</sup> g) = kilo tonne = 1,000 tonnes
<b>Greenhouse Gas</b>	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
<b>GWP</b>	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 <sub>2</sub>
<b>HCFCs</b>	Hydrochlorofluorocarbon
<b>HFCs</b>	Hydrofluorocarbons
<b>HGV</b>	Heavy Goods Vehicle
<b>IEA</b>	International Energy Agency
<b>IEF</b>	Implied Emission Factor
<b>IPC</b>	Integrated Pollution Control
<b>IPCC</b>	Intergovernmental Panel on Climate Change
<b>IUCC</b>	Information Unit on Climate Change
<b>kt</b>	kilo tonne (1,000 tonnes)
<b>Kyoto Protocol</b>	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
<b>LTO</b>	Landing and Take-off cycle
<b>MMS</b>	Manure Management System
<b>Montreal Protocol</b>	Protocol on substances that deplete the ozone layer
<b>Mt</b>	million tonnes or mega tonnes
<b>N<sub>2</sub>O</b>	Nitrous Oxide
<b>NBP</b>	Net Biome Productivity
<b>NEE</b>	Net Ecosystem Exchange
<b>NF<sub>3</sub></b>	Nitrogen trifluoride
<b>NIR</b>	National Inventory Report
<b>NMVOC</b>	Non Methane Volatile Organic Compounds
<b>NO<sub>x</sub></b>	Nitrogen Oxides
<b>NRA</b>	National Roads Authority
<b>OSPAR</b>	Oslo and Paris Convention for the Protection of the Marine Environment
<b>PFCs</b>	Perfluorocarbons
<b>SBSTA</b>	Subsidiary Body for Scientific and Technological Advice
<b>SEAI</b>	Sustainable Energy Authority of Ireland
<b>SF<sub>6</sub></b>	Sulphur Hexafluoride
<b>Sink</b>	The reservoir or pool in which sequestered carbon is stored; the process of sequestration
<b>SO<sub>2</sub></b>	Sulphur Dioxide
<b>Teagasc</b>	Irish Agriculture and Food Development Authority
<b>TPER</b>	Total Primary Energy Requirement
<b>UNECE</b>	United Nations Economic Commission for Europe
<b>UNFCCC</b>	United Nations Framework Convention on Climate Change
<b>VOC</b>	Volatile Organic Compounds

## References

Adams, M., Wagner, A., Goodwin, J., O’Leary, E., Creedon, M., McHugh, M and Gibson, C. (2005). Compiling Emission Inventories of HFCs, PFCs and SF6 for inclusion in Ireland’s greenhouse gas submissions to the EU under Decision 280/2004/EC under the United National Framework Convention on Climate Change. Netcen/ ED48411/R1, AEA Technology UK.

AEA. (2011). HFC consumption and emissions forecasting. Containing an update to the June 2008 HFC projections. Report to Defra.

Alam M S, Duffy P, Hyde B, McNabola A. (2017). Improvement in the estimation and back-extrapolation of CO2 emissions from the Irish road transport sector using a bottom-up data modelling approach, Transportation Research Part D: Transport and Environment 56, pp18-32.

Baesens, B., van Gestel, T., Viaene, S., Stepanova, M. Suykens, J. and Van-thienen, J. (2003). Benchmarking state-of-the-art classification algorithms for credit scoring. Journal of the Operational Research Society, 54:p 627-635.

Barry, S. and O’Regan, B. (2016). FS-2 Activity data for emissions of Non-methane VOC Fellowship 1990-2014: Project Code 2012-CCRP-FS.8, EPA Research Report (In Press).

Benanti, G., Saunders, M., Tobin, B, Osborne, B 2014. Contrasting impacts of afforestation on nitrous oxide and methane emissions. Agricultural and Forest Meteorology 198–199 (82–93)

Bigler, C. and Bugmann, H. (2004). Predicting the time of tree death using dendrochronological data. Ecological Applications, 14(3): p902-914..

Black K (2016) Description, calibration and validation of the CARBWARE single tree-based stand simulator. Forestry 86 (1):55-68 doi: 10.1093/forestry/cpv033

Black, K, Creamer, R.E., Xenakis G., and Cook, S. 2014. Improving the YASSO forest soil carbon model using spatial data and geostatistical approaches. *Geoderma* 232-234:487-499

Black, K., Hendrick, E., Gallagher., G.,Farrington, P., (2012). Establishment of Irelands projected reference level for Forest Management for the period 2013-2020 under Article 3.4 of the Kyoto Protocol. Irish Forestry 69: p7-33.

Black, K., Tobin, B., Saiz, G., Byrne, K. and Osbourne, B. (2004). Improved estimates of biomass expansion factors for Sitka spruce. Irish Forestry 61: p50–65.

Black, K.G., O’Brien, P., Redmond, J., Barrett, F. and Twomey M. (2009a). The extent of peatland afforestation in Ireland. Irish Forestry 65, p61-71.

Bond-Lamberty et al., 2008. Decomposition and Fragmentation of Coarse Woody Debris: Re-visiting a Boreal Black Spruce Chronosequence Ecosystems (2008) 11: 831–840

Bossard, M., Feranec, J. and Otahel, J. (2000). CORINE land cover technical guide – Addendum, 2000. Technical Report No. 40, EEA.

Boudewyn, P. Song, X. Magnussen, S. and Gillis, M.D. 2007. Model-based, volume-to-biomass conversion for forested and vegetated land in Canada. Natural Resources Canada • Canadian Forest Service Pacific Forestry Centre • Victoria, British Columbia Information Report • BC-X-411

- Boyle, O. C., (1987). National Database on Waste. An Foras Forbartha, Dublin.
- Buckley, C., Moran, B., and Donnellan, T. (2020). Teagasc national farm survey - A report on bovine manure management, application and storage practices in Ireland. Agricultural Economics & Farm Surveys Department, Teagasc.
- Burke, F., O'Donovan, M.A., Murphy, J.J., O'Mara, F.P. and Mulligan, F.J. (2008). Effect of pasture allowance and supplementation with maize silage and concentrates differing in crude protein concentration on milk production and nitrogen excretion by dairy cows. *Livestock Production Science* 2008; 114: 325-335.
- Büttner, G., Feranec, J., Jaffrain, G., Mari, L., Maucha, G. and Soukup, T. (2004). The CORINE land cover 2000 project. In Reuter, R. (Ed.), *EARSel eProceedings 3(3)*. Paris (EARSel), pp. 331–346. CEC. 1993. CORINE Land Cover Technical Guide. European Union, Directorate-Environment, Luxembourg.
- Byrne, K.A. and Farrell, E.P. 2005. The effect of afforestation on soil carbon dioxide emissions in blanket peatland in Ireland. *Forestry*, 78, 217-227. doi:210.1093/forestry/cpi1020.
- Byrne, K.A. and Kiely, G. (2006). Partitioning of respiration in an intensely managed grassland Plant and Soil 282:p 281–289.
- Carey, P., Carty, G., Crowe, M., and Rudden, P.J. (1996). National Waste Database Report 1998, Environmental Protection Agency, Johnstown Castle, Wexford, Ireland.
- CEC-Commission of the European Communities, (2004). Commission Decision 2004/156/EC of 29/01/2004 establishing guidelines for the monitoring and reporting of greenhouse gas emissions pursuant to Directive 2003/87/EC. O.J. L59, 26 February 2004.
- CEC-Council of the European Communities, (1991). Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources O.J. L167.
- CEC-Council of the European Communities, (1999). Council Directive 99/13/EC of 11 March 1999 on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain activities and installations. O.J. L85, 29 March 1999.
- CER- Commission for Energy Regulation, (2006) Gas Capacity Statement 2006
- CER- Commission for Energy Regulation, (2007) Gas Capacity Statement 2007
- CEU-Council of the European Union, (1999). Council Directive 1999/31/EC on the landfill of waste. O.J. L182, July 1999.
- Collins, C., Le Bolloch, O. and Meaney, B. (2005). National Waste Report 2004. Environmental Protection Agency, Johnstown Castle, Wexford, Ireland.
- Collins, C., Meaney, B., Nolan, K., Maher, H. and Corish, C. (2004b). National Waste Database Interim Report 2003. Environmental Protection Agency, Johnstown Castle, Wexford, Ireland.
- Collins, C., Meaney, B., Nolan, K., Maher, H. and Murphy, D. (2004a). National Waste Database Interim Report 2002. Environmental Protection Agency, Johnstown Castle, Wexford, Ireland.
- Cossu, R., Andreottola, G. and Muntoni, A., (1996). Modelling Landfill Gas Production. In *Landfilling of Waste Biogas*. Edited by T. H. Christensen, R. Cossu and R. Stegman. E and FN Spon, London.

Crowe, M., Fanning, A., Nolan, K., Carty, G. and Howley, D. (2000). National Waste Database Report 1998, Environmental Protection Agency, Johnstown Castle, Wexford, Ireland.

Crowley, A. M. (2001). Prediction of net energy requirements of beef cattle. M.Agr.Sc. Thesis, National University of Ireland, University College Dublin, November 2001, p145.

Crowley, A. M., Keane, M.G., Agabriel, J. and O'Mara F. P. (2002). Prediction of net energy requirements of beef cattle. Proceedings of Agricultural Research Forum, 11 and 12 March 2002, Tullamore, p 19.

Cruickshank, M.M. and Tomlinson, R.W. (1996). Application of CORINE Land Cover Methodology to the U.K.-Some Issues Raised from Northern Ireland. Global Ecology and Biogeography Letters 5 (4/5) Remote Sensing and GIS in the Service of Ecology and Biogeography: A Series of Case Studies.

Cruickshank, M.M., Tomlinson, R.W. and Trew, S. (2000). Application of CORINE land-cover mapping to estimate the carbon stored in the vegetation of Ireland. Journal of Environmental Management, 58, p269-287.

CSO- Central Statistics Office.(2009-2012). Transport Omnibus 2009-2010 and 2011. 2010 and 2012; Available at: <https://www.cso.ie/en/statistics/transport/archive/>

CSO-Central Statistics Office (2016) Population census 2016 Chapter 9 Housing; Available at [https://www.cso.ie/en/media/csoie/releasespublications/documents/population/2017/Chapter\\_9\\_Housing.pdf](https://www.cso.ie/en/media/csoie/releasespublications/documents/population/2017/Chapter_9_Housing.pdf)

CTC-Clean Technology Centre, (2005). NMVOC Inventory for Ireland (SNAP Sector 6 Solvent and Other Product Use). Report to the Environmental Protection Agency.

DAFF-Department of Agriculture, Fisheries and Food, (2004). CMMS Statistics Report 2003. Department of Agriculture and Food, Dublin; Available at: [CMMS report 2003](#)

DAFF-Department of Agriculture, Fisheries and Food, (2005). CMMS Statistics Report 2004. Department of Agriculture and Food, Dublin; Available at: [CMMS Report 2004](#)

DAFF-Department of Agriculture, Fisheries and Food, (2006). CMMS Statistics Report 2005. Department of Agriculture and Food, Dublin; Available at: [CMMS Report 2005](#)

DAFF-Department of Agriculture, Fisheries and Food, (2007). CMMS Statistics Report 2006. Department of Agriculture and Food, Dublin; Available at: [CMMS Report 2006](#)

DAFF-Department of Agriculture, Fisheries and Food, (2008). CMMS Statistics Report 2007. Department of Agriculture and Food, Dublin; Available at: [CMMS Report 2007](#)

DAFF-Department of Agriculture, Fisheries and Food, (2009). AIM Bovine Statistics Report 2008. Department of Agriculture and Food, Dublin; Available at: [AIM Report 2008](#)

DAFF-Department of Agriculture, Fisheries and Food, (2010). AIM Bovine Statistics Report 2009. Department of Agriculture and Food, Dublin; Available at: [AIM Report 2009](#)

DAFM-Department of Agriculture, Food and the Marine, (2011). AIM Bovine Statistics Report 2010. Department of Agriculture, Food and the Marine, Dublin; Available at: [AIM Report 2010](#)

DAFM-Department of Agriculture, Food and the Marine, (2012). AIM Bovine Statistics Report 2011. Department of Agriculture, Food and the Marine, Dublin; Available at: [AIM Report 2011](#)

DAFM-Department of Agriculture, Food and the Marine, (2013). AIM Bovine Statistics Report 2012. Department of Agriculture, Food and the Marine, Dublin; Available at: [AIM Report 2012](#)

DAFM-Department of Agriculture, Food and the Marine (2014). AIM Bovine Statistics Report 2013. Department of Agriculture, Food and the Marine, Dublin; Available at: [AIM Report 2013](#)

DAFM-Department of Agriculture, Food and the Marine (2015). AIM Bovine Statistics Report 2014. Department of Agriculture, Food and the Marine, Dublin; Available at: [AIM Report 2014](#)

DAFM-Department of Agriculture, Food and the Marine (2016). AIM Bovine Statistics Report 2015. Department of Agriculture, Food and the Marine, Dublin; Available at: [AIM Report 2015](#)

DAFM-Department of Agriculture, Food and the Marine (2017). AIM Bovine Statistics Report 2016. Department of Agriculture, Food and the Marine, Dublin; Available at: [AIM Report 2016](#)

DAFM-Department of Agriculture, Food and the Marine (2018). AIM Bovine Statistics Report 2017. Department of Agriculture, Food and the Marine, Dublin; Available at: [AIM Report 2017](#)

DAFM-Department of Agriculture, Food and the Marine (2019). AIM Bovine Statistics Report 2018. Department of Agriculture, Food and the Marine, Dublin; Available at: [AIM Report 2018](#)

DAFM-Department of Agriculture, Food and the Marine (2020). AIM Bovine Statistics Report 2019. Department of Agriculture, Food and the Marine, Dublin; Available at: [AIM Report 2019](#)

DAFM-Department of Agriculture, Food and the Marine (2020), Industry survey on the crude protein content in compound animal feeds. Department of Agriculture, Food and the Marine, Dublin.

Davis, M. and Condon, L. (2002). Impact of grasslands afforestation on soil carbon in New Zealand: a review of paired-site studies. Australian Journal of Soil Research 40, 675-690.

DECLG-Department of the Environment, Community and Local Government, (2015). Climate Action And Low Carbon Development Act 2015; Available at: <http://www.irishstatutebook.ie/eli/2015/act/46/enacted/en/pdf>

DEHLG-Department of the Environment Heritage and Local Government, (2005). European Communities(Good Agricultural Practice for Protection of Waters) Regulations 2005. SI No 788 of 2005. Government Publications Office, Dublin.

DEHLG-Department of the Environment Heritage and Local Government, (2006). European Communities(Good Agricultural Practice for Protection of Waters) Regulations 2006. SI No 378 of 2006. Government Publications Office, Dublin.

DEHLG-Department of the Environment Heritage and Local Government, (2007). Limitation of emissions of volatile organic compounds due to the use of organic solvents in certain paints, varnishes and vehicle refinishing products regulations 2007. S.I. No. 199 of 2007. Government Publications Office, Dublin.

DEHLG-Department of the Environment Heritage and Local Government, (2008). Waste Management (Certification of Historic Unlicensed Waste Disposal and Recovery Activity) Regulations 2008. S.I. No. 524 of 2008. Government Publications Office, Dublin.

DEHLG-Department of the Environment Heritage and Local Government, (2009). European Communities(Good Agricultural Practice for Protection of Waters) Regulations 2009. SI No 101 of 2009. Government Publications Office, Dublin.

DEHLG-Department of the Environment Heritage and Local Government, (2010). European Communities(Good Agricultural Practice for Protection of Waters) Regulations 2010. SI No 610 of 2010. Government Publications Office, Dublin.

Del Prado, A., Brown, L., Schulte, R., Ryan, M. and Scholefield. (2006). Principles of development of a mass balance N cycle model for temperate grasslands: an Irish case study Nutrient Cycling in Agroecosystems (2006) 74: p 115–131.

DELG-Department of the Environment and Local Government, (1997). Sustainable Development. A Strategy for Ireland. Department of the Environment and Local Government, Custom House, Dublin.

DELG-Department of the Environment and Local Government, (1998). A Policy Statement. Waste Management. Changing our Ways. Department of the Environment and Local Government, Custom House, Dublin.

DeLong, E. R. , DeLong, D. M. and Clarke-Pearson D. L. (1988). Comparing the areas under two or more correlated receiver operating characteristic curves: A nonparametric approach. Biometrics, 44: p837-845.

DHPLG-Department of Housing, Planning and Local Government (2017). European Communities (Good Agricultural Practice for Protection of Waters) Regulations 2017. SI No 605 of 2017. Government Publications Office, Dublin.

DHPLG-Department of Housing, Planning and Local Government (2018). European Communities (Good Agricultural Practice for Protection of Waters) Regulations 2018. SI No 65 of 2018. Government Publications Office, Dublin.

DOE- Department of the Environment, (1997). IRELAND : Second National Communication under the UN Framework Convention on Climate Change. Department of the Environment, Custom House, Dublin.

DOE, DELG, DEHLG, DOT, DOTTS (1990 to 2014), Irish Bulletin of Vehicle and Driver Statistics (27 reports).

DOE-Department of the Environment, (1992). The Environmental Protection Agency Act, 1992. SI No 7 of 1992. Department of the Environment, Custom House, Dublin.

DOE-Department of the Environment, (1994). Recycling for Ireland. A Strategy for Recycling Domestic and Commercial Waste. Department of the Environment, Custom House, Dublin.

Duffy, P., Hyde, B., Hanley, E., Dore, C., O'Brien, P., Cotter, E. and Black, K. (2011). Ireland National Inventory Report 2011. Greenhouse Gas Emissions 1990-2009. Reported to the United Nations Framework Convention on Climate Change. Environmental Protection Agency, Johnstown Castle, Wexford, Ireland.

Duffy, P., Hyde, B., Ryan, A.M. and Murphy, J. (2021). Ireland Informative Inventory Report 2021. Air pollutant emissions in Ireland 1990-2019. Reported to the secretariat of the UNECE convention on long-range transboundary air pollution and to the European Union. Environmental Protection Agency, Johnstown Castle, Wexford, Ireland.

EC- European Commission (2013a). Commission Decision 2013/162/EU on determining Member States' annual emission allocations for the period from 2013 to 2020 pursuant to Decision No 406/2009/EC of the European Parliament and of the Council.

EC- European Commission (2013b). Commission Implementing Decision 2013/634/EU on the adjustments to Member States' annual emission allocations for the period from 2013 to 2020 pursuant to Decision No 406/2009/EC of the European Parliament and of the Council.

EC-European Commission (2020). Report from the Commission on the availability of hydrofluorocarbons on the Union Market (8842 final).

Edwards, P.N., and Christie, J.M. (1981). Yield models for forest management. Forestry Commission Booklet No. 48. HMSO, London.

EMEP/EEA (2013). EMEP/EEA air pollutant emission inventory guidebook 2016. Technical guidance to prepare national emission inventories. EEA Technical report No 12/2013. Publications Office of the European Union, Luxembourg.

EMEP/EEA (2016). EMEP/EEA air pollutant emission inventory guidebook 2016. Technical guidance to prepare national emission inventories. EEA report No 21/2016. Publications Office of the European Union, Luxembourg.

EMEP/EEA (2019). EMEP/EEA air pollutant emission inventory guidebook 2019. Technical guidance to prepare national emission inventories. EEA report No 13/2019. Publications Office of the European Union, Luxembourg.

EP- European Parliament and CEU-Council of the European Union (2009b). Directive 2009/30/EC amending Directive 98/70/EC as regards the specification of petrol, diesel and gas-oil and introducing a mechanism to monitor and reduce greenhouse gas emissions and amending Council Directive 1999/32/EC as regards the specification of fuel used by inland waterway vessels and repealing Directive 93/12/EC.

EP- European Parliament and CEU-Council of the European Union (2013). Regulation of the European Parliament and of the Council No. 525/2013 on a mechanism for monitoring and reporting greenhouse gas emissions and for reporting other information at national and Union level relevant to climate change and repealing Decision No 280/2004/EC

EP- European Parliament and CEU-Council of the European Union, (2001). Directive 2001/81/EC of 23 October 2001 on national emissions ceilings for certain atmospheric pollutants. O.J. L309, 27 November 2001.

EP- European Parliament and CEU-Council of the European Union, (2003). Directive 2003/87/EC establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC. O.J. L275, 25 October 2003.

EP- European Parliament and CEU-Council of the European Union, (2004a). Decision 280/2004/EC of the European Parliament and of the Council concerning a mechanism for monitoring Community greenhouse gas emissions and for implementing the Kyoto Protocol. O.J. L49, 19 February 2004.

EP- European Parliament and CEU-Council of the European Union, (2004b). Directive 2004/42/CE on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain paints and varnishes and vehicle refinishing products and amending Directive 1999/13/EC. O.J. L143, 30 April 2004.

EP- European Parliament and CEU-Council of the European Union, (2009a). Decision No. 406/2009/EC of the European Parliament and of the Council on the effort of Member States to reduce their greenhouse gas emissions to meet the Community's greenhouse gas emission reduction commitments up to 2020.

ERL-Environmental Resources Limited, (1993). Towards a Recycling Strategy for Ireland. Department of the Environment, Custom House, Dublin.

EU- European Union (2015a). Council Decision EU 2015/1339 on the conclusion, on behalf of the European Union, of the Doha Amendment to the Kyoto Protocol to the United Nations Framework Convention on Climate Change and the joint fulfilment of commitments thereunder.

EU- European Union (2015b). Council Decision EU 2015/1340 on the conclusion, on behalf of the European Union, of the Agreement between the European Union and its Member States, of the one part, and Iceland, of the other part, concerning Iceland's participation in the joint fulfilment of commitments of the European Union, its Member States and Iceland for the second commitment period of the Kyoto Protocol to the United Nations Framework Convention on Climate Change.

European Semiconductor Industry Association (2011). PFC Voluntary Agreement Final Report, 2011

Eurocontrol, (2016). EUROCONTROL method for estimating aviation fuel burnt and emissions in the framework of the EMEP/EEA air pollutant emission inventory guidebook 2016

<https://www.eurocontrol.int/publication/eurocontrol-method-estimating-aviation-fuel-burnt-and-emissions>

Farrelly, N., NiDhubhain, A., Nieuwenhuis, M., (2011). Productivity models for Sitka spruce in Ireland based on GIS data and readily accessible site quality factors. Irish Forestry 68: 6-23.

FDA (Forest Development association). 2007. Irish Thinning Protocol. - A complete step by step guide to the requirements and implementation of thinning systems in Ireland. Funded by the Forest Service of the Department of Agriculture and Food.

Fealy, R., and Green, S., (2009). Teagasc-EPA Soils and Subsoils Mapping Project, Final report. EPA, 2009

Fealy, R., Loftus, M. and Meehan, G. (2006). EPA Soil and Subsoil Mapping Project: Summary, Methodology, Description for Subsoils, Land Cover, Habitat and Soils Mapping/Modelling. EPA project report, Environmental Protection Agency, Johnstown Castle, Wexford.

Fehily Timoney and Company, (1985). Code of Good Practice for the Use of Biosolids in Agriculture. Guidelines for Farmers. Department of Environment and Local Government, Dublin.

Finn, J. et al, (2001). Estimation of Emissions of Non-Methane Volatile Organic Compounds from SNAP Sector 6: Solvent and Other Product Use for Ireland in 1998. Prepared for the Environmental Protection Agency by the Clean Technology Centre, Cork Institute of Technology. Environmental Protection Agency, Johnstown Castle, Wexford, Ireland.

Fogarty, G., Coggins, K and Gallagher, G., (1999). Forest Inventory and Planning System (FIPS). Irish Timber Growers Association Forestry Yearbook 2000. ITGA, Dublin.

Forestry Act 2014. Act Number 31 of 2014.

<http://www.irishstatutebook.ie/eli/2014/act/31/enacted/en/pdf>

Forest Service, (2000). Department of the Marine and Natural Resources Forestry Statistics. Internal publication.

Forestry Scheme Manual (2003). Forest Service, Department of Agriculture Food and the Marine. Dublin.

FSAI (Food Safety Authority of Ireland), (1999). Recommended Dietary Allowances for Ireland. Food Safety Authority of Ireland, Dublin. <http://www.fsai.ie/>

Gardiner, M. J. and Radford, T., (1980). Soil Associations of Ireland and their Land Use Potential. Explanatory Bulletin to Soil Map of Ireland 1980, Soil Survey Bulletin No 36, An Foras Taluntais, Dublin.

Gkatzoflias D. (Emisia S.A.), C. Kouridis (Emisia S.A.), L. Ntziachristos (LAT/AUTH), Z. Samaras (LAT/AUTH). (2012). COPERT 4 Computer programme to calculate emissions from road transport. User manual (version 9.0).

Gkatzoflias D., Kouridis C., Ntziachristos L. and Samaras Z., (2007). Copert 4. Computer programme to calculate emissions from road transport. Laboratory of Applied Thermodynamics, Mechanical Engineering Department, Aristotle University Thessaloniki.

Goodwin J., Gschrey B. and Salisbury E., (2013), Emission Inventories for HFCs, PFCs and SF6 for inclusion in Ireland's submission to the EU under Decision 280/2004/EC and the United Nations Framework Convention on Climate Change

Grassi, G., Pilli, R., House, J., Federici, S., & Kurz, W. A. 2018. Science-based approach for credible accounting of mitigation in managed forests. Carbon balance and management, 13(1), 8.

Hamilton, G.J. (1975). Forest Mensuration Handbook. Forestry Commission Booklet 39, HMSO, London.

Hargreaves, K., Milne, R. and Cannell, M.G.R. (2003). Carbon balance of afforested peatland in Scotland. Forestry, 76, p 299-317.

Harty, M.A., Forrestal, P.J., Watson, C.J., McGeough, K.L., ,Carolan, R., Elliot, C., Krol, D., Laughlin, R.J., Richards, K.G. and Lanigan, G.J. (2016). Reducing nitrous oxide emissions by changing N fertiliser use from calcium ammonium nitrate (CAN) to urea based formulations. Science of the Total Environment 563-564; 576--586

Hawkins M and Black K. (2012). Validating generalised diameter-height models for several species and heterogeneous crop structures. Irish Forestry 69: p58.73

Hazeu, G.W. and De Wit, A.J.W. (2004). CORINE land cover database of the Netherlands: monitoring land cover changes between 1986 and 2000. EARSeL eProceedings 3 (3). Paris (EARSeL)

Hyde, B., Carton, O.T. and Murphy, W.E. (2008). Farm Facilities Survey – Ireland 2003. Report prepared for the Department of Agriculture by Teagasc, Johnstown Castle, Co. Wexford. P1-150

ICRL, (1990). Notes on the development and after-use of landfill sites. Guidance Note 17/78. Eight Edition, December, 1990. Interdepartmental Committee on the Redevelopment of Contaminated Land.

INRA, (1989). Ruminant Nutrition. Recommended Allowances and Feed Tables. R. Jarrige, Ed. John Libbey Eurotext, London and Paris.

IPCC-Intergovernmental Panel on Climate Change, (1997). Revised 1996 Guidelines for National Greenhouse Gas Inventories. OECD, Paris.

IPCC-Intergovernmental Panel on Climate Change, (2000). IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. IGES (Institute for Global Environmental Strategies), Kanagawa, Japan.

IPCC-Intergovernmental Panel on Climate Change, (2003). Good Practice Guidance for Land Use, Land-Use Change and Forestry. IGES (Institute for Global Environmental Strategies), Kanagawa, Japan.

IUCC-Information Unit on Climate Change, (1998). The Kyoto Protocol to the Framework Convention on Climate Change. UNEP, Geneva.

Jovani-Sancho, A. J., Cummins, T., Byrne, K.A. 2018. Soil respiration partitioning in afforested temperate peatlands. *Biogeochemistry* 141:1–21

Khalil, M.I., Kiely, G., O'Brien, P. and Müller. C. (2013) Organic carbon stocks in agricultural soils in Ireland using combined empirical and GIS approaches. *Geoderma*, 193-194: p 222–235.

Kiely G., Xu X., Hsieh C.-I, Leahy P., Sottocornola M., Laine A., Mishurov M., Albertson J., Katul G., Oren R. and O. Carton (2009). CELTICFLUX: Measurement and Modeling of GHG Fluxes from Grasslands and a Peatland in Ireland *AsiaFlux Newsletter No 28*, March 2009.

Krol, D.J., Carolan, R., Minet, E., McGeough, K.L., Watson, C.J., Forrester, P.J., Lanigan, G.J. and Richards, K.G. (2016). Improving and disaggregating N<sub>2</sub>O emission factors for ruminant excreta on temperate pasture soil. *Science of the Total Environment* 568; 327-338.

Kull, S.J.; Morcken, S.; Smyth, C.E.; Fellows, M. 2016. Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3): Archive Index Database Table and Parameter Descriptions. Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre, Edmonton, Alberta.

Kurtz, W.A., Dymond, C.C., White, T.M., Stinson, G., Shaw, C.H., Rampley, G.J., Smyth, C., Simpson, B.N., Neilson, E.T., Trofymow, J.A., Metsaranta, J., and Apps, M.J. 2009. CBM-CFS3: a model of carbon-dynamics in forestry and land- use change implementing IPCC standards. *Ecol. Model.* 220(4): 480–504. doi 10.1016/j.ecolmodel.2008.10.018.

Le Bolloch, Meaney, B., Cope, J and Doyle, M., (2006). National Waste Report 2005: Data Update. Environmental Protection Agency, Johnstown Castle, Wexford, Ireland.

Le Bolloch, O., Cope, J., Kurz, I., Meaney, B. and Higgins, T. (2009). National Waste Report 2007. Environmental Protection Agency, Johnstown Castle, Wexford, Ireland.

Le Bolloch, O., Cope, J., Meaney, B and Kurz, I., (2007). National Waste Report 2006. Environmental Protection Agency, Johnstown Castle, Wexford, Ireland.

Li, C., Frohling, S. and Harriss, R. (1994). Modelling carbon biogeochemistry in agricultural soils. *Global Biogeochemical Cycles*, 8, 237-254.

Li, Z., Kurtz, W.A., Apps, M.J., Beukema, S.J., 2003. Belowground dynamics in the Carbon Budget: recent improvements and implications for the estimation of NPP and NEP. *Can. J. For. Res.* 33, 126–136.

Li, C., Narayanan, V. and Harriss, R.C. (1996). Model estimates of nitrous oxide emissions from agricultural lands in the United States. *Global Biogeochemical Cycles* 10, 297-306.

Liski, J., Palosuo, T., Peltoniemi, N., Sievänen, R. (2005) Carbon and decomposition model Yasso for forest soils. *Ecological Modelling*: 189 168–182.

Loftus, M., Bulfin, M., Farrelly, N., Fealy, R., Green, S., Meehan, R. and T. Radford., 2002. The Irish Forest Soils project and its potential contribution to the assessment of biodiversity. *Proceedings of the Royal Irish Academy*, 102B (3), 151-165.

Luyssaert, S., Inglima, I, Jung, M., Richardson, A.D., Reichstein, M., Papale, D., Piao, S.L., Schulze, E.D., Wingate, L., Matteucci, G., Aragao, L., Aubinet, M., Beer, C., Bernhofer, C., Black, K.G., Bonal, D., Bonnefond, J.M., Chambers, J., Ciais, P., Cook, B., Davis, K.J., Dolman, J., Gielen, B., Goudlen, M., Grace, J., Granier, A., Grelle, A., Griffis, T., Grünwald, Guidolotti, G., Hanson, P.J., Harding, R., Hollinger, D.Y., Hutya, L.R., Kolari, P., Kruijt, B., Kutsch, W., Lagergren, F., Laurila, T., Law, B.E., Le Maire, G., Lindroth, A., Loustau, D., Malhi, Y., Mateus, J., Migliavacca, M., Misson, L., Montagnani, L., Moncrieff, J., Moors, E., Munger, J.W., Nikinmaa, E., Ollinger, V., Pita, G., Rebmann, C., Rouspard, O., Saigusa, N., Sanz, M.J., Seufert, G., Sierra, C., Smith, M.L., Tang, J., Valentini, R., Vesala, T. and Janssens, I.A. (2007). CO<sub>2</sub> balance of boreal, temperate, and tropical forests derived from a global database. *Global Change Biology* 13 (12), 2509-2537.

Marcogaz: Technical Association of the European Natural Gas Industry (2019). Assessment of methane emissions for gas Transmission and Distribution system operators, WG\_ME-485.

Matthias Peichl, Paul Leahy, and Gerard Kiely (2011). Six-year Stable Annual Uptake of Carbon Dioxide in Intensively Managed Humid Temperate Grassland Ecosystems 14: p112–126 doi:10.1007/s10021-010-9398-2.

McCooole, F., Derham, J., Kurz, I and McDonagh, M. (2011). National Waste Report 2009. Environmental Protection Agency, Johnstown Castle, Wexford, Ireland.

McCooole, F., Derham, J., Kurz, I. and Higgins, T. (2009). National Waste Report 2008. Environmental Protection Agency, Johnstown Castle, Wexford, Ireland.

McCooole, F., Kurz, I., McDonagh, M. and O’Neill, D. (2013). National Waste Report 2011. Environmental Protection Agency, Johnstown Castle, Wexford, Ireland.

McCooole, F., Kurz, I., McDonagh, M., Derham, J., O’Neill, D. (2012). National Waste Report 2010. Environmental Protection Agency, Johnstown Castle, Wexford, Ireland.

McGoff, N.M., Eaton, J.M., Byrne, K., Leahy, P. and Kiely, G. (2007). Measurement of soil carbon stocks in Irish soils. British Ecological Society Annual Meeting, September 10-12, University of Glasgow, UK.

McInnes, G. (ed.), (1996). CORINAIR/EMEP Atmospheric Emission Inventory Guidebook. First Edition. European Environment Agency, Copenhagen.

MCOS - M C O’Sullivan & Co. Ltd, (1994). Report on Solid Waste Recycling (Packaging). Department of the Environment, Custom House, Dublin.

Meaney, B., Collins, C., Nolan, K., Cahill, E., Delaney, J., Murray, B., Healy, J. and Carty, G. (2003). National Waste Database Report 2001, Environmental Protection Agency, Johnstown Castle, Wexford, Ireland.

Monaghan, S., Smith, D., Wall, B. and O’Leary, G. (2009). Urban Waste Water Discharges in Ireland for Population Equivalents Greater than 500 Persons. A Report for the years 2006 and 2007. Environmental Protection Agency, Johnstown Castle, Wexford, Ireland.

Monteith J.L., 2002. Fundamental equations for growth in uniform stands of vegetation. *Agricultural and Forest Meteorology* 104: 5–11.

Mulqueen et al., (1999). *Forest Drainage Engineering: A design Manual*. COFORD, Dublin

NEUT-Working Group on Nutrients and Eutrophication under the OSPAR Convention, (1999). *Screening Procedure for Irish Coastal Waters with Regard to Eutrophication Status*.

NFI- National Forest Inventory (2007a). *National Forest Inventory - Republic of Ireland - Results*. Forest Service, Department of Agriculture, Fisheries and Food, Johnstown Castle Estate, Co Wexford.

NFI- National Forest Inventory (2007b). *National Forest Inventory - Republic of Ireland - Methodology*. Forest Service, Department of Agriculture, Fisheries and Food, Johnstown Castle Estate, Co Wexford.

O'Brien, P. (2007). *Data Analysis and Estimation of Greenhouse Gas Emissions and Removals for the IPCC Sector Land Use Land-Use Change and Forestry in Ireland*. Environmental Protection Agency, Johnstown Castle, Wexford, Ireland (in preparation).

O'Brien, D. and Shalloo, L. (2019), *A review of livestock methane emission factors*. Report prepared by Teagasc for the Environmental Protection Agency, Johnstown Castle, Wexford, Ireland.

O'Doherty, S. and McCulloch, A. (2002). *Emission Inventories of HFC, PFC and SF6*. RTDI Project L.S.-5.1.3(a) Final Report. Environmental Protection Agency, Johnstown Castle, Wexford.

O'Leary, E., (2002). *Emission Inventories for HFCs, PFCs and SF6 for Ireland 1995-2000*. Environmental Protection Agency, Johnstown Castle, Wexford, Ireland.

O'Leary, E., Finn, J. and Cunningham, D., (2002). *Emission Inventories for HFCs, PFCs and SF6 for Ireland 1998*. RTDI Project L.S.-5.1.3(b) Final Report. Environmental Protection Agency, Johnstown Castle, Wexford, Ireland.

O'Leary, G. and Carty, G. *Urban Waste Water Discharges in Ireland (1998)*. A Report for the years 1996 and 1997. Environmental Protection Agency, Johnstown Castle, Wexford, Ireland.

O'Leary, G., Fanning, A. and Carty, G. (2000). *Urban Waste Water Discharges in Ireland*. A Report for the years 1998 and 1999.

O'Leary, G., Meaney, B. and Carty, G. (1997). *Urban Waste Water Discharges in Ireland*. A report for the years 1994 and 1995. Environmental Protection Agency, Johnstown Castle, Wexford, Ireland.

O'Mara, F., (2006). *Development of Emission Factors for the Irish Cattle Herd*. Environmental Protection Agency, Johnstown Castle, Wexford, Ireland.

O'Mara, F., Caffrey, P. J., and Drennan, M. J., (1997). *Net energy values of grass silage determined from comparative feeding trials*. *Irish Journal of Agricultural and Food Research*, 36, p110.

O'Rielly, C., Hasslacher, D., Murphy, W., Hendrick, E., Ward, D., Sheridan, J., Kelleher, D. and Gardiner, J. (1997). *Christmas tree growing in Ireland*. A sectoral report outlining the opportunities and problems. Council for Forest Research and Development.

Ordnance Survey Ireland (2005). *Ortho Photography*. <https://www.osi.ie/products/professional-mapping/osi-aerial-imagery/>

Pastramas, N.; Samaras, Ch.; Mellios, G.; Ntziachristos, L. (2014). *Update of the Air Emissions Inventory Guidebook - Road Transport 2014 Update*.

Peichl, M., Leahy, P. and Kiely, G. (2011). Six year stable annual uptake of carbon dioxide in intensively managed humid temperate grassland. *Ecosystems* 14, 122-126.

Petros, K. , Ntziachristos, L., Mellios, G. (2012). Description of new elements in COPERT 4 v10.0.

Phillips, H. (2011). All-Ireland Roundwood Production Forecast 2011-2028. COFORD, Department of Agriculture, Fisheries and Food, Dublin.

Pilli R, Grassi G, Kurz WA, Smyth CE, Blujdea V. Application of the CBM-CFS3 model to estimate Italy's forest carbon budget, 1995–2020. *Ecol Modell.* 2013;266(1):144–171. doi: 10.1016/j.ecolmodel.2013.07.007.

Pilli R, Grassi G, Kurz WA, Viñas RA, Guerrero NH. Modelling forest carbon stock changes as affected by harvest and natural disturbances. I. Comparison with countries' estimates for forest management. *Carbon Balance Manag.* 2016;11(1):5. doi: 10.1186/s13021-016-0047-8.

Purcell, T. (1979). Inventory of Private Woodlands – 1973. Forest and Wildlife Service, Dublin.

Richards, K.G., Fenton, O., Khalil, M.I., Haria, A.H., Humphreys, J., Doody, D., Moels, R., Morgan, G. and Jordan, P. (2009). Good water status: The integration of sustainable grassland production and water resources in Ireland. *Tearmann: Irish journal of agri-environmental research*, 7, p143-160.

Richardson, S. (ed), (1999). CORINAIR/EMEP Atmospheric Emission Inventory Guidebook. Second Edition. European Environment Agency, Copenhagen.

Roche, L., Forrestal, P.J., Lanigan, G.J., Richards, K.G., Shaw, L.J. and Wall, D.P. Impact of fertiliser nitrogen formulation, and N stabilisers on nitrous oxide emissions in spring barley. *Agricultural, Ecosystems and Environment* 233; 229-237.

RSA- Road Safety Authority (2006). Survey of Free Speed 2006: Urban and Rural, Research Department.

RSA- Road Safety Authority (2007). Survey of Free Speed 2007: Urban and Rural, Research Department.

RSA- Road Safety Authority (2008). Free speed survey 2008 (Urban and Rural), Research Department.

RSA- Road Safety Authority (2011). Free speed survey 2011 (Urban and Rural), Research Department.

Ryan, M. Brophy, C., Connolly, J., McNamara, K. and Carton, O.T. (2006). Monitoring of nitrogen leaching on a dairy farm during four drainage seasons. *Irish Journal of Agricultural and Food Research* 45: p115–134.

SBSTA -Subsidiary Body for Scientific and Technological Advice, (1999). Guidelines for the Preparation of National Communications by Parties included in Annex I to the Convention. Part I: UNFCCC Reporting Guidelines on Annual Inventories. FCCC/SBSTA/1999/6/Add.1. UNFCCC Secretariat, Bonn.

SBSTA-Subsidiary Body for Scientific and Technological Advice, (2002). Guidelines for the Preparation of National Communications by Parties included in Annex I to the Convention. Part I: UNFCCC Reporting Guidelines on Annual Inventories. FCCC/SBSTA/2002/L.5/Add.1, UNFCCC Secretariat, Bonn.

Schwarz, W.; Gschrey, B.; Kimmel, T.; Stöbener, S. (2012). Inventarermittlung der F-Gase 2012 - Daten von HFKW, FKW und SF6 für die nationale Emissionsberichterstattung gemäß Klimarahmenkonvention für das Berichtsjahr. Commissioned by Umweltbundesamt (German EPA).

Sing, T., Sander, O. Beerenwinkel, N. and Lengauer, T. (2005). ROC: Visualizing classifier performance in R. *Bioinformatics*, 21(20): p3940-3941.

Smith, D., O'Neill, N., Doris, Y. and Moriarty, J., (2004). Urban Waste Water Discharges in Ireland. A Report for the Years 2002/2003. Environmental Protection Agency, Johnstown Castle, Wexford, Ireland.

Smith, D., O'Neill, N., Wall, B and Crowe, M. (2007). Urban Waste Water Discharges in Ireland. A Report for the years 2004 and 2005. Environmental Protection Agency, Johnstown Castle, Wexford, Ireland.

Smith, D., O'Neill, N., Clinton, F. and Crowe, M. (2003). Urban Waste Water Discharges in Ireland. A Report for the years 2000 and 2001. Environmental Protection Agency, Johnstown Castle, Wexford, Ireland.

Stange, F., Butterbach-Bahl, H., Papen, H. 2000. A process-oriented model of N<sub>2</sub>O and NO emissions from forest soils 2. Sensitivity analysis and validation. *JOURNAL OF GEOPHYSICAL RESEARCH*, VOL. 105, NO. D4, PAGES 4385–4398

Thistlethwaite, G., Baggott, S. L. and Goodwin, J., (2005). National Inventory System Scoping Report for the Greenhouse Gas Emission Inventory in Ireland. AEAT/ENV/R/1990 Issue 1, NETCEN, UK.

Tobin, B., Black, K., Osborne, B. (2006). Assessment of allometric algorithms for estimating leaf biomass, leaf area index and litter fall in different aged Sitka spruce forests. *Forestry* 79: p453-465

Tomlinson, R.W., Cruickshank, M.M., Cruickshank, J.G., Mallon, G., McStravick, A., Byrne, K., Collins, J., O'Toole, P., Farrell, E., Cunningham, D., Milne, R. and Walsh, M. (2005). Impact of land use and land-use change on carbon emission/fixation. Environmental Protection Agency, Johnstown Castle, Wexford, Ireland.

UN- United Nations, (2007). Report of the individual review of the greenhouse gas inventory of Ireland, Available at: <http://unfccc.int/resource/docs/2007/arr/irl.pdf>

UNECE-United Nations Economic Commission for Europe (1999). Protocol to the 1979 Convention on Long-Range Transboundary Air Pollution to Abate Acidification, Eutrophication and Ground Level Ozone. UNECE Secretariat, Geneva.

UNFCCC-United Nations Framework Convention on Climate Change, (2014). Report of the individual review of the annual submission of Ireland submitted in 2013. FCCC/ARR/2013/IRL (In-country review, Ireland).

UNFCCC-United Nations Framework Convention on Climate Change, (2015). Report of the individual review of the annual submission of Ireland submitted in 2014. FCCC/ARR/2014/IRL (UN Secretariat, Bonn).

UNFCCC-United Nations Framework Convention on Climate Change, (2014). Decision 24/CP.19 Revision of the UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention

UNFCCC-United Nations Framework Convention on Climate Change, (2013). 1/CMP.8 Amendment to the Kyoto Protocol pursuant to its Article 3, paragraph 9 (the Doha Amendment)

Waldchen et al 2013. The influence of changes in forest management over the past 200 years on present soil organic carbon stocks. *Forest Ecology and Management* 289(1):243–254.

WB -World Bank. World Development Indicators (Ireland), (2013); Available at: <http://data.worldbank.org/country/ireland>.

Wilson, D., Wilson, F.R., Farrell, C., Bullock, C. and Müller, C. (2012). *Carbon Restore – The Potential of Restored Irish Peatlands for Carbon Uptake and Storage*. CCRP Report Series No.15. Environmental Protection Agency, Johnstown Castle, Wexford, Ireland

Yamulki, S., Anderson, R., Peace, A. and Morison, J.I.L. (2013) Soil CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O fluxes from an afforested lowland raised peatbog in Scotland: implications for drainage and restoration. *Biogeosciences* 10: p1051-1065.

Yan, T., Agnew, R. E., Gordon, F. J. and Porter, M. G. (2000). Prediction of methane energy output in dairy and beef cattle offered grass silage-based diets. *Livestock Production Science*, 64: p 253-263.

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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\$) & Population (Total); Adjusted  $R^2$ : 0.89; VIF<5; Validation  $R^2$ :0.95,
- Bus Model: variables: Road sector energy consumption (% of total) & Urban population (% of total); Adjusted  $R^2$ : 0.95; VIF<2; Validation  $R^2$ :0.94).

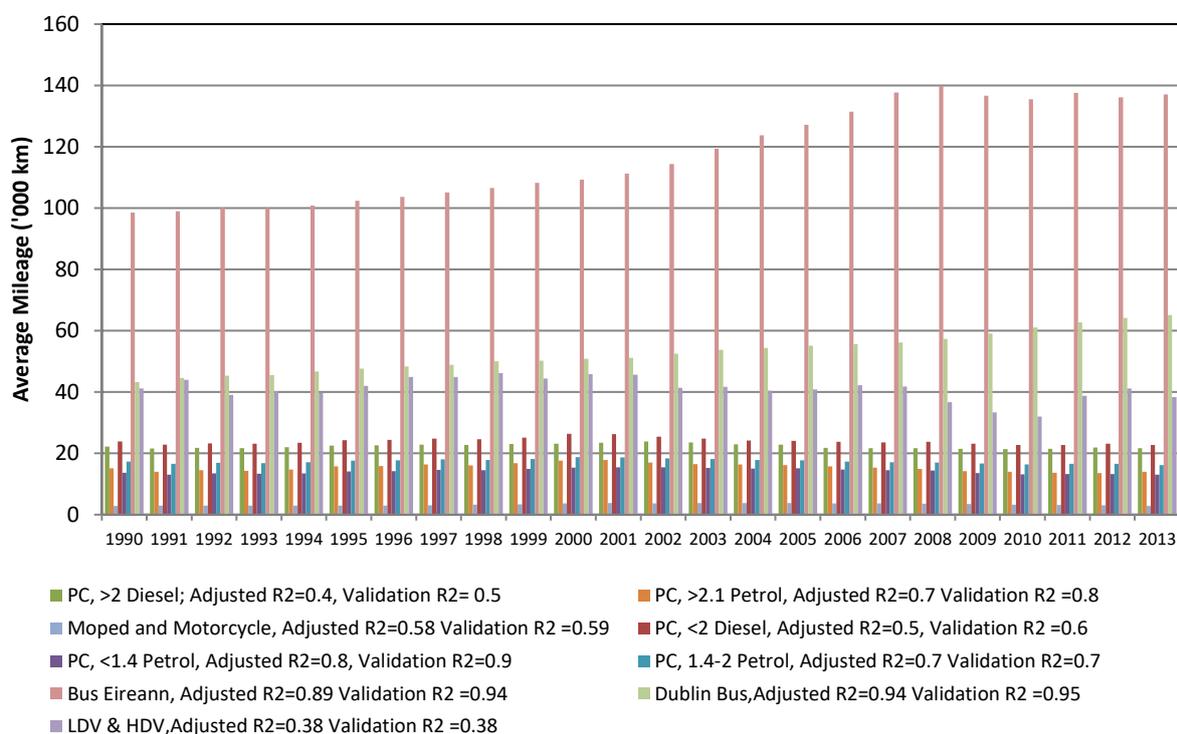
However, Bus and coach mileage data for some years were required initially to develop the Bus and Coach models. Thus, the mileage for buses and coaches were developed first since 1999 from total mileage, fleet and passenger numbers. Information regarding annual total mileage, fleet size and passenger 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. Passengers 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.

$$\text{Coach mileage} = (MB * BF + MB * 0.7 * PF) / (BF + PF)$$

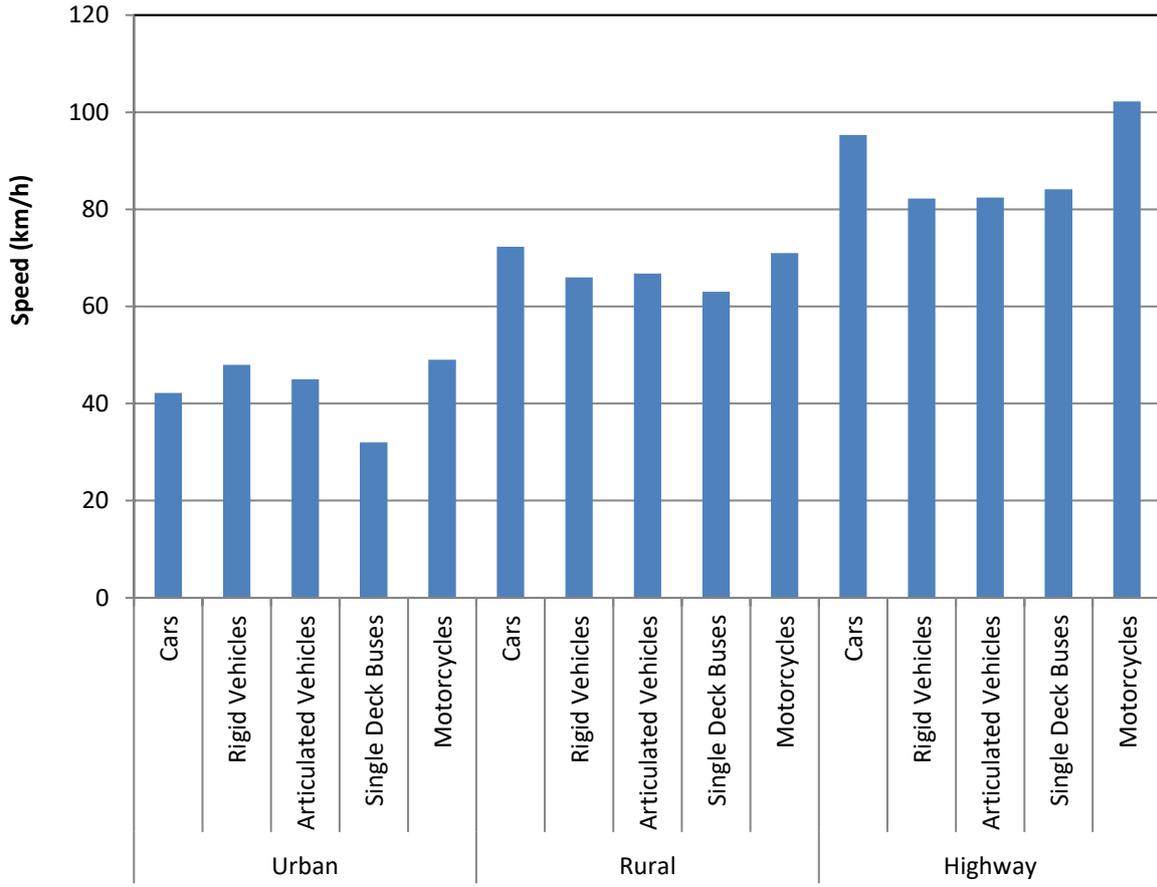
Where, MB = Coach mileage by national operator, BF = fleet size of the national coach operator & PF = Fleet size of the private coaches.

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<sup>2</sup> was 0.59 and validation R<sup>2</sup> 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

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- 3.3.H Activity data, parameters and emission factors for Crop Residue (3.D.1.4) 1990-2019
  - 3.3 I Nitrogen excretion by Manure Management System
  - 3.3 J Energy intake and milk yield parameters for cattle
  - 3.3 K Slurry storage and spreading methods 1990-2019

### 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. 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:

$$N_{\text{ex}(T)} = N_{\text{intake}(T)} \cdot (1 - N_{\text{retention}(T)}) \quad \text{Eq 10.31 (2006 IPCC Guidelines)}$$

Where

$N_{\text{ex}(T)}$  = annual N excretion rate, kg N animal<sup>-1</sup> year<sup>-1</sup>

$N_{\text{intake}(T)}$  = annual N intake per head, kg N animal<sup>-1</sup> year<sup>-1</sup>

$N_{\text{retention}(T)}$  = 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<sub>4</sub> from enteric fermentation and manure management (O'Mara, 2006) as discussed in sections 5.2.1.1 and 5.3.1.1 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  $N_{\text{retention}(T)}$  (equation 10.33, section 10.5.2 Chapter 10, Volume 4 of the 2006 IPCC guidelines) as follows:

$$N_{\text{intake}}(T) = \frac{GE}{18.8} \times \frac{CP\%/100}{6.25} \quad \text{Eq 10.32 (2006 IPCC Guidelines)}$$

Where:

$N_{\text{intake}(T)}$  = annual N intake per head, kg N animal<sup>-1</sup> year<sup>-1</sup>

GE = gross energy intake of the animal (MJ animal<sup>-1</sup> day<sup>-1</sup>) sourced from the Tier 2 model for the estimation of CH<sub>4</sub> emissions from enteric fermentation and manure management (O'Mara, 2006).

18.8 = conversion factor for dietary GE per kg of dry matter, MJ kg<sup>-1</sup> (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)<sup>-1</sup>

The annual N retention by the animal  $N_{\text{retention}(T)}$  is calculated based on the dietary assumptions used in the development of the Tier 2 emission factors for CH<sub>4</sub> from enteric fermentation and manure management (O'Mara, 2006) as discussed in sections 5.2.1.1 and 5.3.1. utilising equation 10.33, section 10.5.2 Chapter 10, Volume 4 of the 2006 IPCC guidelines.

$$N_{\text{retention}(T)} = \left[ \frac{\text{Milk} \cdot \left( \frac{\text{Milk PR}\%}{100} \right)}{6.38} \right] + \left[ \frac{\text{WG} \cdot \left[ 268 - \left( \frac{7.03 \cdot \text{NE}_g}{\text{WG}} \right) \right]}{6.25} \right]$$

Eq 10.33 (2006 IPCC Guidelines)

Where:

$N_{\text{retention}(T)}$  = fraction of annual N intake that is retained by the animal per head

Milk = milk production, kg animal<sup>-1</sup> day<sup>-1</sup> (CSO)

Milk PR % = percent of protein in milk (CSO)

6.38 = conversion from milk protein to milk N, kg Protein (kg N)<sup>-1</sup>

WG = weight gain, kg day<sup>-1</sup> (O'Mara, 2006)

268 and 7.03 = constants from Equation 3-8 in NRC (1996)

NE<sub>g</sub> = net energy for growth, MJ day<sup>-1</sup> (O'Mara, 2006)

### **Partitioning of nitrogen excretion from cattle into nitrogen excreted in dung and nitrogen excreted in urine**

Once the nitrogen excreted ( $N_{\text{ex}}$ ) is calculated as described in the previous section the proportion of N in both urine ( $N_{\text{urine}}$ ) and dung ( $N_{\text{dung}}$ ) can be determined with the following equation:

$$N_{\text{ex}(T)} = N_{\text{urine}} + N_{\text{dung}}$$

Where:

$N_{\text{ex}(T)}$  = annual N excretion rate, kg N animal<sup>-1</sup> year<sup>-1</sup>

$N_{\text{urine}}$  = N excreted in urine, kg N animal<sup>-1</sup> year<sup>-1</sup>

$N_{\text{dung}}$  = N excreted in dung kg N animal<sup>-1</sup> year<sup>-1</sup>

For dairy cattle (dairy cows),  $N_{\text{dung}}$  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<sub>4</sub> emissions from enteric fermentation and manure management (O'Mara, 2006) as discussed in sections 5.2.1.1 and 5.3.1.1.  $N_{\text{urine}}$  is then estimated as the difference between  $N_{\text{ex}(T)}$  and  $N_{\text{dung}}$ .

For all other cattle categories,  $N_{\text{urine}}$  is estimated based on the regression of De Prado et al (2006):

$$N_{\text{urine}} = ((0.1369 \times \% \text{ Nitrogen in diet}) + 0.262)$$

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<sub>4</sub> emissions from enteric fermentation and manure management (O'Mara, 2006) as discussed in sections 5.2.1.1 and 5.3.1.1.  $N_{\text{dung}}$  is then estimated as the difference between  $N_{\text{ex}(T)}$  and  $N_{\text{urine}}$ .

***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<sub>2</sub>O Emissions from Agricultural Soils

The input parameters for the calculation of N<sub>2</sub>O emissions from agricultural soils are presented in Table 3.3.F.2. Specific information in relation to EF<sub>1</sub> for synthetic nitrogen fertiliser application and EF<sub>3</sub> for urine and dung deposited on grazed pasture by cattle is discussed as follows.

#### *Country-specific emission factors from synthetic nitrogen fertiliser application (EF<sub>1</sub>)*

The default value for EF<sub>1</sub>, (0.010 kg N<sub>2</sub>O-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<sub>2</sub>O 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 2018, CAN accounted for 86.6 percent of total N fertiliser sales with urea and inhibited urea accounting for 12.9 per cent and 0.5 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<sub>2</sub>O 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<sub>2</sub>O 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<sub>4</sub><sup>+</sup> by impeding the activities of soil-nitrifying bacteria. Thus, by retaining nitrogen in the form of NH<sub>4</sub><sup>+</sup> 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<sub>1</sub> now used in the national inventory is on average 24 per cent higher (0.0124 kg N<sub>2</sub>O-N/kg N) than the default value present for EF<sub>1</sub> 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 <sub>1</sub> kg N <sub>2</sub> O-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<sub>3</sub>, 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<sub>2</sub>O and nitrate leaching. The default emissions factor, EF<sub>3</sub> applies one single value (0.02 kg N<sub>2</sub>O-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<sub>2</sub>O 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<sub>2</sub>O emission factors from urine and dung and to assess the effect of soil type and season of application on the magnitude of N<sub>2</sub>O 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<sub>2</sub>O 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<sub>2</sub>O-N/kg N and 0.012 kg N<sub>2</sub>O-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<sub>2</sub>O emissions from urine and dung deposition on pasture. The resultant combined implied emission factor of 0.0086 kg N<sub>2</sub>O-N/kg N from this analysis is 56 per cent lower than the default emission factor for EF<sub>3</sub>.

## Annex 3.4

### Methodology development and activity Data for LULUCF (IPCC Sector 4)

#### **3.4.A Derivation of Historic Deforestation Areas for LULUCF and KP LULUCF**

3.4.A.1 Tracking Deforestation using CORINE Land Cover Datasets (Approach 3)

3.4.A.2 Sampling approach: NFI grid points and aerial photography (modified GPG approach 3)

3.4.A.3 Modification to deforestation records from 2006 onwards

#### **3.4.B Calibration and detailed description of CBM**

3.4.B.1 Definition of species, productivity index and area matrices

3.4.B.2 Defining silvicultural rules for simulation of management events

3.4.B.3 Deriving stand level biomass and merchantable volume estimates from NFI data

3.4.B.4 Merchantable volume to biomass equations

3.4.B.5 Volume increment curves

3.4.B.6 Turnover and transfers rates of C pools

3.4.B.7 Disturbance matrices

#### **3.4.C Description of the FORCARB model**

3.4.C.1 Time Series Adjustment of Living Biomass and DOM Pools

3.4.D Detailed Non-Forest Land Use Change Matrix

### 3.4.A Derivation of Historic Deforestation Areas for LULUCF and KP LULUCF

Lack of a method to record historic land use change 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 since 2006.

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)

The reporting of LUC matrices in Table 6.2 of chapter 6 show deforestation areas since 1990 (KP\_CRF, Chapter 11) and 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 ( $\pm 1$  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 grassing 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 definition (chapter 11). 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 (see chapter 6).

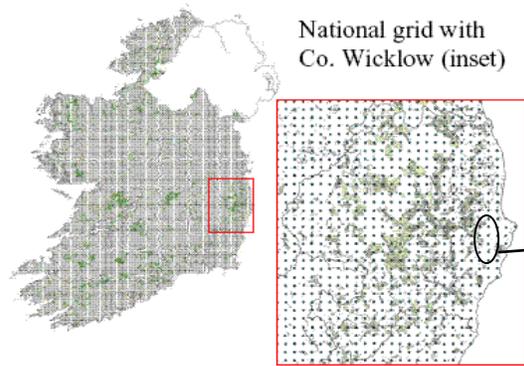
For this exercise, the following codes were extracted; CLC 311, 312 and 313 to represent forest land area that were present in 1990, but were converted to land cover other than forest in the 2000 and 2006 time series. The resulting polygons were then intersected with a national soils map using ARC GIS 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)

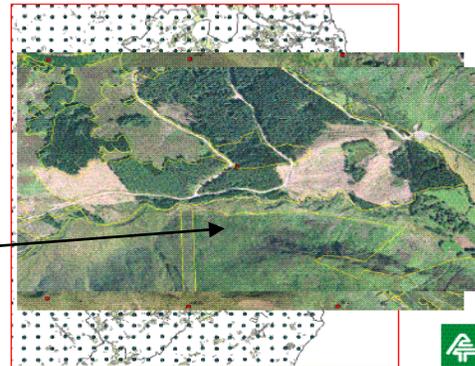
This sampling approach is a modification of approach 3, where the grids or centroids are sampled using a systematic sampling procedure adopted in the NFI. Note:

- 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 (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), so is in conflict 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.

PHASE 1- SAMPLE GRID – 2 x 2 km



Forest Identification

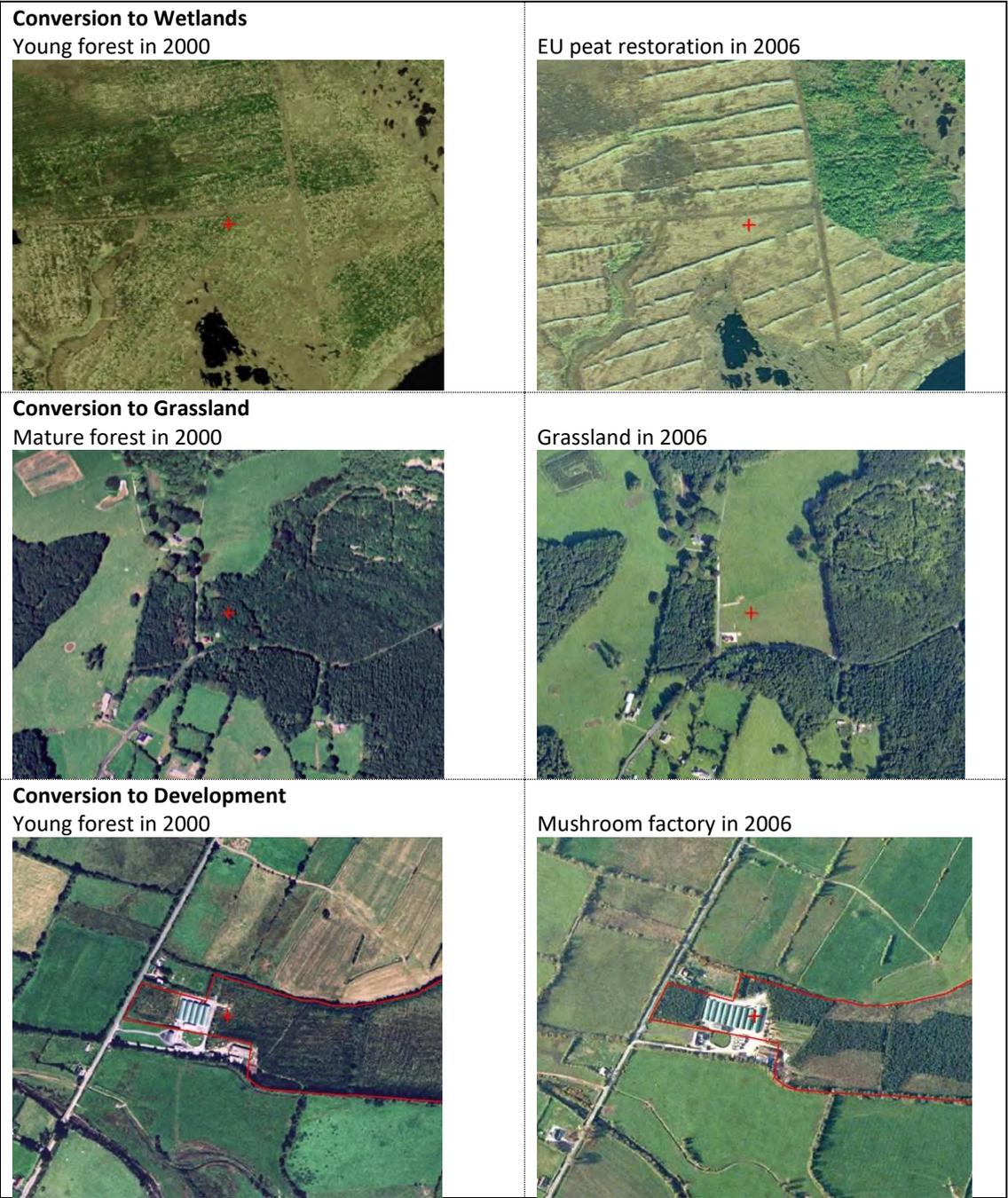


*Figure 3.4.A2-1: The NFI systematic sample approach used to classify land use for each permanent sample plot (PSP)*

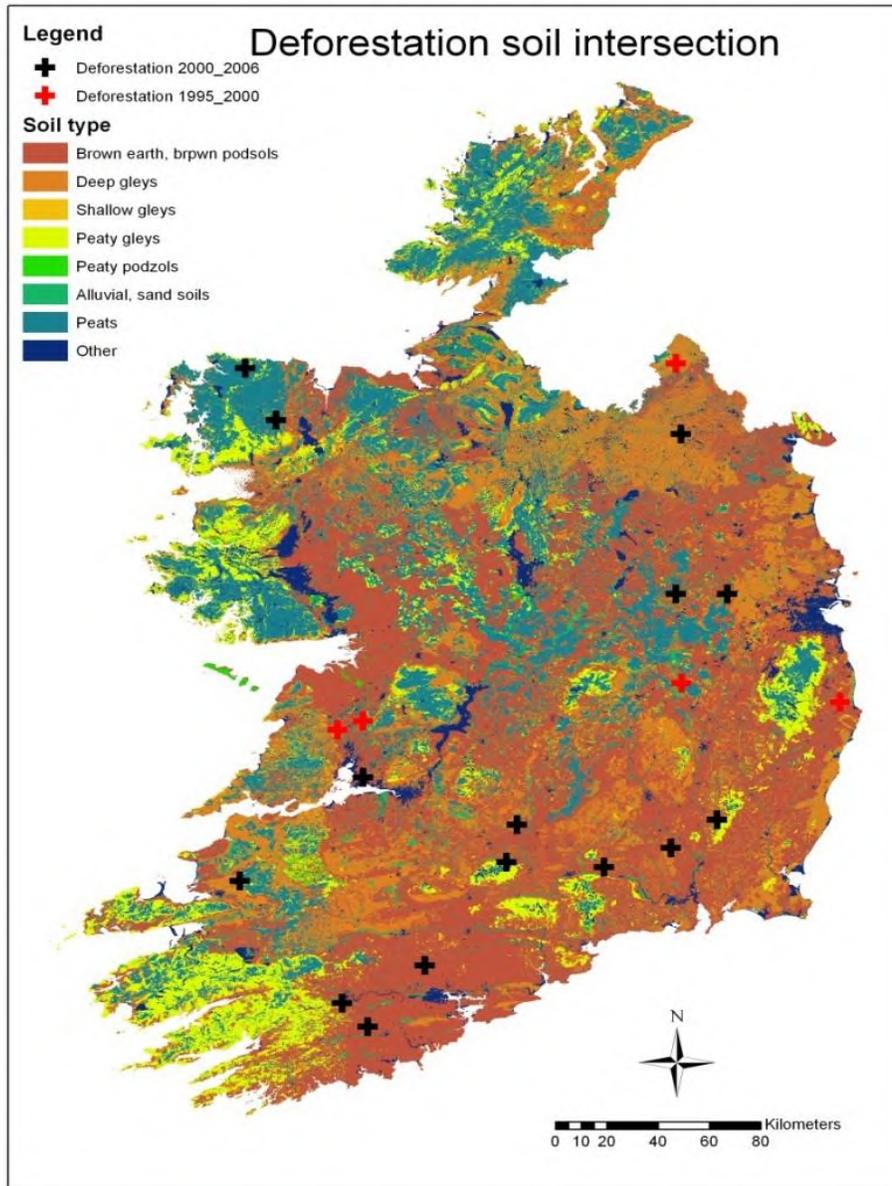
The use of the NFI stratified sample 2x2 km grid of PSP is described in chapters 6 and 11. Assessment of ca.18,000 point intersects with aerial photographs from 2000 and 2006 provides the opportunity to assess deforestation for this period. This method identified 15 NFI PSP grid samples which were deemed 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), see database for detailed information.



*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
<b>1990-1994</b>	<b>CLC1990-2000</b>			<b>20.6<sup>15</sup></b>	<b>100</b>
		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		
<b>1995-1999</b>	<b>NFI-FIPs 95</b>			<b>333.3<sup>16</sup></b>	<b>100</b>
		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
<b>2000-2005</b>	<b>NFI-2000-2006</b>			<b>857.1<sup>17</sup></b>	<b>100</b>
		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

<sup>15</sup> The CLC 1990-1994 area was calculated using the values show in table 1a to be, where annual deforestation area 1990-1994 =  $\frac{\text{area}_{1990 \rightarrow 2000}}{10 \times 5} \times 5$

<sup>16</sup> NFI 1995-1999 area was calculated using the values show in table 2a to be, where the annual deforested area 1995-1999 =  $\frac{\text{area}_{1995 \rightarrow 2000}}{6 \times 5} \times 5$

<sup>17</sup> NFI 2000-2005 area was calculated using the values show in table 2b to be, where the annual deforested area 2000-2005 =  $\frac{\text{area}_{2000 \rightarrow 2006}}{7 \times 6} \times 6$

Period	Source	Land use	Soil category	Area (ha) per year	% for period
		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
<b>2006</b>	<b>Felling licence and land taken out</b>			<b>376.44</b>	<b>100</b>
	242.34+134.1	Grassland	Mineral	5.3	1.4
	(LFL+LTO) <sup>18</sup>	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
<b>2007</b>	<b>Felling licence and land taken out</b>			<b>338.7</b>	<b>100</b>
	174.83+163.9	Grassland	Mineral	0.6	0.2
	(LFL+LTO) <sup>4</sup>	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		
<b>2008</b>	<b>Felling licence and land taken out</b>			<b>294.5</b>	<b>100</b>
	26.42+268	Grassland	Mineral	80.2	27.2
	(LFL+LTO) <sup>4</sup>	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

<sup>18</sup> 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
		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
<b>2009</b>	<b>Felling licence and land taken out</b>			<b>196.9</b>	<b>100</b>
	49.9+147	Grassland	Mineral	5.1	2.6
	(LFL+LTO) <sup>4</sup>	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
<b>2010</b>	<b>Felling licence and land taken out</b>			<b>124</b>	<b>100</b>
	26+98	Grassland	Mineral	39.7	39.1
	(LFL+LTO) <sup>4</sup>	Grassland	Peat		
		Grassland	Peaty mineral		
		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

### 3.4.B.1 Definition of species, productivity index and area matrices

CBM 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 (Kull et al., 2016). Consideration of the modelling requirements and data sources influenced 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<sup>2</sup>, so this equated to ca 1700-1900 stands over the period 2006-2017. The number of NFI plots impose 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 afforestation inventory tables are over 3000 rows, too large to show, but a summary of species/soil type matrix is shown in Table 3.4.B.1-1

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 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 so these emissions are applied after the CBM 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<sup>-1</sup>, 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 2017.*

Species strata	Soil strata (% of total area 2017)					Grand Total
	Peat	Cambisols	Gleysols	Luvisols	Podzolic	
<b>CBmix</b>	1.5	1.0	2.2	0.0	0.0	4.8
<b>Cmix</b>	7.1	0.6	3.4	0.0	0.3	11.3
<b>FGB</b>	2.2	0.4	2.9	0.2	0.2	5.9
<b>OC</b>	0.9	0.3	1.1	0.0	0.5	2.8
<b>Pine12-20</b>	4.8	0.4	0.0	0.6	0.0	5.9
<b>Pine4-12</b>	2.2	0.0	0.0	0.0	0.0	2.2
<b>SGB</b>	0.0	0.1	1.1	0.0	0.0	1.2
<b>Spruce 13-16</b>	4.4	0.0	0.2	0.2	0.2	5.0
<b>Spruce 17-20</b>	9.7	0.8	1.9	0.4	0.3	13.0
<b>Spruce 24-30</b>	7.5	1.6	9.3	0.0	2.0	20.3
<b>Spruce 4-12</b>	4.9	0.1	0.2	0.0	0.2	5.4
<b>Spruce20-24</b>	12.3	0.7	7.4	0.7	0.9	22.1
<b>Grand Total</b>	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 FM areas in 2016*

Description of strata	Code	Area (ha)	Mean volume ha <sup>-1</sup>
Conifer mixtures (more than 25% of conifer or broadleaf)	CBmix	19333.1	245.5
Conifer broadleaf mixtures (less than 75% of dominant conifer spp)	Cmix	21514.8	186.9
Fast growing broadleaves (birch, ash, alder, sycamore etc)	FGB	94241.1	155.0
Slow growing broadleaves (oak, beech etc)	SGB	20423.9	178.8
Open areas within forest boundaries e.g. roads	forest open area	27635.6	
Other conifers (except Pine or Spruce)	OC	14969.4	270.9
Pine (Lodgepole, Scots pine and others) with a site index of 4-12m*	Pine4-12	14605.8	144.3
Pine (Lodgepole, Scots pine and others) based on a site index of 12-20m*	Pine12-20	28060.2	299.5
Spruce (Sitka spruce or Norway spruce) based on a site index of 4-12m**	Spruce4-12	37150.9	227.1
Spruce (Sitka spruce or Norway spruce) based on a site index of 13-16m**	Spruce13-16	36423.7	331.8
Spruce (Sitka spruce or Norway spruce) based on a site index of 17-20m**	Spruce17-20	44726.6	356.3
Spruce (Sitka spruce or Norway spruce) based on a site index of 20-24m**	Spruce20-24	63696.0	426.3
Spruce (Sitka spruce or Norway spruce) based on a site index of 24-30m**	Spruce24-30	14242.2	404.2
Clearfelled areas yet to be replanted	temporarily unstocked	9342.5	

446366.5

\*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)

### 3.4.B.2 Defining silvicultural rules for simulation of management events

CBM 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 2006-2012. The thinning practices are also reflected in the Irish Thinning Protocol published during the RP (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 0.5. Merchantable volume for individual trees was derived using equations used on the NFI (NFI, 2017) and those published by Black (2016)

Scaling from individual trees to stand based estimates required the use of proportional area expansion factors (NFI, 2017) 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:

$$\frac{R_3^2}{R_i^2} \dots\dots\dots (3.4.1)$$

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  $\frac{R_3^2}{R_i^2} \times n_i$ , 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).

$$n_{ij} \times EXF_{ij} = N \dots\dots\dots (3.4.2)$$

where  $n_{ij} \times EXF_{ij}$  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:

$$GTOTAL_{(AB)} = \frac{\sum[AB_{ij} \times EXF_{ij}] \times 20}{1000} \dots\dots\dots (3.4.3)$$

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<sup>-1</sup>)**

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), LHR= 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 <sup>2</sup>	RMSE	Slope	Source
				a	b	c	d				
<b>Spruce</b>											
1	AB	H>4.5m	$a \times DBH^b + c \times H^d$	0.23	2.12	$5 \times 10^{-7}$	4.99	0.91	0.29	1.01	i, ii
2	AB	H<4.5m	$a \times H^b \times c$	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			0.91	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	0.003		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	LHR		AB-SB								
<b>Pines</b>											
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			0.96	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	LHR		AB-SB								
<b>Larch</b>											
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			0.99	0.25	0.99	ii, iii
4	BB		TB-AB								

Eq	Function	Range	Equation	Coefficients				r <sup>2</sup>	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	LHR		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			0.99	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	LHR		AB-SB								
Slow 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	$a \times (DBH \times 10)^b$	0.009	1.47			0.96			v
24	FB	DBH<10cm	$AB \times 0.3$					0.78	1.2	0.79	i, ii
25	SB	DBH>19cm	$a \times (DBH \times 10)^b$	0.0002	2.5			0.97			v
26	SB	DBH<9cm	$\frac{AB + BB}{1.4}$								BEF
7	LHR		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 <sup>2</sup>	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	LHR		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 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 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).

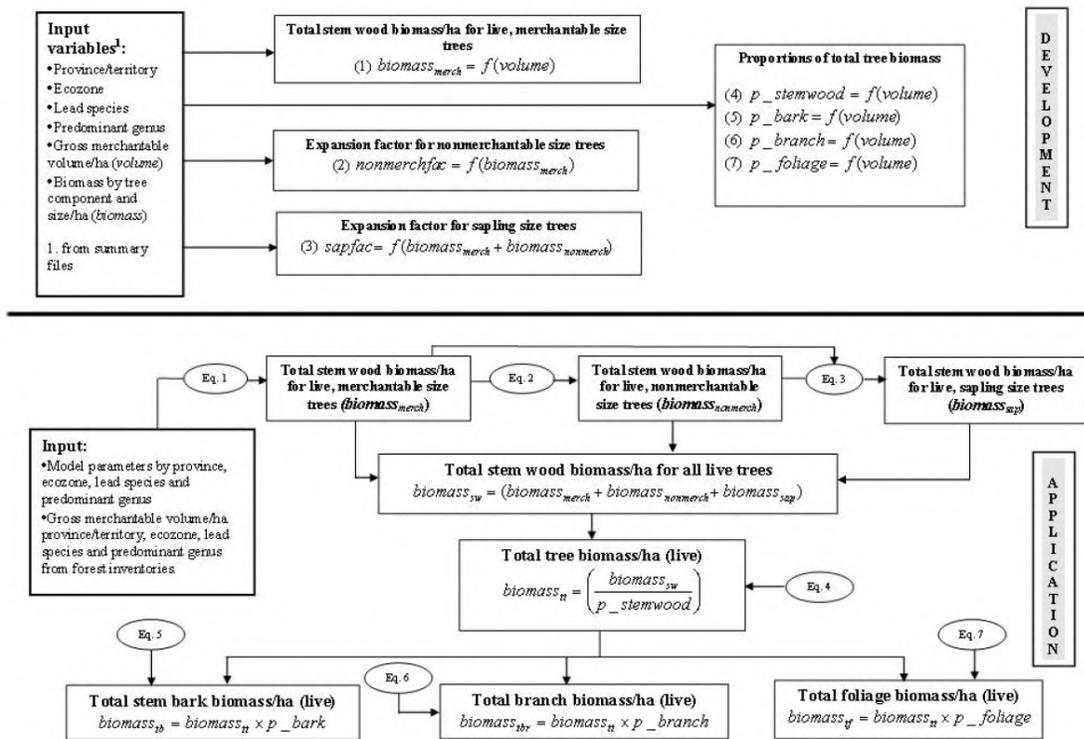


Figure 3.4.B.4-1 Summary flow chart of development and application of biomass component functions in CBM, taken from Boudewyn et al (2007). Note that eq. references in the diagram do not match the text below, but the equation names do.

**Biomass equations**

Merchantable stem biomass ( $bm$ , t ha<sup>-1</sup>), which excludes stumps, tops and non-merchantable trees, to volume ( $v$ , m<sup>3</sup>ha<sup>-1</sup>), 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
<b>Spruce</b>	1.583	0.764	1020	3.6	10.4
<b>Pine</b>	0.974	0.899	1120	2.1	17.7
<b>Other conifers</b>	1.406	0.799	950	5.42	11.7
<b>*Fast growing broadleaves (FGB)</b>	0.384	1.150	650	4.2	42.5
<b>*Slow growing broadleaves (SGB)</b>	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:

$$nonmerchfactor(f) = k + a \times bm^b \quad (3.4.5)$$

$$nonmerchfactor = \frac{bnm}{bm}, \text{ where } bnm=bn+bm$$

*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
<b>Spruce</b>	0.863	0.597	-0.302	3.4	1	0.08
<b>Pine</b>	0.723	1.728	-0.363	4.5	1	0.17
<b>Other conifers</b>	0.906	1.304	-0.536	2.1	1	0.06
<b>*FGB</b>	0.471	49.165	-0.942	7.2	1.05	32
<b>*SGB</b>	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:

$$\text{saplingfactor}(f) = k + a \times bnm^b \quad (3.4.6)$$

$$\text{saplingfactor} = \frac{bsnm}{bnm}, \text{ where } bsnm = bs + bnm$$

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 ( $v$ ,  $m^3 \text{ ha}^{-1}$ ), based on eq 3.4.7 (Boudewyn et al 2007):

$$Biomass_{ag} = \frac{Biomass_{swt}}{p_{stemwood}} \quad (3.4.7)$$

and

$$p_{stemwood} = \frac{1}{1 + e^{a_1 + a_2 \times v + a_3 \times lv} + e^{b_1 + b_2 \times v + b_3 \times lv} + e^{c_1 + c_2 \times v + c_3 \times lv}} \quad (3.4.8)$$

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 ( $Biomass_{bk}$ ) is estimated as follows:

$$Biomass_{bk} = Biomass_{ag} \times p_{bark} \quad (3.4.9)$$

$$p_{bark} = \frac{e^{a_1 + a_2 \times v + a_3 \times lv}}{1 + e^{a_1 + a_2 \times v + a_3 \times lv} + e^{b_1 + b_2 \times v + b_3 \times lv} + e^{c_1 + c_2 \times v + c_3 \times lv}} \quad (3.4.10)$$

Branch biomass ( $Biomass_{br}$ ) is estimated as follows:

$$Biomass_{br} = Biomass_{ag} \times p_{branch} \quad (3.4.11)$$

$$p_{branch} = \frac{e^{b_1+b_2 \times v+b_3 \times lv}}{1+e^{a_1+a_2 \times v+a_3 \times lv}+e^{b_1+b_2 \times v+b_3 \times lv}+e^{c_1+c_2 \times v+c_3 \times lv}} \quad (3.4.12)$$

Foliage biomass (*Biomass<sub>fl</sub>*) is estimated as follows:

$$Biomass_{fl} = Biomass_{ag} \times p_{bark} \quad (3.4.13)$$

$$p_{foliage} = \frac{e^{c_1+c_2 \times v+c_3 \times lv}}{1+e^{a_1+a_2 \times v+a_3 \times lv}+e^{b_1+b_2 \times v+b_3 \times lv}+e^{c_1+c_2 \times v+c_3 \times lv}} \quad (3.4.14)$$

**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:

$$CAI = a \times \exp^{-b \times age} \times 1 - \exp^{(-b \times age)^{c-1}} \quad (3.4.15)$$

*Table 3.4.B.5.1: Solved parameters for CAI of different species cohorts*

Cohort	Parameter		
	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 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*

Cohort	Parameter		
	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.**

<b>CBM pool</b>	<b>Turnover rates (%C yr<sup>-1</sup>)</b>	<b>DOM pool receiving turnover</b>	<b>Litterfall transfers (% transferred to DOM pool)</b>
Merchantable stem (SW,HW) <sup>a</sup>	1	Snag stems	100
Other wood (HW, SW) <sup>b</sup>	4	Snag branches	25
		AG fast	75
Foliage (SW) <sup>c</sup>	15	AG very fast	100
Foliage (HW) <sup>b</sup>	95	AG very fast	100
Fine roots (HW,SW) <sup>d</sup>	64.1	AG very fast	50
		BG very fast	50
Coarse roots (HW,SW) <sup>d</sup>	2	AG fast	50
		BG fast	50

<sup>a</sup> Derived from NFI 2012-2017; <sup>b</sup>Kurz et al. (1992) <sup>c</sup>Tobin et al., 2007; <sup>d</sup> 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. CO2	Em. CH4	Em.CO	Em. N2O	Products
Softwood merchantable	1																			0.03										0.97
Softwood foliage		1											0.9													0.10				
Softwood others			1											0.7									0.3							
Softwood sub-merch				1										0.7									0.3							
Softwood coarse roots					1									0.5	0.5															
Softwood fine roots						1							0.5	0.5																
Hardwood merchantable							1															0.10								0.90
Hardwood foliage								1					0.9													0.10				
Hardwood others									1					0.7										0.3						
Hardwood sub-merch										1				0.7									0.3							
Hardwood coarse roots											1			0.5	0.5															
Hardwood fine roots												1	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.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*

<b>Cohort</b>	<b>Species table</b>	<b>Proportion</b>
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

<b>Period :1990-1999 (Source FIPS 95)</b>				
Species cohort	Yield class	Proportion of cohort	Silviculture	Rotation
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
<b>Period :2000-2012 (Source NFI-Coillte intersect)</b>				
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:

$$St = Mt \left[ \frac{1 - e^{-k_s(k_t - t)}}{1 - e^{-k_s k_t}} \right] \dots\dots\dots(3.4.17)$$

where:

$$Mt = \frac{Cm}{Rm} \ln \left[ 1 + \frac{Co}{Cm} e^{Rmt} \right] \dots\dots\dots(3.4.18)$$

where:

$Mt$  is Monteith's function,  $Cm$  is maximum growth rate,  $Co$  is initial absolute growth rate and  $Rm$  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:

$$\Delta C_b = St_{n+1} - St_n \dots\dots\dots(3.4.19)$$

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).

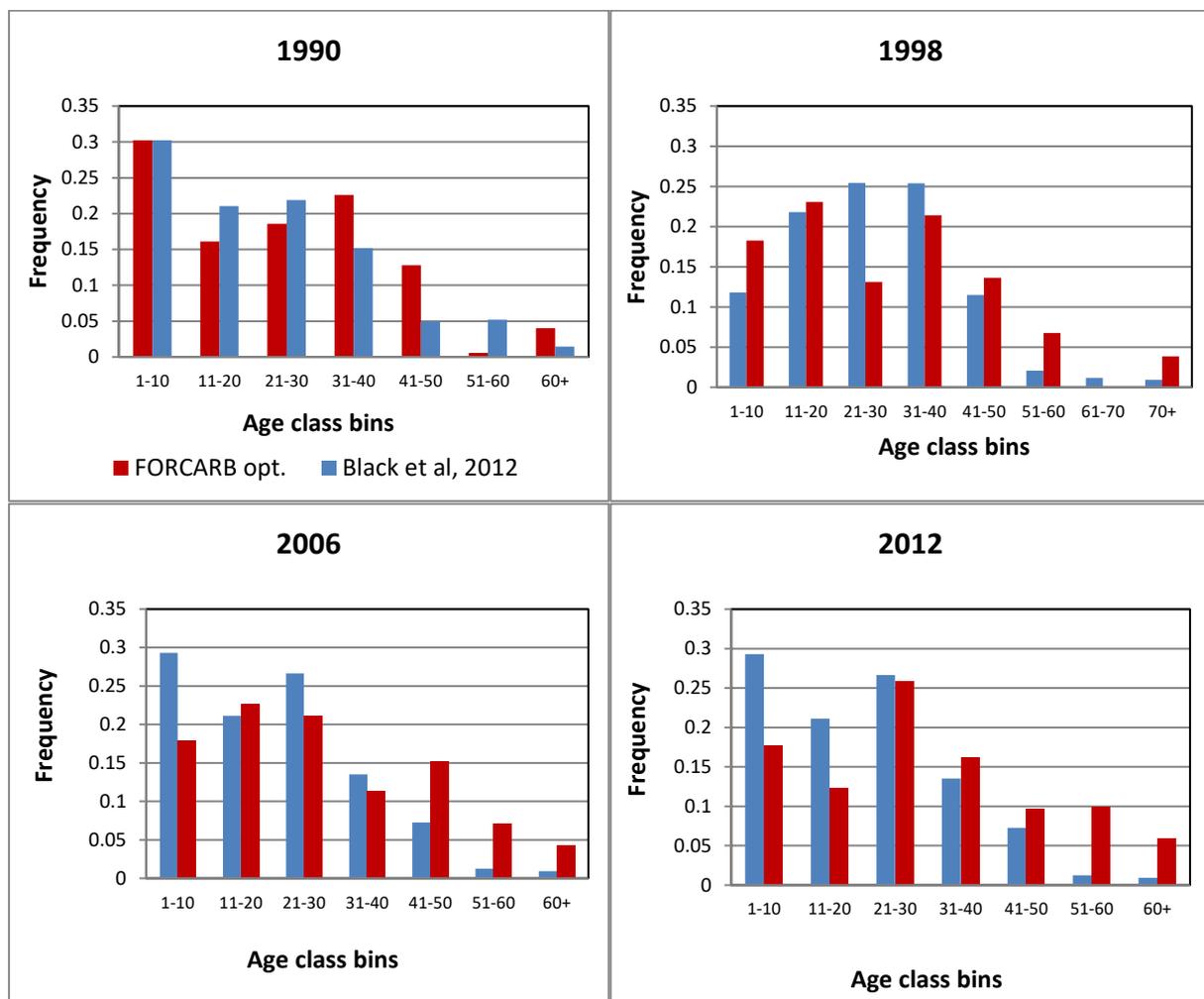


Figure 3.4.C-1 Validation of optimised age-class distributions

### 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 (*LBgain*, kt C) from the 2006 to 2012 time series for the CBM and FORCARB model outputs were compared. The ratio (2.19) of the total CBM and FORCARB *LBgain* values for 2006-2012 was used to adjust the time series:

$$LB\ gain_{adj} = LB\ gain_{ini.} \times 2.10 \dots \dots \dots (eq\ 3.4.20)$$

where, *LBgain<sub>adj</sub>* is the adjusted living biomass gain value and *LBgain<sub>ini</sub>* 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:

$$LB\ loss_{adj(1990)} = LBgain_{adj(1990)} \times \frac{LB\ loss_{ini(1990)}}{LBgain_{ini(1990)}} \dots \dots \dots (eq\ 3.4.21)$$

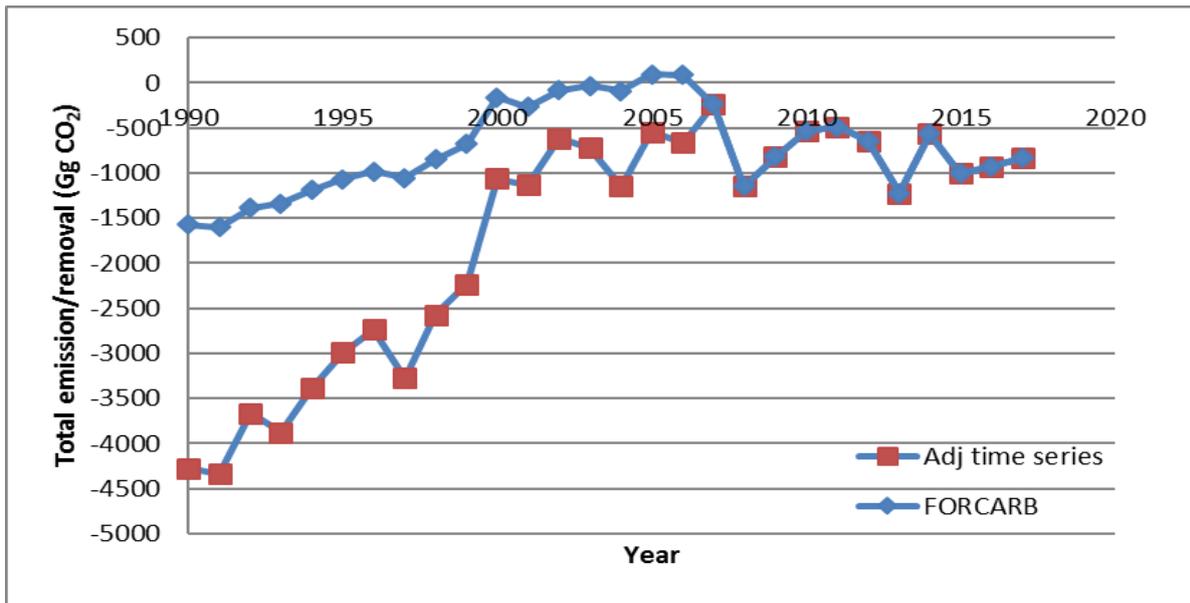
- c) For dead organic matter (DOM), the ratio (1.06) of the average CBM to average FORCARB values for 2007-2012 was used to adjust the time series:

$$DOM_{adj} = DOM_{ini.} \times 1.06 \dots \dots \dots (eq\ 3.4.22)$$

- 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 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<sub>2</sub>. This is due to fundamental differences in the model input variables and the spatial scale at with the FORCARB and CBM 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 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 than 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) and national research information;



*Figure 3.4.C.1-1 Adjusted time series for forest category 4.A.1*

- d) The CBM 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 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 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
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
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	5.38	3.03	5.37
Wetland (unmanaged) to Forest	9.43	9.80	8.50	5.74	11.01	14.17	11.21	6.92	7.50	4.83	7.84	9.64	9.35	5.74	4.05
Wetland (managed) to Forest	NO	0.32	0.32	0.32	0.32	0.32	0.14	0.14	0.14	0.14	0.14	0.33	0.33	0.33	0.33
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
Converted to Wetlands (managed)	NO														
Converted to Wetlands (unmanaged)	NO	0.17	0.17	0.17	0.17	0.17									
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
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
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
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
Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Forest remaining Forest	692.26	700.35	706.79	711.97	717.41	723.26	729.98	735.83	740.88	746.73	752.09	757.58	763.86	769.20	773.10
Grassland to Forest	5.85	6.03	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
Wetland (unmanaged) to Forest	3.92	1.88	1.55	NO	1.58	0.79	0.95	0.33	0.42	0.55	0.77	0.79	0.39	0.86	0.35
Wetland (managed) to Forest	0.33	0.13	0.13	NO	NO	NO	NO	0.18	NO	0.13	0.13	0.13	0.04	0.00	NO
Converted to Grassland (managed)	0.40	NO	NO	0.40	0.40	0.80	1.20	NO	1.20	NO	NO	0.40	0.02	0.06	0.01
Converted to Wetlands (managed)	NO	NO	NO	NO	0.40	NO	0.02	NO							
Converted to Wetlands (unmanaged)	0.17	NO	0.40	NO	NO	NO	0.40	NO	0.40	0.40	0.80	0.40	0.03	NO	0.01
Converted to Settlements	0.17	0.40	1.20	1.20	NO	NO	NO	0.80	NO	NO	NO	NO	0.18	0.11	0.11
Converted to Other land	0.11	1.60	NO	0.40	NO	0.00									
Initial area	693.11	702.35	708.39	713.97	718.21	724.06	731.58	736.63	742.48	747.13	752.89	758.38	764.08	769.39	773.23
Final area	702.35	708.39	713.97	718.21	724.06	731.58	736.63	742.48	747.13	752.89	758.38	764.08	769.39	773.23	776.65

**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
Cropland Remaining Cropland	739.97	739.94	739.91	739.89	739.85	739.81	739.77	739.72	739.66	739.60	739.55	739.48	739.42	739.34	739.25
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
Initial Area	740.00	739.97	739.94	739.91	739.89	739.85	739.81	739.77	739.72	739.66	739.60	739.55	739.48	739.42	739.34
Final Area	739.97	739.94	739.91	739.89	739.85	739.81	739.77	739.72	739.66	739.60	739.55	739.48	739.42	739.34	739.25
Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Cropland Remaining Cropland	739.15	739.05	739.01	739.01	738.93	738.85	738.84	738.82	738.80	738.79	738.77	738.75	738.73	738.71	738.67
Cropland to Settlement	0.10	0.10	0.04	0.00	0.08	0.08	0.02	0.01	0.02	0.01	0.02	0.02	0.02	0.02	0.03
Initial Area	739.25	739.15	739.05	739.01	739.01	738.93	738.85	738.84	738.82	738.80	738.79	738.77	738.75	738.73	738.71
Final Area	739.15	739.05	739.01	739.01	738.93	738.85	738.84	738.82	738.80	738.79	738.77	738.75	738.73	738.71	738.67

**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
Grassland Remaining Grassland	4402.19	4392.90	4384.71	4374.50	4365.97	4356.31	4346.44	4341.77	4336.12	4327.99	4320.00	4314.15	4308.48	4304.94	4298.96
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
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	5.38	3.03	5.37
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
Initial Area	4408.89	4402.20	4392.91	4384.71	4374.51	4365.98	4356.58	4346.71	4342.03	4336.38	4328.26	4320.40	4314.55	4308.88	4305.34
Final Area	4402.20	4392.91	4384.71	4374.51	4365.98	4356.58	4346.71	4342.03	4336.38	4328.26	4320.40	4314.55	4308.88	4305.34	4299.36
Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Grassland Remaining Grassland	4292.44	4285.71	4279.80	4273.50	4267.99	4259.98	4254.90	4249.81	4243.78	4239.34	4233.73	4227.92	4222.98	4219.60	4216.16
Forest to Grassland	0.40	0.00	0.00	0.40	0.40	0.80	1.20	0.00	1.20	0.00	0.00	0.40	0.02	0.06	0.01
Grassland to Forest	5.85	6.03	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
Grassland to Settlement	1.08	1.10	0.43	0.05	0.84	0.89	0.17	0.15	0.20	0.16	0.22	0.24	0.23	0.23	0.30
Initial Area	4299.36	4292.84	4285.71	4279.80	4273.90	4268.39	4260.78	4256.10	4249.81	4244.98	4239.34	4233.73	4228.32	4222.99	4219.65
Final Area	4292.84	4285.71	4279.80	4273.90	4268.39	4260.78	4256.10	4249.81	4244.98	4239.34	4233.73	4228.32	4222.99	4219.65	4216.17

**Table 3.4.D-3a Managed Wetland Matrix ('000 ha)**

<b>Year</b>	<b>1990</b>	<b>1991</b>	<b>1992</b>	<b>1993</b>	<b>1994</b>	<b>1995</b>	<b>1996</b>	<b>1997</b>	<b>1998</b>	<b>1999</b>	<b>2000</b>	<b>2001</b>	<b>2002</b>	<b>2003</b>	<b>2004</b>
Managed Wetland Remaining	78.44	77.50	76.90	75.91	76.30	75.43	77.18	77.03	78.46	76.25	75.16	73.63	71.36	80.28	70.93
Managed Wetland															
Unmanaged Wetlands to Managed Wetlands	0.00	0.00	0.06	2.06	0.05	3.11	0.89	2.46	0.71	0.00	1.26	0.00	13.34	0.00	0.00
Managed Wetland to Forest	0.00	0.32	0.32	0.32	0.32	0.32	0.14	0.14	0.14	0.14	0.14	0.33	0.33	0.33	0.33
Managed Wetland to Unmanaged Wetland	0.60	0.62	0.28	0.72	1.35	0.60	1.22	0.90	0.90	2.78	0.95	2.46	1.95	4.08	9.03
Initial Area	79.04	78.44	77.50	76.95	77.97	76.35	78.54	78.08	79.50	79.16	76.25	76.42	73.63	84.69	80.28
Final Area	78.44	77.50	76.95	77.97	76.35	78.54	78.08	79.50	79.16	76.25	76.42	73.63	84.69	80.28	70.93
<b>Year</b>	<b>2005</b>	<b>2006</b>	<b>2007</b>	<b>2008</b>	<b>2009</b>	<b>2010</b>	<b>2011</b>	<b>2012</b>	<b>2013</b>	<b>2014</b>	<b>2015</b>	<b>2016</b>	<b>2017</b>	<b>2018</b>	<b>2019</b>
Managed Wetland Remaining	63.86	63.29	62.76	62.95	61.39	60.48	59.52	61.18	63.99	77.87	77.04	89.26	85.10	76.03	68.67
Managed Wetland															
Unmanaged Wetlands to Managed Wetlands	0.02	0.09	0.94	0.00	0.00	0.35	2.04	3.41	15.38	0.00	13.05	3.14	0.00	0.00	1.35
Managed Wetland to Forest	0.33	0.13	0.13	0.00	0.00	0.00	0.00	0.18	0.00	0.13	0.13	0.13	0.04	0.00	0.00
Managed Wetland to Unmanaged Wetland	6.74	0.46	0.49	0.75	1.56	1.31	1.31	0.20	0.60	1.36	0.69	0.69	7.26	9.06	7.39
Initial Area	70.93	63.88	63.38	63.70	62.95	61.79	60.83	61.56	64.59	79.36	77.87	90.09	92.40	85.10	76.06
Final Area	63.88	63.38	63.70	62.95	61.79	60.83	61.56	64.59	79.36	77.87	90.09	92.40	85.10	76.06	70.02

**Table 3.4.D-3b Unmanaged Wetland Matrix ('000 ha) (continued)**

<b>Year</b>	<b>1990</b>	<b>1991</b>	<b>1992</b>	<b>1993</b>	<b>1994</b>	<b>1995</b>	<b>1996</b>	<b>1997</b>	<b>1998</b>	<b>1999</b>	<b>2000</b>	<b>2001</b>	<b>2002</b>	<b>2003</b>	<b>2004</b>
Unmanaged Wetland Remaining															
Unmanaged Wetland	1278.38	1269.19	1261.25	1253.73	1243.39	1227.47	1215.97	1207.80	1200.50	1196.57	1190.24	1181.72	1161.67	1158.05	1158.25
Forest to Unmanaged Wetland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.17	0.17	0.17	0.17
Managed Wetlands to Unmanaged Wetlands	0.60	0.62	0.28	0.72	1.35	0.60	1.22	0.90	0.90	2.78	0.95	2.46	1.95	4.08	9.03
Unmanaged Wetland to Forest	9.43	9.80	8.50	5.74	11.01	14.17	11.21	6.92	7.50	4.83	7.84	9.64	9.35	5.74	4.05
Unmanaged Wetland to Managed Wetland	0.00	0.00	0.06	2.06	0.05	3.11	0.89	2.46	0.71	0.00	1.26	0.00	13.34	0.00	0.00
Initial Area	1287.81	1278.98	1269.81	1261.53	1254.45	1244.75	1228.07	1217.18	1208.70	1201.40	1199.35	1191.36	1184.35	1163.79	1162.30
Final Area	1278.98	1269.81	1261.53	1254.45	1244.75	1228.07	1217.18	1208.70	1201.40	1199.35	1191.36	1184.35	1163.79	1162.30	1167.45
<b>Year</b>	<b>2005</b>	<b>2006</b>	<b>2007</b>	<b>2008</b>	<b>2009</b>	<b>2010</b>	<b>2011</b>	<b>2012</b>	<b>2013</b>	<b>2014</b>	<b>2015</b>	<b>2016</b>	<b>2017</b>	<b>2018</b>	<b>2019</b>
Unmanaged Wetland Remaining															
Unmanaged Wetland	1163.51	1168.45	1166.42	1167.31	1166.47	1166.89	1165.21	1163.18	1147.59	1148.04	1135.99	1133.55	1134.25	1140.68	1148.04
Forest to Unmanaged Wetland	0.17	0.00	0.40	0.00		0.00	0.40	0.00	0.40	0.40	0.80	0.40	0.03	0.00	0.01
Managed Wetlands to Unmanaged Wetlands	6.74	0.46	0.49	0.75	1.56	1.31	1.31	0.20	0.60	1.36	0.69	0.69	7.26	9.06	7.39
Unmanaged Wetland to Forest	3.92	1.88	1.55	0.00	1.58	0.79	0.95	0.33	0.42	0.55	0.77	0.79	0.39	0.86	0.35
Unmanaged Wetland to Managed Wetland	0.02	0.09	0.94	0.00	0.00	0.35	2.04	3.41	15.38	0.00	13.05	3.14	0.00	0.00	1.35
Initial Area	1167.45	1170.42	1168.91	1167.31	1168.05	1168.03	1168.20	1166.92	1163.38	1148.59	1149.80	1137.48	1134.64	1141.54	1149.74
Final Area	1170.42	1168.91	1167.31	1168.05	1168.03	1168.20	1166.92	1163.38	1148.59	1149.80	1137.48	1134.64	1141.54	1149.74	1155.43

**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
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
Forest to Settlement	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.17	0.17	0.17	0.17	0.17
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
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
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
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
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
Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Settlement Remaining Settlement	113.86	115.27	116.94	118.63	119.89	120.85	121.88	122.08	123.05	123.28	123.46	123.71	123.99	124.44	124.82
Forest to Settlement	0.17	0.40	1.20	1.20	0.00	0.00	0.00	0.80	0.00	0.00	0.00	0.00	0.18	0.11	0.11
Cropland to Settlement	0.10	0.10	0.04	0.00	0.08	0.08	0.02	0.01	0.02	0.01	0.02	0.02	0.02	0.02	0.03
Grassland to Settlement	1.08	1.10	0.43	0.05	0.84	0.89	0.17	0.15	0.20	0.16	0.22	0.24	0.23	0.23	0.30
Other land to Settlement	0.06	0.07	0.03	0.00	0.05	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02
Initial Area	113.86	115.27	116.94	118.63	119.89	120.85	121.88	122.08	123.05	123.28	123.46	123.71	123.99	124.44	124.82
Final Area	115.27	116.94	118.63	119.89	120.85	121.88	122.08	123.05	123.28	123.46	123.71	123.99	124.44	124.82	125.28

**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
Other Land Remaining Other Land	27.38	27.36	27.34	27.33	27.31	27.28	27.32	27.35	27.38	27.41	27.44	27.51	27.59	27.65	27.70
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
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
Initial Area	27.39	27.38	27.36	27.35	27.33	27.31	27.35	27.39	27.42	27.45	27.48	27.56	27.63	27.70	27.76
Final Area	27.38	27.36	27.35	27.33	27.31	27.35	27.39	27.42	27.45	27.48	27.56	27.63	27.70	27.76	27.82
Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Other Land Remaining Other Land	27.75	27.80	29.38	29.38	29.73	29.67	29.66	29.65	29.64	29.63	29.62	29.61	29.59	29.58	29.56
Forest to Other Land	0.11	1.60	0.00	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other Land to Settlement	0.06	0.07	0.03	0.00	0.05	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02
Initial Area	27.82	27.87	29.40	29.38	29.78	29.73	29.67	29.66	29.65	29.64	29.63	29.62	29.61	29.59	29.58
Final Area	27.87	29.40	29.38	29.78	29.73	29.67	29.66	29.65	29.64	29.63	29.62	29.61	29.59	29.58	29.56

### 3.4E. Detailed KP LULUCF matrix

Table 3.5 ARD and FM timeseries ('000 ha)

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
<b>Afforestation and reforestation</b>															
Remaining AR	NO	15.82	34.96	51.66	67.66	87.12	110.83	131.81	143.25	156.17	168.84	184.54	200.00	215.06	224.15
GM to AR	NO	9.03	7.88	9.94	8.13	9.22	9.63	4.37	5.29	7.70	7.71	5.50	5.38	3.03	5.37
Other to AR	15.82	10.12	8.82	6.06	11.33	14.49	11.35	7.06	7.64	4.97	7.98	9.97	9.68	6.06	4.37
Changed to D	NO														
Total area at the end of the previous year	NO	15.82	34.96	51.66	67.66	87.12	110.83	131.81	143.25	156.17	168.84	184.54	200.00	215.06	224.15
Total area at the end of the current year	15.82	34.96	51.66	67.66	87.12	110.83	131.81	143.25	156.17	168.84	184.54	200.00	215.06	224.15	233.89
<b>Deforestation</b>															
Remaining D	NO	0.02	0.04	0.06	0.08	0.10	0.44	0.77	1.10	1.44	1.77	2.63	3.48	4.34	5.20
Total area at the end of the previous year	NO	0.02	0.04	0.06	0.08	0.10	0.44	0.77	1.10	1.44	1.77	2.63	3.48	4.34	5.20
Total area at the end of the current year	0.02	0.04	0.06	0.08	0.10	0.44	0.77	1.10	1.44	1.77	2.63	3.48	4.34	5.20	6.05
<b>Forest management</b>															
Changed to D	NA	0.02	0.02	0.02	0.02	0.33	0.33	0.33	0.33	0.33	0.86	0.86	0.86	0.86	0.86
Remaining FM	NA	465.24	465.22	465.20	465.18	464.84	464.51	464.18	463.84	463.51	462.65	461.79	460.94	460.08	459.22
Total area at the end of the previous year	NA	465.26	465.24	465.22	465.20	465.18	464.84	464.51	464.18	463.84	463.51	462.65	461.79	460.94	460.08
Total area at the end of the current year	465.26	465.24	465.22	465.20	465.18	464.84	464.51	464.18	463.84	463.51	462.65	461.79	460.94	460.08	459.22

Table 3.5 ARD and FM timeseries ('000 ha) cont.

Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
<b>Afforestation and reforestation</b>															
Remaining AR	233.89	243.99	252.02	259.20	265.45	272.10	280.41	286.26	292.91	298.77	304.92	311.22	317.62	323.07	327.05
GM to AR	5.85	6.03	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
Other to AR	4.25	2.01	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
Changed to D	NO	0.80	NO	0.40	NO	NO	0.10	0.08	0.04						
Total area at the end of the previous year	233.89	243.99	252.02	259.20	265.45	272.10	280.41	287.06	292.91	299.17	304.92	311.22	317.72	323.15	327.09
Total area at the end of the current year	243.99	252.02	259.20	265.45	272.10	280.41	287.06	292.91	299.17	304.92	311.22	317.72	323.15	327.09	330.60
<b>Deforestation</b>															
Remaining D	6.05	6.91	8.91	10.51	12.51	13.31	14.11	15.71	16.51	18.11	18.51	19.31	20.11	20.33	20.53
Total area at the end of the previous year	6.05	6.91	8.91	10.51	12.51	13.31	14.11	15.71	16.51	18.11	18.51	19.31	20.11	20.33	20.53
Total area at the end of the current year	6.91	8.91	10.51	12.51	13.31	14.11	15.71	17.31	18.11	18.51	19.31	20.11	20.33	20.53	20.65
<b>Forest management</b>															
Changed to D	0.86	2.00	1.60	2.00	0.80	0.80	1.60	0.80	1.60	NO	0.80	0.80	0.12	0.11	0.09
Remaining FM	458.37	456.37	454.77	452.77	451.97	451.17	449.57	449.57	447.97	447.97	447.17	446.37	446.24	446.14	446.05
Total area at the end of the previous year	459.22	458.37	456.37	454.77	452.77	451.97	451.17	450.37	449.57	447.97	447.97	447.17	446.37	446.24	446.14
Total area at the end of the current year	458.37	456.37	454.77	452.77	451.97	451.17	449.57	449.57	447.97	447.97	447.17	446.37	446.24	446.14	446.05

**Table 3.6 Cropland Management timeseries ('000 ha)**

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
CM remain CM Total area	739.97	739.94	739.91	739.89	739.85	739.81	739.77	739.72	739.66	739.60	739.55	739.48	739.42	739.34	739.25
Area of mineral soil	739.97	739.94	739.91	739.89	739.85	739.81	739.77	739.72	739.66	739.60	739.55	739.48	739.42	739.34	739.25
Area of organic soil	NO														
CM to Settlement Total area	0.03	0.05	0.08	0.11	0.14	0.18	0.23	0.28	0.34	0.40	0.45	0.51	0.58	0.66	0.75
Area of mineral soil	0.03	0.05	0.08	0.11	0.14	0.18	0.23	0.28	0.34	0.40	0.45	0.51	0.58	0.66	0.75
Area of organic soil	NO														
Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
CM remain CM Total area	739.15	739.05	739.01	739.01	738.93	738.85	738.84	738.82	738.80	738.79	738.77	738.75	738.73	738.71	738.67
Area of mineral soil	739.15	739.05	739.01	739.01	738.93	738.85	738.84	738.82	738.80	738.79	738.77	738.75	738.73	738.71	738.67
Area of organic soil	NO														
CM to Settlement Total area	0.85	0.95	0.98	0.99	1.06	1.14	1.16	1.17	1.19	1.21	1.23	1.25	1.27	1.29	1.32
Area of mineral soil	0.85	0.95	0.98	0.99	1.06	1.14	1.16	1.17	1.19	1.21	1.23	1.25	1.27	1.29	1.32
Area of organic soil	NO														

**Table 3.6 Grazing Land Management timeseries ('000 ha)**

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
GM remain GM Total area	4402.19	4392.89	4384.69	4374.48	4365.94	4356.27	4346.13	4341.19	4335.28	4326.89	4318.63	4312.38	4306.31	4302.36	4295.99
Area of mineral soil	4025.54	4017.12	4009.68	4002.60	3994.06	3984.40	3974.26	3969.32	3968.67	3961.60	3954.39	3948.14	3942.06	3938.12	3931.75
Area of organic soil	376.66	375.78	375.01	371.88	371.88	371.88	371.88	371.88	366.60	365.29	364.24	364.24	364.24	364.24	364.24
GM to Settlement Total area	0.31	0.58	0.91	1.18	1.59	2.04	2.55	3.11	3.74	4.43	4.97	5.72	6.42	7.33	8.34
Area of mineral soil	0.31	0.58	0.91	1.18	1.59	2.04	2.55	3.11	3.74	4.43	4.97	5.72	6.42	7.33	8.34
Area of organic soil	NO														
Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
GM remain GM Total area	4289.06	4281.93	4276.02	4269.72	4263.81	4255.40	4249.53	4243.24	4237.20	4231.57	4225.96	4220.14	4214.80	4211.41	4207.83
Area of mineral soil	3924.82	3917.69	3913.26	3909.80	3905.34	3899.92	3896.12	3892.04	3888.36	3885.28	3882.37	3879.38	3876.81	3874.87	3873.19
Area of organic soil	364.24	364.24	362.76	359.92	358.48	355.48	353.41	351.19	348.84	346.29	343.58	340.77	337.99	336.53	334.64
GM to Settlement Total area	9.42	10.52	10.95	11.00	11.84	12.73	12.90	13.05	13.25	13.41	13.63	13.87	14.10	14.34	14.72
Area of mineral soil	9.42	10.52	10.95	11.00	11.84	12.73	12.90	13.05	13.25	13.41	13.63	13.87	14.10	14.34	14.72
Area of organic soil	NO														

## 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.

SEAI has a lead role in developing and maintaining comprehensive national and sectoral statistics for energy production, transformation and end use. This data is a vital input in meeting international reporting obligations, for advising policy makers and informing investment decisions. The Energy Policy Statistical Support Unit (EPSSU) is SEAI's specialist statistics team.

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>
- European Communities (Energy End-use Efficiency and Energy Services) Regulations 2009, (S.I. No. 542 of 2009).  
<http://www.irishstatutebook.ie/pdf/2009/en.si.2009.0542.pdf>
- Sulphur Content of Heavy Fuel, Gas Oil, and Marine Fuel Regulations 2008, (S.I. 119 of 2008). <http://www.irishstatutebook.ie/pdf/2008/en.si.2008.0119.pdf>

Further information on Ireland's Energy Statistics can be found here;

<https://www.seai.ie/data-and-insights/seai-statistics/key-publications/national-energy-balance/>

In this release we have also published significant revisions to the historical energy balances going back as far as 1990. This is because we have incorporated a major new data set on business energy use for the first time. This is the Business Energy Use Survey (BEUS), first published by the Central Statistics Office (CSO) in December 2018. This valuable new data source provides a new basis for the breakdown of energy use in the commercial services, public services and industrial sectors, at a level of detail not previously possible. SEAI have revised the National Energy Balances from 1990 to 2018 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.

There are some significant methodological differences between the BEUS and the National Energy Balances. These differences mean that the BEUS and the National Energy Balance data are not always directly comparable. To make use of the BEUS, the data needs to be carefully examined and compared on a fuel by fuel and sector by sector basis, and expert judgement is required to assess the most appropriate use of the data.

Due to the scale and importance of these revisions we have prepared a supporting report. This report explains the new data that is available, the methodology for incorporating it into the National Energy Balance, and a detailed comparison between the old and revised Energy Balance data for each fuel and sector. We have also made available a supporting excel spreadsheet comparing the old and revised data.

More information on the BEUS is also available directly from the CSO:

<https://www.cso.ie/en/methods/surveybackgroundnotes/businessenergyuse/>

### 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. SEAI submit annual and monthly energy statistics to Eurostat on energy supply, transformation and end-use for solid fuels, natural gas, electricity & heat and renewables & wastes (Oil statistics are supplied by DECC). This data is also used for Ireland's Energy Balance.

<http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32008R1099:EN:NOT>

- Information regarding gas and electricity prices is sent to Eurostat twice a year under the EU Gas and Electricity Price Transparency Directive 90/377/EEC.

[http://europa.eu/legislation\\_summaries/other/l27002\\_en.htm](http://europa.eu/legislation_summaries/other/l27002_en.htm)

### Department of Environment, Climate and Communications (DECC) - Oil Security Division

The Oil Security Division of the Department of Communications, Energy and Natural Resources is responsible for the development and implementation of Ireland's strategic oil supply policy, with particular regard to the areas of contingency planning and Ireland's obligations under the EU and International Energy Agency (IEA), in order to ensure an effective system of security of supply at times of physical oil supply disruption.

The National Oil Reserves Agency (NORA) is responsible for holding Ireland's strategic oil stocks for use in the event of a supply disruption. NORA is funded by a levy on disposals of petroleum products currently 2 cents per litre.

Oil Security Division collects monthly returns from oil companies and consumers on disposals of petroleum products and calculates the levy liability of each company. This is done under the NORA Act 2007 and associated returns and levy Regulations. A full list of legislation is available on the NORA website at [www.nora.ie](http://www.nora.ie)

Oil Security Division also provides Monthly Oil Statistics to the IEA and Eurostat.

## Solid Fuels & Petroleum Coke

### Fuels

- Bituminous Coal
- Anthracite
- Manufactured Ovoids
- Lignite
- Milled & Sod Peat
- Peat Briquettes
- Petroleum Coke

### Frequency

- Monthly solid fuel survey
- Annual CHP Survey

### Data Sources

This data collection is a monthly survey of solid fuel imports and producers to obtain solid fuel statistics as required under the European Energy Statistics Regulation of 2008, no.1099. This data is aggregated for the annual Energy Balance.

In the Energy Balance, anthracite and manufactured ovoids are combined to protect confidentiality.

### Estimations

Smaller solid fuel distributors are not surveyed. To cover these smaller units, a technique was developed in 2009 to estimate the total data for the smaller units. The estimation method used data from Ireland's National Statistical Institute (CSO) monthly trade statistics publication to identify overall solid fuel imports which in turn highlighted areas that were missing.

Sod Peat is currently estimated.

### Validation

These data are validated against the Emissions Trading Scheme data once it becomes available and there is a data point match. If there is a discrepancy between the ETS figure and the survey figure, the ETS figure is used as this has been audited by the Environmental Protection Agency.

### Sectoral Breakdown

The sectoral breakdown is sourced from the monthly solid fuel surveys, except for industry where this is sourced from ETS data for bituminous coal, milled peat and petroleum coke.

## Oil & Biofuels

### Fuels

- Crude Oil
- Refinery Gas
- Gasoline
- Kerosene

- Jet Kerosene
- Fueloil
- LPG
- Gasoil/Diesel/DERV
- Liquid Biofuel
- Bioethanol
- Biodiesel

### Frequency

- Monthly oil & biofuels survey
- Annual CHP Survey

### Data Sources

Oil data is collected monthly by the Department of Environment, Climate and Communications (DECC). Oil companies are required to report to DECC under the National Oil Reserves Agency Act 2007 (No. 7 of 2007) and the National Oil Reserves Agency Act 2007 (Returns and Levy) Regulations 2007 (S.I. 567 of 2007). Each oil company sends their monthly return to DECC in a prescribed Excel format. This data is then analysed and manually transferred to a single monthly Excel sheet called the OCS system. All fuels are collected in litres, except for LPG which is collected in tonnes. In March each year, DECC provide SEAI with all twelve OCS Excel sheets from the previous year. From the 2013 data collection a new online database, OLA, was rolled out to all companies. Data will be drawn from the OLA system rather than the OCS Excel spread sheets and will be provided to SEAI on this basis.

Liquid Biofuel data is collected monthly by DECC under the Biofuel Obligation Scheme introduced in the Energy (Biofuel Obligation and Miscellaneous Provisions) Act 2010 and is provided to SEAI on an annual basis.

Revenue excise data on oil (litres) is provided on a monthly basis to SEAI.

### Validation

Oil data are validated against the Emissions Trading Scheme data once it becomes available and there is a data point match. If there is a discrepancy between the ETS figure and the survey figure, the ETS figure is used as this has been audited by the Environmental Protection Agency.

### Sectoral Breakdown

Census of Industrial Production data may be used for the industry breakdown. A joint CSO/SEAI Business Energy Use Survey (BEUS) was introduced to address energy consumption in the commercial and industry sectors. The survey results are not available yet but will eventually replace the CIP when calculating the breakdown of the industry sub-sectors.

The TFC is split further as follows:

### Gasoline

- Total TFC sourced from Revenue excise data
- Transport
  - Road Private Car – calculated from vehicle stock and average annual consumption
  - Public Passenger Services – calculated from vehicle stock and average annual consumption
  - Domestic Aviation – sourced from Revenue excise data

- Fuel Tourism - estimates provided by the Department of the Environment, Climate and Communications
- Unspecified - remainder

### Kerosene

- Total TFC sourced from Revenue excise data
- Industry
  - Estimated as 10% of TFC
  - Industry sub sectors are calculated using the Heavy Fuel Oil split from the 2009 CIP
  - The new BEUS will improve on this estimate
- Residential
  - Estimated as 90% of TFC
  - The new BEUS will improve on this estimate

### Jet Kerosene

- Total TFC sourced from OCS system
- Transport
  - Domestic Aviation – Split based on EPA modelling
  - International Aviation – Split based on EPA modelling

### Fueloil

- Total TFC sourced from Revenue excise data plus ETS data
- Industry – total less 10 kilotonnes used in Commercial/Public Services sector
  - Total Basic metals and fabricated metal comes from ETS data.
  - The remaining sub sectors are calculated using the Heavy Fuel Oil split from the 2009 CIP after subtracting Basic metals
  - The new BEUS will improve on this estimate
- Commercial/Public Services – estimated as 10 kilotonnes

### LPG

- Total TFC sourced from OCS system
- Industry
  - Total industry based on supplier split from OCS sheets
  - Industry sub sectors calculated using the Derived Gas split from the 2009 CIP
- Transport
  - Sourced from Revenue data as a differential excise duty is charged
- Residential
  - Total residential based on supplier split from OCS sheets
- Commercial/Public Services
  - Total commercial/public services based on supplier split from OCS sheets

### Gasoil/Diesel/Derv

- Industry
  - Total industry estimated based on 1990 sector split (15% of Revenue gasoil less fuel input for electricity generation)
  - Industry sub sectors are calculated using the Gas Oil split from the 2009 CIP

- The new BEUS will improve on this estimate
- Transport
  - Road Freight – calculated from CSO tonne kilometres and European data on energy use per tonne kilometre
  - Road Private Car – calculated from vehicle stock and average annual consumption
  - Public Passenger Services – calculated from vehicle stock and average annual consumption plus Revenue excise data for buses
  - Rail – Provided by the rail network operator
  - Fuel Tourism - estimates provided by the Department of the Communications, Climate Action and Environment
  - Sourced from Revenue data as a differential excise duty is charged
  - Unspecified - remainder
- Residential
  - Total residential estimated based on 1990 sector split (19% of Revenue gasoil)
  - The new BEUS will improve on this estimate
- Commercial/Public Services
  - Total commercial/public services estimated based on 1990 sector split (44% of Revenue gasoil), less navigation and fisheries
  - The new BEUS will improve on this estimate
- Agriculture
  - Total agriculture estimated based on 1990 sector split (21% of Revenue gasoil)
- Fisheries
  - Sourced from Revenue data as a differential excise duty is charged

## Natural Gas

### Frequency

Monthly and annual surveys of Bord Gáis Networks

Annual CHP Survey

### Data Sources

Natural gas data is collected monthly and annually from Gas Networks Ireland (formerly Bord Gáis Networks). Gas Networks Ireland own, operate, build and maintain the natural gas network in Ireland and connect all customers to the network.

Supply data are collected in cubic metres and in gross energy units (Terajoules). Data on the demand side are received in TJ only.

### Validation

Data are validated against the Emissions Trading Scheme data once it becomes available and there is a data point match. If there is a discrepancy between the ETS figure and the survey figure, the ETS figure is used as this has been audited by the Environmental Protection Agency.

### Sectoral Breakdown

Census of Industrial Production data are used for the industry breakdown. A joint CSO/SEAI Business Energy Use Survey was introduced recently in order to address energy consumption in

the commercial and industry sectors. The survey results are not available yet but will eventually replace the CIP when calculating the breakdown of the industry sub-sectors.

## Renewables & Non-Renewable Waste

### Fuels

- Wind
- Hydro
- Biomass
- Renewable Waste
- Landfill Gas
- Biogas
- Solar
- Thermal
  - Photovoltaic
- Geothermal
- Non-Renewable Waste

### Frequency

Annual renewable surveys

Annual CHP survey

### Data Sources

Wind & Hydro

- Sourced from monthly electricity surveys – see electricity data collection

Wind (auto generation)

- Wind auto production data is sourced from annual surveys of the auto producers.

Biomass, Renewable Waste & Non-Renewable Waste

- Wood suppliers are surveyed annually; however there is usually a high non-response rate.
- Residential non-traded wood is calculated using estimation techniques.
- Boardmills and the major sawmills that use wood waste for energy are also surveyed.

The remaining smaller sawmills are estimated.

- The Environmental Protection Agency provides administrative data on some renewable and non-renewable waste.
- The Department of Agriculture, Food and the Marine provide administrative data on tallow used for energy purposes.
- Biomass and waste data are validated against the Emissions Trading Scheme data once it becomes available and there is a data point match. If there is a discrepancy between the ETS figure and the survey figure, the ETS figure is used as this has been audited by the Environmental Protection Agency.

Landfill Gas

- Landfill Gas data is sourced from annual surveys of landfill gas operators and from administrative data provided by the Environmental Protection Agency.

#### Biogas

- Biogas data is sourced from annual surveys of sludge biogas installations and other biogas installations in Ireland

#### Solar

- Solar thermal contribution to energy in Ireland is calculated on an annual basis from administrative data. Data for retrofits on older buildings comes from government grant schemes administered by SEAI since 2006 both for residential and commercial properties. Solar statistics on new residential buildings in Ireland is sourced from the Building Energy Rating system which is also administered by SEAI.

#### Geothermal

- Geothermal contribution to energy in Ireland is calculated on an annual basis from administrative data. Data for retrofits on older buildings comes from government grant schemes administered by SEAI since 2006 both for residential and commercial properties. However, the residential grants ended in 2011 and SEAI have been working on a new source for this data.

## Electricity

### Frequency

Monthly electricity generator survey

Monthly TSO survey

Quarterly electricity retail market reports

### Data Sources

Electricity Supply data is collected through a monthly survey of all electricity generators and the Transmission System Operator (Eirgrid) as required under the European Energy Statistics Regulation of 2008, no.1099. This data is aggregated for the annual Energy Balance.

The electricity generator survey is a business survey of all of the main activity electricity producers in Ireland. The Transmission System Operator survey is an administrative survey as this is data collected or generated by the TSO.

Since 2012, electricity consumption data is sourced from the quarterly Electricity and Gas Retail Markets Annual Report which is published by the Commission for Energy Regulation. Prior to this, each electricity supplier was surveyed annually for consumption data.

### Validation

The electricity generator data are validated against the Emissions Trading Scheme data on fuel inputs once available. If there is a discrepancy between the ETS figure and the survey figure, the ETS figure is used as this has been audited by the Environmental Protection Agency.

### Sectoral Breakdown

Census of Industrial Production data are used for the industry breakdown. A joint CSO/SEAI Business Energy Use Survey was introduced recently in order to address energy consumption in the commercial and industry sectors. The survey results are not available yet but will eventually replace the CIP when calculating the breakdown of the industry sub-sectors.

## Annex 5.1 UNFCCC review recommendations responses

Sector/ID	Issue	Recommendation	ERT assessment and rationale	Party response	NIR Section	Status
G.1	Article 3, paragraph 14, of the Kyoto Protocol (G.11, 2018) KP reporting adherence	Report in the NIR any change in the information provided under Article 3, paragraph 14, of the Kyoto Protocol in accordance with decision 15/CMP.1 in conjunction with decision 3/CMP.11.	Resolved. The Party reported that there are no changes to the information since the previous submission relating to Article 3, paragraph 14, of the Kyoto Protocol in its NIR (p.364).	NA	-	Resolved
G.2	Key category analysis (G.5, 2018) (G.7, 2016) (G.7, 2015) (table 4 and para. 77, 2014) Transparency	Include a paragraph explaining the assessment of key categories for KP-LULUCF activities in chapter 11 of the NIR.	Resolved. The Party reported in chapter 11 of its NIR (pp.322–323) the assessment of key categories for KP-LULUCF activities.	NA	-	Resolved
G.3	Key category analysis (G.7, 2018) Convention reporting adherence	Provide a summary table for the key category analysis for the latest reporting year (by level and trend) in accordance with the UNFCCC Annex I inventory reporting guidelines.	Resolved. The Party reported a summary table for the key category analysis in its NIR (annex 1, section 1.G) in addition to CRF table 7.	NA	-	Resolved
G.4	KP-LULUCF supplementary information (G.6, 2018) (G.9, 2016) (G.9, 2015) Transparency	Include the value of the FM cap in the NIR and in the CRF accounting table, together with information on its calculation.	Addressing. The Party reported the FM cap in the CRF accounting table but not in the NIR. During the review, the Party clarified that it will endeavour to include details of the FM cap and information on its calculation in its next NIR. The ERT considers that the recommendation has not yet been addressed because the Party has not yet reported information on the FM cap or its calculation in the NIR	-	-	-
G.5	NIR (G.3, 2018) (G.4, 2016) (G.4, 2015) (table 3, 2014) Transparency	Improve the descriptions in the NIR of the use of EU ETS data in the energy sector and the assumptions and methodologies used for estimating emissions.	Resolved. The Party improved its reporting regarding identified transparency issues (see ID# E.7 and W.2). During the review, Ireland highlighted the improved descriptions, including assumptions and methodologies used for estimating emissions in the NIR of its use of EU ETS data (i.e. in the energy chapter (sections 3.1.2, 3.1.3, 3.2.4 and 3.2.5) and the IPPU chapter (section 4.2)). The ERT considers that the Party has addressed the recommendation and instances where transparency regarding the use of EU ETS data can be improved are covered under the findings on the energy sector (see ID# E.2 below).	NA	-	Resolved

Sector/ID	Issue	Recommendation	ERT assessment and rationale	Party response	NIR Section	Status
G.6	Notation keys (G.2, 2018) (G.2, 2016) (G.2, 2015) (table 3, 2014) Comparability	Improve the use of notation keys.	Resolved. Ireland has improved the consistency of its use of notation keys between the NIR and the CRF tables (see ID# E.7 and E.13 below). The ERT considers that there is no general issue regarding the Party's use of notation keys and that sector-specific issues with notation keys, if any, can be addressed under the relevant recommendations or encouragements.	NA	-	Resolved
G.7	Notation keys (G.10, 2018) Transparency	Reconcile and cross-check the information reported in section 1.8 and table 1.14 with information reported elsewhere in the NIR and the CRF tables and apply the notation keys "NO", "NA" and "NE", where relevant, instead of providing partial reporting. Explain why the reporting on CH4 and N2O emissions for the categories referred to was incomplete	Addressing. During the review, the Party clarified that NIR table 1.14, on summary of completeness, has not been reconciled and cross-checked for the current submission and as a result, some information is incorrect, such as the reporting on completeness under category 2.A for gases that are not applicable. The ERT noted that the Party has improved completeness, for example by reporting N2O from natural gas flaring (category 1.B.2) in the NIR (chap. 3, section 3.3.2.2), but has not updated NIR table 1.14 for summarizing completeness. The ERT considers that the recommendation has not yet been fully addressed because the some of the previously identified inconsistencies remain.	-	-	-
G.8	Uncertainty analysis (G.8, 2018) Convention reporting adherence	Enhance QA/QC procedures and ensure that the tables containing the results of the uncertainty analysis represent the entire inventory.	Resolved. The Party has enhanced its QC procedures and corrected the headings of NIR tables 1.12 and 1.13 (pp.33–40) and NIR tables 2.A. and 2.B in annex 2 to make it clear that the tables contain the results of an uncertainty analysis representing the entire inventory; that is, including all emission and removal categories as required by paragraphs 15 and 25(c) of the UNFCCC Annex I inventory reporting guidelines.	-	-	Resolved
G.9	Uncertainty analysis (G.9, 2018) Convention reporting adherence	In addition to reporting the uncertainty assessment for the latest inventory year and the trend uncertainty between 1990 and the latest inventory year, include the results of the base-year uncertainty analysis in the NIR.	Resolved. The Party reported the results of the base-year uncertainty analysis with and without LULUCF in its NIR (tables 1.12 and 1.13 and annex 2).	-	-	Resolved
G.10	CPR. KP reporting adherence	The ERT recommends that the Party, in future annual submissions, present the calculation of the CPR and ensure that the comparison calculation uses the most recent GHG inventory	The Party reported the calculation of the CPR in its NIR (pp.355–366) by referencing a link to document FCCC/IRR/2016/IRL. It did not present the actual calculation of the CPR using the most recent inventory in the NIR (i.e. 2018 GHG emissions excluding LULUCF in the current submission), which is not in accordance with decision 15/CMP.1, in conjunction with 3/CMP.11, annex, paragraph 18. During the review, Ireland provided the ERT with the updated calculation using the current submission to confirm the information that should be included. The ERT acknowledges that updating the calculation will not change the CPR.	-	-	-

Sector/ID	Issue	Recommendation	ERT assessment and rationale	Party response	NIR Section	Status
G.11	Recalculations. Transparency	The ERT recommends that the Party provide in the NIR explanatory information and justifications for the recalculations in accordance with the UNFCCC Annex I inventory reporting guidelines, paragraphs 43–45 and 50(h).	The Party has improved its inventory and implemented recalculations for the energy and IPPU sectors. However, the NIR did not include explanations or sufficient explanations on justifications and reasons for recalculations (see ID#s E.22, E.23, E.24, E.25 and L.15 below). This is not in accordance with the UNFCCC Annex I inventory reporting guidelines, paragraphs 43–45 and 50(h), as recalculations shall be reported in the NIR for all applicable years with explanatory information and justifications.	Recalculations are reported in the NIR 2021 for all applicable years with explanatory information and justifications.	-	-
G.12	Uncertainty analysis. Transparency	The ERT recommends that the Party report the underlying assumptions informing the uncertainty estimates in the NIR for category 1.B.2 and subcategories under 3.A, 3.B, 3.D, 3.G, 3.H and 5.B.1.	The Party reported uncertainty estimates for all source and sink categories, including methods, base year, latest year and trend uncertainty, using approach 1 outlined in the 2006 IPCC Guidelines, vol. 1, chap. 3 in its NIR (pp.24–26 and annex 2). For some categories, Ireland did not transparently report on underlying assumptions. For some categories, it provided a table in the NIR noting underlying assumptions, including source and reference information (e.g. for forest land remaining forest land (p.207) and deforested lands (p.223)), but provided no information on underlying assumptions for category 1.B.2, and subcategories under 3.A, 3.B, 3.D, 3.G, 3.H and 5.B.1. This is not in accordance with the UNFCCC Annex I inventory reporting guidelines, paragraph 42. During the review, the Party clarified that it does not have plans to further update the approach to explaining the uncertainty analysis in the NIR but will try to report more information to improve transparency.	-	-	-
E.1	1.A.1.a Public electricity and heat production – biomass – CH4 and N2O (E.12, 2018) Transparency	Include in the next NIR information on the applied EFs and energy consumption values for the individual biomass fuels.	Resolved. The Party reported in its NIR (p.73) additional information on the EFs and energy consumption values for individual biomass fuels.	-	-	Resolved

Sector/ID	Issue	Recommendation	ERT assessment and rationale	Party response	NIR Section	Status
E.2	1.A.1.b Petroleum refining – gaseous fuels – CO2 (E.3, 2018) (E.15, 2016) (E.15, 2015) Transparency	Provide an explanation of the low IEF for gaseous fuels and investigate the reason for the differences in the breakdown of fuels, especially for refinery gas and natural gas, used in refining between the EU ETS and SEAI data and report the results of the investigation in the NIR together with the proper allocation of fuels among fuel categories; and transparently describe in the NIR the AD and method used for the estimation of CO2 emissions.	Addressing. The Party reported in its NIR (p.75) that since activity data is derived from the energy balance and CO2 emissions originate from ETS the resulting CO2 IEF fluctuate significantly. The Party also reported that the issue regarding national energy balance fuel proportions in comparison with EU ETS data is still to be resolved. During the review, the Party clarified that historical emissions that have been reported since 2005 under category 1.A.1.b are based on country-specific and plant-specific data, which are in turn independently verified (EU ETS data). The Party acknowledged that the historical IEF trends within category 1.A.1.b may not be in line with the emissions. This is a result of applying the TJ values calculated using a different collection method used by the national energy statistics provider in order to balance the fuel data as a whole for the entire energy sector. This means that there were two different collection systems for similar data, whereby verified EU ETS data takes precedence for the reporting of emissions. Ireland explained that it is very difficult for various reasons to retrospectively align AD from the two collection systems for historical years, given the relatively small amount of energy (0.9 per cent of energy sector AD in 2018). The Party discussed this issue recently with the national energy statistics provider and is better placed to trace and align the AD attributed to category 1.A.1.b for future reporting as a result of requesting specific breakdown data from both sources. The Party has now retrospectively aligned the data for 2013 onward and this will be reflected in the next submission. The ERT considers that the recommendation has not yet been fully addressed because the Party has not yet provided an explanation of the low CO2 IEF for gaseous fuels and the results of the investigation on the differences in the breakdown of fuels between SEAI and the EU ETS and the allocation of fuels among fuel categories. The ERT notes the Party's intention to provide an update its next submission.	-	-	-
E.3	1.A.3.a Domestic aviation – liquid fuels – CO2 (E.4, 2018) (E.16, 2016) (E.16, 2015) Transparency	Provide information in the NIR on which category includes CH4 and N2O emissions from aviation gasoline.	Resolved. The Party explained in its NIR (pp.80–81) that the EUROCONTROL advanced emission model does not split CH4 and N2O emissions between jet kerosene and gasoline, and that its use of aviation gasoline is minimal. Therefore, Ireland reported aviation gasoline as “IE” and included the emissions under jet kerosene.	-	-	Resolved
E.4	1.A.3.a Domestic aviation – liquid fuels – CO2, CH4 and N2O (E.13, 2018) Transparency	Include in the NIR information on the Irish Aviation Authority data and the approach used to implement the tier 3a methodology from the EMEP/EEA air pollutant emission inventory guidebook 2016.	Resolved. The Party updated its approach from a tier 3a to a tier 3b methodology and described the new approach in its NIR (pp.80–84).	-	-	Resolved

Sector/ID	Issue	Recommendation	ERT assessment and rationale	Party response	NIR Section	Status
E.5	1.A.3.a Domestic aviation – liquid fuels – CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O (E.14, 2018) Accuracy	Revise the definition of domestic flights and include all flights according to the definition of domestic aviation in the 2006 IPCC Guidelines; discuss with the Irish Aviation Authority whether there are any domestic flights (as defined by the 2006 IPCC Guidelines) that are not included in the provided data, and, if there are, provide estimates or collect additional data on fuel consumption and emissions for those flights (especially training flights).	Resolved. The Party reported in its NIR (pp.80–84) an update to its approach from a tier 3a to a tier 3b methodology. During the review, the Party clarified that the method was updated to capture the additional flights and emissions that were missed using the tier 3a methodology.	-	-	Resolved
E.6	1.A.3.b Road transportation – biomass – CH <sub>4</sub> and N <sub>2</sub> O (E.15, 2018) Transparency	Include in the NIR information on the COPERT calibration procedure for adjusting the average annual mileage based on the statistical fuel consumption and describe the estimation approach applied for biofuels.	Addressing. The Party reported in its NIR (p.92) that the option to balance the mileage on the basis of statistical fuel consumption in the COPERT 5 model was selected. The Party also reported that 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. During the review, Ireland clarified that 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 and the emissions are calculated as a whole (i.e. fossil + 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. Ireland also clarified that, in terms of calibration, it follows the formal step-by-step process that is built within the software and that cross checks are carried out to ensure mileage is adjusted by comparing the input data with the updated modified data. The Party further clarified that it will include this information in the next submission. The ERT considers that the recommendation has not yet been fully addressed because the Party has not transparently described in its NIR the calibration procedure used.	-	-	-
E.7	1.A.3.e Other transportation – liquid fuels – CO <sub>2</sub> (E.5, 2018) (E.6, 2016) (E.6, 2015) (30, 2014) Comparability	Review the notation key used to report liquid fuels and, as appropriate, change the notation key from “NO” to “IE”, and provide a transparent description of the basis for dividing fuel consumption between road and non-road traffic.	Resolved. The Party described its use of notation keys for this source category in its NIR (pp.96–97). It indicated that it reported emissions from liquid fuels as “NO” as there are no known emissions related to off-road vehicles for other transportation	-	-	Resolved

Sector/ID	Issue	Recommendation	ERT assessment and rationale	Party response	NIR Section	Status
E.8	1.A.3.e.i Pipeline transport – gaseous fuels – CH4 and N2O (E.16, 2018) Accuracy	Update the currently applied EFs to the default EFs from the 2006 IPCC Guidelines (vol. 2, chap. 2, table 2.2), which are 1.0 and 0.1 kg/TJ for CH4 and N2O, respectively, and provide the relevant reference in the NIR.	Resolved. The Party used default EFs from the 2006 IPCC Guidelines and referred to their use in the NIR (pp.96–97).	-	-	Resolved
E.9	1.A.5 Other (not specified elsewhere) – all fuels – CO2, CH4 and N2O (E.6, 2018) (E.17, 2016) (E.17, 2015) Transparency	Include the information on the allocation of emissions and the AD and resulting emissions for subcategories 1.A.5.a (stationary) and 1.A.5.b (mobile) provided during the review (i.e. fuel associated with military vehicles is included in category 1.A.3 (transport) and fuel associated with military bases is included in category 1.A.4.a (commercial/institutional)).	Addressing. The Party reported in its NIR (p.99) that other emissions (category 1.A.5) are included in categories 1.A.4.a and 1.A.3 as Ireland’s national statistics and the EUROCONTROL Advanced Emission Model do not provide a split for these minor sources. It is reported in CRF table 9, that emissions for category 1.A.5.b are included in transport (1.A.3). However, no information was reported in CRF table 9 on the reporting of “IE” for category 1.A.5.a. During the review, the Party clarified that CRF table 9 was not complete for category 1.A.5.a owing to importing issues with CRF Reporter and indicated that the issue will be resolved in its next submission. The ERT considers that the recommendation has not yet been fully addressed because the Party has not yet included in CRF table 9 all information on where emissions for category 1.A.5.a are included.	-	-	Resolved
E.10	1.B.1.a Coal mining and handling – solid fuels – CH4 (E.17, 2018) Transparency	Describe in the NIR the national circumstances surrounding abandoned coal mines (e.g. no history of explosions and the depth of the coal seam) to justify the choice of EF.	Resolved. The Party expanded the description in its NIR (p.101) on the national circumstances surrounding abandoned coal mines, including information about mine depths and the history of few explosions and outbursts.	-	-	Resolved
E.11	1.B.2 Oil, natural gas and other emissions from energy production – gaseous fuels – CO2 and CH4 (E.7, 2018) (E.7, 2016) (E.7, 2015) (31, 2014) Transparency	Provide an explanation of where fugitive emissions of CH4 and CO2 from natural gas exploration and transmission are reported both in the CRF tables and in the NIR, and provide a detailed description in the NIR of how the emissions from each activity are estimated.	Addressing. The Party reported in its NIR (pp.103–104) an expanded description of how fugitive emissions of CH4 and CO2 from natural gas transmission are calculated. It explained that they were reported together with emissions from natural gas distribution owing to the source data being reported together for these two sources. Regarding emissions from natural gas exploration, the Party reported CO2 emissions as “NO” and CH4 emissions as “IE”, indicating in CRF table 1.B.2 that CH4 emissions were reported under production (category 1.B.2.b.2). During the review, the Party clarified that CO2 emissions from natural gas exploration are not estimated but they may not occur because the heavy drilling muds used during exploratory drilling may prevent hydrocarbons from escaping the well. The Party informed the ERT that it will include a description in the NIR regarding emissions from exploration in its next submission.. The ERT considers that the recommendation is not yet fully resolved because a justification for reporting CO2 emissions as NO and a description of how the CH4 emissions from natural gas exploration are estimated is not included in the NIR.	A description is now included in NIR section 3.3.2.2.1 regarding exploration and emissions from exploration are reported as NO. Emissions from transmission are now reported separately to Distribution.	NIR Chapter 3 section 3.3.2.2.1	Resolved

Sector/ID	Issue	Recommendation	ERT assessment and rationale	Party response	NIR Section	Status
E.12	1.B.2 Oil, natural gas and other emissions from energy production – gaseous fuels – CO2 and CH4 (E.8, 2018) (E.8, 2016) (E.8, 2015) (32, 2014) Transparency	Explain where fugitive CO2 emissions from natural gas and fugitive CH4 emissions from venting and flaring are allocated in the CRF tables.	Resolved. The Party expanded section 3.3.2.2 of the NIR (pp.102–106) and stated that fugitive CO2 emissions from natural gas are included under category 1.B.2.b.5 (distribution) and CH4 emissions from venting and flaring are reported under 1.B.2.c (venting and flaring) in CRF table 1.B.2. The Party improved its reporting by providing numerical values for CH4 emissions from venting and flaring in CRF table 1.B.2, instead of a notation key.	-	-	Resolved
E.13	1.B.2 Oil, natural gas and other emissions from energy production – gaseous fuels – CO2 and CH4 (E.10, 2018) (E.9, 2016) (E9, 2015) (32, 2014) Convention reporting adherence	Use the notation keys consistently between the NIR and the CRF tables for CO2 emissions from natural gas and CH4 emissions from venting and flaring (“NO” in NIR table 3.1 and “IE” in CRF table 1.B.2).	Resolved. The Party reported notation keys consistently between its NIR (pp.102–106) and CRF table 1.B.2.	-	-	Resolved

Sector/ID	Issue	Recommendation	ERT assessment and rationale	Party response	NIR Section	Status
E.14	1.B.2.b Natural gas – gaseous fuels – CO2 (E.9, 2018) (E.18, 2016) (E.18, 2015) Completeness	Report CO2 emissions from natural gas exploration and processing	<p>Not resolved. The Party reported CO2 emissions from natural gas exploration as “NO” and CO2 emissions from gas processing as “IE” in CRF table 1.B.2. It explained in its NIR (pp.102–103) that CO2 emissions from processing were conservatively assumed to be CH4 and therefore CO2 emissions were included with CH4 emissions from natural gas processing. The ERT noted that CH4 emissions from natural gas processing were also reported as “IE”.</p> <p>During the review, the Party clarified that CO2 emissions from natural gas exploration are not estimated but they may not occur because the heavy drilling muds used during exploratory drilling may prevent hydrocarbons from escaping the well. Regarding CO2 emission from processing, the Party provided an analyses of the gas stream composition after processing at the entry points into the gas network; however, it was unable to provide data on the gas composition prior to processing. As CO2 is often removed during processing, these analyses were unable to provide the CO2 composition of the unprocessed natural gas streams. During the review, Ireland indicated that CO2 emissions for categories 1.B.2.b.2 and 1.B.2.b.3 should be reported as “NE” and informed the ERT that it will report emissions from these sources as “NE” in its next submission.</p> <p>The ERT considers that the recommendation has not yet been addressed because the Party has not yet adequately or transparently reported CO2 emissions from natural gas exploration and processing. If CO2 emissions from exploration are reported as “NO” the Party should provide a justification to confirm that emissions have not been underestimated. If CO2 emissions from processing are reported as “NE” the Party should demonstrate in its NIR that the sources are below the significance threshold and are eligible to be reported as “NE”.</p>	Emissions of CO2 from categories 1.B.2.b.2 and 1.B.2.b.3 are reported as “NE” and justification is provided in NIR section 3.3.2.2.2 which demonstrates that these emissions are below the significance threshold.	NIR Chapter 3 Section 3.3.2.2.2	-
E.15	1.B.2.b Natural gas – gaseous fuels – CO2 and CH4 (E.18, 2018) Transparency	Include in the NIR the information provided during the review on the Kinsale storage facility (e.g. type of facility and methodology for assessing the emissions from it), clarifying that the emissions from underground storage of natural gas are included under production of natural gas.	Resolved. The Party included information in its NIR (pp.103–104) about the Kinsale storage facility and where emissions are reported. According to the information provided in the NIR, emissions from underground storage are covered under venting of natural gas. The Party explained that emission estimates for this facility, including data from the offshore venting of gas, are reported to the Department of Communications Climate Action and Environment under the Convention for the Protection of the Marine Environment of the North-East Atlantic.	-	-	Resolved

Sector/ID	Issue	Recommendation	ERT assessment and rationale	Party response	NIR Section	Status
E.16	1.B.2.b Natural gas – gaseous fuels – CO2 and CH4 (E.19, 2018) Completeness	Estimate CO2 and CH4 emissions from natural gas production and CH4 emissions from natural gas processing applying the default EFs and methodologies from the 2006 IPCC Guidelines (vol. 2, chap. 4, table 4.2.4); if any category is determined to be below the significance threshold, as defined in paragraph 37(b) of the UNFCCC Annex I inventory reporting guidelines, report “NE” for the category and provide appropriate documentation in the NIR.	<p>Addressing. The Party reported CH4 emissions for natural gas production and processing together under the production subcategory (1.B.2.b.2). The Party also reported CO2 emissions from natural gas production (1.B.2.b.2) and processing (1.B.2.b.3) as “IE” and stated in the NIR (pp.102–103) that emissions from natural gas production and processing are conservatively assumed to be CH4 (i.e. CO2 emissions are reported as CH4 emissions under category 1.B.2.b.2).</p> <p>The Party further reported in the NIR (pp.103) that the default EFs were not applied for estimating natural gas production and processing emissions; however, the Party used plant-specific EFs derived from the average emissions from monitored data measured in 2017 and 2018. Ireland indicated that the default EFs were not appropriate and would lead to significant overestimation if used.</p> <p>The ERT considers that the recommendation has not yet been fully addressed because the Party has not sufficiently documented CO2 emissions from natural gas production. The ERT also considers that assuming CO2 emissions are covered by overestimating CH4 emissions is not good practice. If CO2 emissions are not estimated, they should be reported as “NE” and a justification should be provided in the NIR to demonstrate that the source is below the significance threshold as defined in paragraph 37(b) of the UNFCCC Annex I inventory reporting guidelines.</p>	<p>CH4 emissions for natural gas production and processing are reported together under the production sub category (1.B.2.b.2). Emissions of CO2 from categories 1.B.2.b.2 and 1.B.2.b.3 are reported as NE and justification is provided in NIR which demonstrates these emissions are below the significance threshold.</p>	NIR Chapter 3 Section 3.3.2.2.2	-
E.17	1.B.2.b Natural gas – gaseous fuels – CO2 and CH4 (E.20, 2018) Transparency	Update the description in the NIR of the method, AD and EFs used to estimate fugitive CO2 and CH4 emissions from natural gas transmission (the estimates were revised in response to the list of potential problems and further questions from the ERT).	<p>Addressing. The Party expanded the description in its NIR (pp.103–104) of the methods, AD and EFs used for estimating CO2 and CH4 emissions from natural gas transmission.</p> <p>During the review, the Party clarified that Gas Networks Ireland performs a monthly analysis of the separate gas streams and provides 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 calculate EFs 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.</p> <p>The ERT considers that the recommendation has not yet been fully addressed because the Party has not yet included sufficient detail on the methods, AD and EFs used for calculating CO2 and CH4 emissions from natural gas transmission in its NIR. The Party should include the information provided during the review in its next submission.</p>	<p>Ireland has updated its description of AD and Efs used to estimate fugitive emissions from natural gas transmission and distribution in NIR sections 3.3.2.2.3 and 3.3.2.2.4</p>	NIR Chapter 3 section 3.3.2.2.3 and 3.3.2.2.4	-

Sector/ID	Issue	Recommendation	ERT assessment and rationale	Party response	NIR Section	Status
E.18	1.B.2.b Natural gas – gaseous fuels – CO2 and CH4 (E.21, 2018) Transparency	Update the description in the NIR of the method, AD and EFs used to estimate fugitive CO2 and CH4 emissions from natural gas distribution (the estimates were revised in response to the list of potential problems and further questions from the ERT).	Addressing. The Party expanded the description in its NIR (p.104) of the methods, AD and EFs used for estimating CO2 and CH4 emissions from natural gas distribution. During the review, the Party clarified the source of the EFs. Gas Networks Ireland performs a monthly analysis of the separate gas streams and provides 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 calculate EFs 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. The ERT considers that the recommendation has not yet been fully addressed because the Party has not yet included in its NIR the sources of the EFs (provided during the review) used for estimating emissions from natural gas distribution for 2010–2018.	Ireland has updated its description of AD and Efs used to estimate fugitive emissions from natural gas transmission and distribution in NIR sections 3.3.2.2.3 and 3.3.2.2.4	NIR Chapter 3 section 3.3.2.2.3 and 3.3.2.2.4	-
E.19	1.B.2.c Venting and flaring – gaseous fuels – CH4 and N2O (E.22, 2018) Completeness	Either report CH4 and N2O emissions from flaring in the Kinsale gas field using available AD and the EFs provided in the 2006 IPCC Guidelines (vol. 2, chap. 2, table 2.2) (namely 1.0 and 0.1 kg/TJ for CH4 and N2O, respectively), or, if emissions are determined to be insignificant in accordance with paragraph 37(b) of the UNFCCC Annex I inventory reporting guidelines, report them as “NE” and include appropriate justification in the NIR.	Resolved. The Party reported CH4 and N2O emissions from flaring in CRF table 1.B.2 under category 1.B.2.c (venting and flaring) and updated the methodology reported in its NIR (pp.104–105).	-	-	Resolved

Sector/ID	Issue	Recommendation	ERT assessment and rationale	Party response	NIR	
					Section	Status
E.20	Comparison with international data – liquid fuels. Not an issue/problem	The ERT encourages the Party to provide an update on the efforts to align IEA and inventory data, and to include in the NIR any explanations for significant differences between the data reported to IEA and data reported in the CRF tables.	<p>There are discrepancies between the data reported by Ireland to the IEA and the inventory data in CRF table 1.D for international marine bunkers. The data reported in the inventory for residual fuel oil are systematically greater by 3–4 per cent for until 2012, 5 per cent for 2013–2014 and 3 per cent for 2015 onward. For gas/diesel oil, the data are within 2 per cent for all years except 2002 (–4 per cent). These differences were not discussed in the NIR and could not be addressed during the review owing to an ongoing investigation by Ireland into these differences.</p> <p>During the review, the Party clarified that SEAI is investigating differences between data reported to the IEA and data used in the inventory and will be revising international data for all years to better align marine bunker values in the energy balance. The Party also indicated that it did not intend to discuss these checks and revisions to reference approach data in the next submission but will be including revised data for the reference approach.</p> <p>The ERT noted that the inventory agency does not currently have access to the submissions made to IEA and has been unable to undertake comparisons. It also noted that the inventory agency has been working with SEAI, which compiles the data for submission to IEA, to confirm quantities of fuel. SEAI has advised that it will revise the data for submission to IEA to match the inventory values.</p>	-	-	-
E.21	1.A Fuel combustion – sectoral approach – liquid fuels – CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O Transparency	The ERT recommends that Ireland provide in the NIR a description of the research project on AD for off-road vehicles and other machinery and how it will be implemented in order to improve emission estimates for off-road vehicles and other machinery reported under categories 1.A.2 and 1.A.4. If the notation key “IE” is used to report emissions from off-road vehicles and other machinery, the ERT also recommends that Ireland provide information in CRF table 9 on where these emissions are included in the inventory.	<p>Ireland reported emissions from liquid fuel use in off-road vehicles and other machinery in categories 1.A.2.g.vii, 1.A.4.a.ii and 1.A.4.b.ii as “IE”. For 1.A.4.c.ii, emissions are reported for diesel oil while emissions of all other liquid fuels are reported as “NO”. Moreover, for emissions reported as “IE” the Party did not provide information on where these emissions were included in CRF table 9 or in the NIR.</p> <p>During the review, the Party explained that a research project is under way looking at AD for the purpose of improving the reporting of emissions for subcategories concerning off-road vehicles and other machinery (1.A.2.g.vii, 1.A.4.a.ii, 1.A.4.b.ii and 1.A.4.c.ii) and splitting emissions across these categories.</p> <p>The ERT could not identify a description of these planned improvements in the NIR. On page 99 it is stated that there were no planned improvements for category 1.A.4, and the planned improvements for category 1.A.2 discussed in the NIR (p.79) did not appear to reference this research project.</p>	-	-	-

Sector/ID	Issue	Recommendation	ERT assessment and rationale	Party response	NIR Section	Status
E.22	1.A.1.a Public electricity and heat production – other fossil fuels and biomass – CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O -Transparency	The ERT recommends that Ireland expand the description of the methodology for estimating emissions from public electricity and heat production to include AD related with the use of waste for electricity and heat production and EFs used.	The Party described in the NIR (p.74) how estimates for public electricity and heat production were recalculated due to available revised data for waste-to-energy plants. During the review, the Party clarified that the revisions were the result of SEAI revising the net calorific value for municipal solid waste at one plant for the time series. It added that EPA has changed the way it estimates CO <sub>2</sub> emissions; it now uses data from the European Pollutant Release and Transfer Register for both waste-to-energy plants. The ERT could not identify this information on the methodology in the NIR. During the review, the Party stated that it will include information on the updated methodology in the NIR of its next submission.	-	-	-
E.23	1.A.1.b Petroleum refining – gaseous fuels – CH <sub>4</sub> and N <sub>2</sub> O. Transparency	The ERT recommends that Ireland document in its NIR the recalculations carried out for this category, including cause and impact, and demonstrate that they are applied consistently and accurately.	The Party reported no changes to estimates for this category in its NIR (pp.75); however, the ERT noted an unexplained recalculation that resulted in a decrease of 377.57 TJ (-6.18 per cent) in estimated gaseous fuel consumption for 2017 between the 2020 and the 2019 submissions. There were similar decreases in the estimated CH <sub>4</sub> , N <sub>2</sub> O and non-methane volatile organic compound emissions for this source, but CO <sub>2</sub> emissions did not change as the estimates are based on plant-specific EU ETS data. The ERT noted that the Party did not transparently describe the recalculations that occurred and did not demonstrate that the recalculations were applied consistently and carried out to improve accuracy and/or completeness. During the review, the Party confirmed that the CO <sub>2</sub> emission estimates are based on verified EU ETS data for 2005–2018, and that these data have not been revised. Conversely, SEAI provides an energy balance that EPA uses to calculate non-CO <sub>2</sub> emissions, and recalculations have occurred in this time series.	-	-	-
E.24	1.A.2 Manufacturing industries and construction – liquid, gaseous, biomass and other fossil fuels – CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O. Transparency	The ERT recommends that Ireland transparently document recalculations in its NIR, including the specific reasons for the recalculations, and demonstrate that they have been applied consistently and accurately. The ERT also recommends that any plans for future recalculations, including those to replace data derived from expert judgment and/or interpolation where other data are not available, be included in the next submission.	The Party reported in its NIR (p.79) that emissions from gaseous fuels were recalculated for 2009, 2013 and 2015, and emissions from fuel oil, biomass and other non-renewable waste were recalculated for 2017. The Party described the effects of these recalculations; however, it did not provide the reasons for the recalculations. During the review, the Party clarified that the recalculations of emissions from gaseous fuels were the result of corrected AD within this category, which can vary slightly in retrospect as a result of receiving delayed survey data, corrected values from the operators and other new sources of data that were unavailable at the time of the previous submission. Recalculations of emissions from fuel oil, biomass and other non-renewable waste were caused by delayed delivery of data regarding the national energy statistics. The data for 2017 in the previous submission that were estimated by expert judgment and interpolation were replaced by these delayed data.	-	-	-

Sector/ID	Issue	Recommendation	ERT assessment and rationale	Party response	NIR Section	Status
E.25	1.A.3.a Domestic aviation – liquid fuels – CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O. Transparency	The ERT recommends that Ireland transparently document recalculations in its NIR, including the specific cause or causes of the recalculation. The ERT also recommends that Ireland transparently document in the NIR the methods and assumptions used in the model to calculate emissions for category 1.A.3.a.	The Party carried out various minor recalculations to jet kerosene reported under category 1.A.3.a (domestic aviation) in CRF table 1.A(a)s3. In its NIR (pp.84), Ireland described the impact on the time series 1990–2004 of incorporating minor revisions to average fuel burn landing and take-off rates for some Irish airports. During the review, the Party explained that the revisions to the average fuel burn landing and take-off rates at Cork and Shannon airports were previously based on an average of EUROCONTROL data for 2005–2010, whereas the landing and take-off rates at all other regional airports were based on an average of data for 2004–2010. Revisions to the time series were the result of updating the average to 2004–2010 to correct the inconsistency. The ERT considers that the causes of the recalculations were not described transparently in the NIR. Additionally, the method of using the average of EUROCONTROL data for 2004–2010 was not described in the NIR.	-	-	-
E.26	1.B.2.b Natural gas – gaseous fuels – CO <sub>2</sub> and CH <sub>4</sub> . Comparability	The ERT recommends that Ireland use the Gas Networks Ireland data to report emissions from natural gas transmission (category 1.B.2.b.4) and distribution (category 1.B.2.b.5) separately by applying the Gas Networks Ireland splits consistently and as accurately as possible across the whole time series, document all input data and assumptions applied, and transparently describe the method used in the NIR. To ensure comparability, the ERT further recommends that the data from Vermillion Energy's underground storage facility be reported with the emissions from natural gas transmission under category 1.B.2.b.4, and that these data be removed from the combined natural gas transmission and distribution estimates prior to splitting the two sources using the pipeline ratios.	The Party reported in its NIR (pp.103–104) that emissions from natural gas transmission (category 1.B.2.b.4) and distribution (category 1.B.2.b.5) are reported together under category 1.B.2.b.5 because the AD and EFs for both sources are reported together by Gas Networks Ireland. The Party also reported in the NIR that emissions from storage are reported directly by Vermillion Energy, which operates the only applicable facility in Ireland and also included under 1.B.2.b.5. During the review, the Party clarified that Gas Networks Ireland provided a percentage breakdown of fugitive emissions across the high-pressure transmission network and the distribution network for 2014–2019, which indicated that there is a ratio of approximately 21:79 for transmission:distribution across the available years. Ireland also indicated that it will endeavour to include this information in its next inventory submission and report transmission and distribution emissions separately.	Ireland now reports transmission and distribution emissions separately based on the percentage breakdown provided by Gas networks Ireland for fugitive emissions across the transmission and distribution network.	Chapter 3, Section 3.3.2.2.3 and 3.3.2.2.4	-
I.1	2.F.2 Foam blowing agents – HFCs (I.4, 2018) Transparency	Provide in the NIR descriptions for the whole lifetime of fluorinated gas emissions.	Resolved. The Party reported in its NIR (section 4.7.2.1, p.136) information about the manufacture, use and disposal of foam blowing agents, confirming that emissions from those sources do not occur.	-	-	Resolved

Sector/ID	Issue	Recommendation	ERT assessment and rationale	Party response	NIR Section	Status
I.2	2.G.1 Electrical equipment – SF6 (I.3, 2018) (I.5, 2016) (I.5, 2015) Transparency	Describe in the NIR the result of efforts to review the approach used by the Electricity Supply Board to estimate the quantity of SF6 used for maintenance with a view to clarifying its appropriateness as a tier 1 or higher-tier method.	Resolved. The Party reported in its NIR (section 4.8.1.2, p.140) information on the results of the review of the approach taken by the Electricity Supply Board to estimate the quantity of SF6 used.	-	-	Resolved
I.3	2.G.3 N2O from product uses – N2O (I.5, 2018) Transparency	Include a clearer justification of why category 2.G.3.b is excluded from the inventory in accordance with paragraph 37(b) of the UNFCCC Annex I inventory reporting guidelines; include information either in section 4.8.3.1 or a cross-cutting chapter of the NIR to clarify that N2O emissions from propellant use for pressure and aerosol products is the only category considered insignificant in Ireland.	Resolved. The Party reported in its NIR (section 4.8.3.2, p.143) information showing, using basic assumptions, why emissions from N2O used as a propellant reported under category 2.G.3.b (other) are below the significance threshold.	-	-	Resolved
I.4	2.G.4 Other (other product manufacture and use) – CO2 (I.6, 2018) Transparency	As emissions reported in CRF table 2(I).A-Hs2 are automatically included in Ireland’s national totals by CRF Reporter, include a cell comment regarding subcategory 2.G.4 to clearly indicate that the emissions are indirect CO2 emissions.	Resolved. The Party reported CO2 emissions from tobacco use under category 2.G.4 (other) in CRF table 2(I).A-Hs2 and included a comment in the documentation box indicating that these are indirect CO2 emissions.	-	-	Resolved
I.5	2.F.1 Refrigeration and air conditioning – HFCs. Comparability	The ERT recommends that the Party report recovered HFCs from mobile air conditioning	The Party reported in CRF table 2(II)B-Hs2 disposal emissions of HFC-134a from mobile air conditioning assuming that 12.83 per cent of the initial charge is emitted during the decommissioning process. However, the ERT noted that recovery amounts were not reported in CRF table 2(II)B-Hs2. During the review, the Party indicated that the inventory agency is currently reviewing the estimation methodology for mobile air conditioning with the assumption that 50 per cent of the initial charge will be recovered. Ireland also stated that the inventory agency is attempting to find actual recovery rates for mobile air conditioning in the country from end-of-life vehicles.	Ireland has updated the recovery factor for Mobile air conditioning and has described this in NIR Chapter 4 section 4.7.1.2	Chapter 4 section 4.7.1.2 and 4.7.1.5	-

Sector/ID	Issue	Recommendation	ERT assessment and rationale	Party response	NIR Section	Status
A.1	3.A.1 Cattle – CH4 (A.3, 2018) Transparency	Provide in the NIR input parameter tables for various cattle subcategories, including feed digestibility, live weight, weight gain and duration before slaughter, for the entire time series.	<p>Not resolved. The Party did not include in its NIR the information requested in the previous recommendation. The Party reported in its NIR (section 5.2, p.152) that two large research projects have greatly contributed to improving the estimation of emissions from enteric fermentation and manure management in Ireland: O'Mara (2006) and Hyde et al. (2008).</p> <p>During the review, the Party clarified that the methodological approach to deriving emission estimates for cattle is based on the report by O'Mara (2006). The Party further clarified that, as part of improvement plans, detailed in section 5.2.1.1.6 of the NIR, updated assumptions and key AD will be included in future submissions.</p> <p>The ERT considers that the Party has not yet addressed the recommendation as the input parameter tables for various cattle subcategories were not provided in the NIR.</p>	Additional input parameter tables for various cattle subcategories have been included in the Annex 3.3 of NIR 2021 (Tables 3.3.B, 3.3.C, 3.3.D, 3.3.E, 3.3.I, 3.3.J)	Chapter 5 Section 5.2.1 & NIR Annex 3.3	-
A.2	3.A.2 Sheep – CH4 (A.4, 2018) Accuracy	Collect country-specific data for applying the IPCC tier 2 method for this category, and update the description of the methodology, AD and EFs in the NIR; if this is not possible, include an update on the progress of developing tier 2 EFs for enteric fermentation for sheep in the NIR.	Addressing. The Party reported in its NIR (section 5.2.1.2.6, p.159) that the inventory agency is in the process of investigating the applicability of developing tier 2 estimates for CH4 emissions from enteric fermentation for sheep. This investigation is being done in tandem with the review of tier 2 estimates for cattle as discussed in section 5.2.1.1.6 of the NIR (see ID# A.1 above). Outputs are being reviewed with a view to including relevant information in the national inventory, as appropriate. During the review, the Party stated that some outstanding country-specific data are being collated and appropriate references from national studies are being gathered. The inventory agency will review these materials once the work is complete and endeavour to include tier 2 estimates for sheep in future submissions.	The inventory agency continues to investigate the applicability of developing Tier 2 estimates of CH4 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 (Chap 5, Section 5.3.2.6).	Chapter 5, Section 5.3.2.6 & 5.2.1.2.2	-
A.3	3.D.b Indirect N2O emissions from managed soils – N2O (A.5, 2018) Accuracy	Revise the description of FON in the equations for N2O(L)-N, N2O-NN inputs, N2O-NPRP or the equation for N2O(ATD)-N in the NIR (section 5.5.2.2) to avoid the potential double counting of sewage sludge N, and correct the typographical error in relation to the reference for FracGASM2 in NIR table 5.7.	Resolved. The Party has updated the methodological description in section 5.5.1.2 of the NIR (p.116). The reference for FracGASM2 has also been corrected in NIR table 5.7 (p.171).	-	Chapter 5, Section 5.5.1.2	Resolved

Sector/ID	Issue	Recommendation	ERT assessment and rationale	Party response	NIR Section	Status
A.4	3.G Liming – CO2 (A.2, 2018) (A.3, 2016) (A.3, 2015) Accuracy	Collect country-specific data and apply a tier 2 method for this category for future submissions, noting that the use of tier 1 is conservative.	<p>Addressing. The Party reported in its NIR (section 5.8.2, p.172) that the inventory agency has undertaken some initial discussions with agricultural and environmental researchers and funding agencies with a view to exploring the development of more refined estimates for this category. During the review, the Party stated that only five Parties included in Annex I to the Convention report emissions from lime application to soils using a tier 2 or a country-specific methodology. The Party also stated that in 2018 emissions from lime application to soils accounted for only 0.75 per cent of national total emissions (excluding LULUCF). The inventory agency has raised the issue with agricultural research funding bodies in Ireland and to date the development of refined estimates has not been prioritized for research.</p> <p>The ERT considers that the recommendation has not yet been fully addressed because the Party continues to apply a tier 1 method for estimating CO2 emissions for this key category.</p>	The inventory agency will continue to discuss that issue with agricultural research community in Ireland with a view to exploring the development of more refined estimates from this category (Chap 5, Section 5.8.2).	Chapter 5 Section 5.8.2	-

Sector/ID	Issue	Recommendation	ERT assessment and rationale	Party response	NIR Section	Status
A.5	3. General (agriculture) – CH4 and N2O. Accuracy	The ERT recommends that Ireland report CH4 and N2O emissions from anaerobic digesters or alternatively, if data are not available, report them as “E” instead of “NO” and indicate in the CRF table 9 where in the inventory the emissions have been included. The ERT also recommends that Ireland provide information on the biogas industry in Ireland (e.g. number of plants, capacity, gas production and if available treated amounts of manure and other biomass) in the next NIR, including information on other organic fertilizers being applied to soils as part of the digestate.	<p>The agriculture chapter of the NIR makes no mention of the use of anaerobic digesters in Ireland and this was reported as “NO” in CRF tables 3.B(a)s2 and 3.B(b). However, in the waste chapter of the NIR (section 7.4.2, p.290), it is mentioned that the digestion of animal manure (agricultural slurry) does occur. The NIR (p.165) includes a generic statement on planned improvements indicating that the inventory agency is in the process of investigating the availability of new data for manure management practices in Ireland and will provide relevant information when data becomes available.</p> <p>During the review, the Party stated that all animal manure under category 3.B was fully accounted for and no manure was reported as “NE”. 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. The Party also stated that there is a lack of precise estimates 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. The inventory agency continues to engage with other research and national agencies to fill data gaps and create robust systems to track the use of anaerobic digesters as a manure management system in Ireland and will include the relevant information in the NIR when it becomes available. Reporting emissions for this category as “NO” is not in accordance with the UNFCCC Annex I inventory reporting guidelines as such emissions do seem to occur.</p> <p>The ERT noted that the impact on emissions from the current allocation of manure to different management systems will not lead to an underestimation of emissions from manure management. Further, the ERT noted that the digestate produced from biogas plants will contain other biomass sources than animal manure and therefore will constitute an additional nitrogen input to the fields. The ERT considers that the potential underestimation falls far below the threshold of significance considering the few and small biogas plants currently in operation in Ireland. However, this could change if the use of digesters as manure management system gains in popularity.</p>	Planned improvements to the characterisation of material digested at anaerobic digestion facilities described in section 7.4 (Chapter 7).	Chapter 7, Section 7.4.2.6	-

Sector/ID	Issue	Recommendation	ERT assessment and rationale	Party response	NIR Section	Status
A.6	3.D.a.6 Cultivation of organic soils (i.e. histosols) – N2O. Accuracy	The ERT recommends that Ireland justify in the NIR the characterization of all organic grassland soils as nutrient-poor and take steps to collect country-specific data on histosols in order to ensure the appropriate characterization of grassland soils when data become available.	All cultivated histosols in Ireland are categorized as nutrient-poor (NIR, p.168). However, in the LULUCF chapter of the NIR (p.203) drained forest soils are referred to as both nutrient-rich and nutrient-poor. It is also stated that deforested grassland is assumed to be nutrient-rich. During the review, the Party clarified that it used a tier 1 method to estimate CSC in grassland soils, as discussed in section 6.5.2.4 of the NIR. However, for forest soils a tier 3 method was used on the basis of country-specific soils data available from the national forest inventory, as discussed in section 6.3.6 of the NIR. Such plot-level information does not exist for grassland to allow for a detailed analysis. The ERT noted that Ireland was using the EFs from the IPCC Wetlands Supplement for 'grassland, drained, nutrient-poor'. The ERT noted that there are default tier 1 EFs available for both nutrient-rich and nutrient-poor organic soils in the IPCC Wetlands Supplement (table 2.5) and that a recent scientific paper (Paul et al., 2018) considers that both soil types occur in Ireland.	See section 6.4.12 (Chapter 6) for discussion of future improvements planned for characterisation of croplands in Ireland.	Chapter 6, Section 6.4.12	-
L.1	4. General (LULUCF) – CO2 (L.1, 2018) (L.4, 2016) (L.4, 2015) (57, 2014) Transparency	Report removals for the mineral soils pool, report the pool as "NE" instead of "NO" or report the CSC as "NA" if the CSC in the pool is assumed to be zero because the losses are balanced out by the gains.	Resolved. The Party estimated CSC in mineral soils for forest land remaining forest land, land converted to forest land and forest land converted to grassland and other land as recommended by the ERT.	-	-	Resolved
L.2	4. General (LULUCF) (L.7, 2018) Convention reporting adherence	Correct the total forest land area reported in NIR table 6.3.	Resolved. The Party corrected the total forest land area reported in NIR table 6.3.	-	-	Resolved
L.3	4. General (LULUCF) (L.8, 2018) Transparency	Ensure the consistency of the land areas reported between NIR table 6.3, CRF tables 4.A–4.F and CRF table 4.1.	Resolved. The forest land area reported in NIR table 6.3 is consistent with that reported in CRF tables 4.A–4.F and CRF table 4.1.	-	-	Resolved
L.4	4.A Forest land – CO2 (L.2, 2018) (L.3, 2016) (L.3, 2015) (56, 2014) Transparency	Correct the typographical error regarding the value of the country-specific EF for organic forest soils.	Resolved. The EF for soil organic carbon was corrected to 0.59 t carbon/ha/year in section 6.3.4.3 of the NIR (p.200).	-	-	Resolved
L.5	4.A.1 Forest land remaining forest land – CO2 (L.9, 2018) Transparency	Explain the trends in emissions from the dead organic matter pool and provide the reviewed decay coefficients for litter and deadwood, when available, in the NIR.	Resolved. During the review, the Party clarified that it is now using a new model framework (CBM), which shows a different covariance between biomass and dead organic matter trends compared to the CARBWARE model reviewed by the previous ERT. While the Party has not explained the emission trends in the dead organic matter pool, given the change in modelling for this category, the ERT considers that this issue is no longer relevant. Identified issues specific to CBM are raised in ID#s L.10 and L.11 in table 5.	-	-	Resolved

Sector/ID	Issue	Recommendation	ERT assessment and rationale	Party response	NIR Section	Status
L.6	4.E.1 Settlements remaining settlements – CO2 (L.5, 2018) (L.8, 2016) (L.8, 2015) (62, 2014) Transparency	Report CSC in soils for settlements remaining settlements as “NA” instead of “NO” and include an explanation for the use of the notation key in the NIR.	Addressing. The Party reported the CSC in soils as “NA” in CRF table 4.E, as recommended by the previous ERT. However, the use of this notation key was not clearly explained in the NIR (section 6.7.2.2, p.270). The ERT considers that the recommendation has not been fully addressed as an explanation for the use of the notation key “NA” was not included in the NIR.	An explanation for the use of the notation key will be included in the NIR	-	-
L.7	4(V) Biomass burning – CO2, CH4 and N2O (L.6, 2018) (L.11, 2016) (L.11, 2015) Transparency	Explain in the NIR and the documentation box of the relevant CRF table that CO2, CH4 and N2O emissions from wildfires on land converted to cropland reported as “IE” are included under cropland remaining cropland.	Resolved. During the review, the Party clarified that there are no conversions of land to cropland, as reported in CRF table 4.B, and therefore there is no biomass burning on land converted to cropland. The previously reported “IE” in CRF table 4(V) has been corrected and changed to “NO”.	-	-	Resolved
L.8	4. General (LULUCF). Not an issue/problem	The ERT encourages Ireland to correct errors, omissions and inconsistencies between the NIR and the CRF tables in the next submission.	The ERT noted throughout the NIR and CRF tables a number of minor reporting errors, omissions or inconsistencies. For example, NIR table 6.6 data were misaligned for all lines of data for 2009 onward, being two years out (data presented for 2009 were in fact 2007 data), NIR table 1.5 did not include information on category 4.B (cropland), which was omitted by mistake, and key underlying AD on land-use change matrices for forest land use and FM were not included in annex 3.4.D to the NIR (whereas this information was provided for non-forest land use). During the review, the Party provided clarifications and indicated that any errors noted will be rectified in the next submission.	Errors will be rectified for the next submission	Annex 3.4 D updated	-

Sector/ID	Issue	Recommendation	ERT assessment and rationale	Party response	NIR Section	Status
L.9	4. General (LULUCF) – CO2. Completeness	<p>The ERT recommends that Ireland conduct an in-depth evaluation of other land-use conversion categories other than forest land where the areas and the associated emissions and removals start in 1990 and have been accumulated since then, for example conversion of land to grassland, and revise the reporting, if appropriate. The ERT further recommends that Ireland report on its findings regarding the above-mentioned analysis in the NIR. The ERT also recommends that the Party document the approach chosen in the next submission by providing information on its methodological decisions, including the Party’s decision regarding the conversion period, with respect to land conversion categories, and the rationale for reporting land conversion categories starting in 1990 and maintaining the reporting of these land areas within a specific land conversion category as a cumulative total for all future years.</p>	<p>Ireland started to report its conversions from non-forest land to forest land (category 4.A.2) in 1990 and has accumulated the area since then (NIR, p.188). Therefore, the ERT concluded that emissions and removals from conversions of land to forest land before 1990 were not taken into account (see ID# L.13 below) and that it is unclear whether spatial coverage was ensured (see ID# L.12 below). The ERT noted that conversions to other land-use categories, such as land converted to grassland, were accounted using a similar approach. During the review, the Party clarified that for grassland conversions the land area has been aggregated since 1990 as indicated in CRF table 4.C and NIR table 6.17, and that the method is based on the principles of Article 3, paragraphs 3–4, of the Kyoto Protocol, as discussed in chapter 11 of the NIR, and not on reporting under the Convention. The ERT concluded that emissions and removals from conversions of land to grassland before 1990 were not taken into account in the inventory reporting, leading to a completeness issue for land converted to grassland. Furthermore, from the description in the NIR, it is not clear where areas converted to grassland prior to 1990 were reported and whether the spatial coverage of grassland (categories 4.C.1 and 4.C.2) was ensured, leading to a transparency issue.</p>	Further description will be provided in the NIR	Section 6.3.5	-

Sector/ID	Issue	Recommendation	ERT assessment and rationale	Party response	NIR Section	Status
L.10	4.A Forest land – CO <sub>2</sub> . Transparency	<p>The ERT therefore recommends that Ireland provide further information, ideally in section 6.3 of the NIR, on:</p> <p>(1) its modelling approach, including the rationale for not applying the conversion period when a tier 3 method is used;</p> <p>(2) the rationale for selecting 1990 to start reporting land converted to forest land and maintaining the reporting of these land areas within land converted to forest land as a cumulative total for all future years;</p> <p>(3) the approach to modelling biomass in recently afforested areas;</p> <p>(4) the rationale for not considering previous carbon stocks in simulations of forest land remaining forest land; and (5) the assumptions used for simulation of the dead organic matter pool and their rationale.</p> <p>The ERT also recommends that Ireland justify the appropriateness of the modelling approach used in relation to its national circumstances, discuss the completeness and accuracy of the modelling approach, in accordance with the UNFCCC Annex I inventory reporting guidelines, paragraph 50(a), and discuss whether this approach is compatible with the 2006 IPCC Guidelines and is well documented and scientifically based.</p>	<p>The Party deployed CBM to generate estimates of emissions and removals from land converted to forest land, as described in section 6.3 of its NIR (p.182). The modelling approach and method used by Ireland is not common practice for Parties reporting under the Convention, for example in not defining a transition period and reporting land areas for land converted to forest land accumulating only from 1990 onward (see also ID# L.13 below). The ERT notes that the transparency of the modelling and the rationale to explain the approach used by Ireland is of critical importance to enable the ERT to assess the quality of the methodology. The ERT acknowledges that the Party has provided substantive details in the NIR (p.182 and p.194) and in annex 3.4.B to the NIR, including all parameters and disturbance matrices and information on how the volume growth and biomass models were parameterized. However, given the novel modelling approach, the ERT considers that the description in section 6.3 of the NIR does not include sufficient detail on the modelling approach and method selection to transparently describe the calculation methodology applied by the Party, nor to justify that the modelling approach delivers complete and accurate reporting of emissions and removals according to Ireland’s national circumstances.</p> <p>During the review, the Party provided the ERT with detailed and critical methodological clarifications which will greatly assist future ERTs to assess the quality of the novel modelling methodology in detail, including:</p> <p>(1) The decision regarding the conversion period, which is not applied in the tier 3 methodology;</p> <p>(2) The rationale for reporting land converted to forest land starting in 1990 and maintaining the reporting of these land areas within land converted to forest land as a cumulative total for all future years;</p> <p>(3) The approach to modelling biomass in young forest stands for recently afforested areas;</p> <p>(4) Documentation and explanation or justification of the modelling approach, including that CBM does not consider previous carbon stocks in land use when forest land remaining forest land simulations are run; and that the dead organic matter pool is equilibrated to represent the initial dead organic matter pools before simulations are run; and a more detailed description of the implications of these methodological and model set-up decisions in terms of the completeness and accuracy of the model outputs.</p>	Further description will be provided in the NIR	Sections 6.3.4 and 6.3.5. Annex 3.4	-

Sector/ID	Issue	Recommendation	ERT assessment and rationale	Party response	NIR Section	Status
L.11	4.A Forest land – CO2. Convention reporting adherence	The ERT recommends that the Party report on the research to validate CBM, conduct a model-specific uncertainty analysis and present the findings, including comparisons of CBM outputs against other models and/or against in-situ measurements, in order to adhere to the UNFCCC Annex I inventory reporting guidelines, para. 50(a), regarding requirements for reporting using country-specific tier 3 models.	<p>The Party deployed CBM to derive estimates of emissions and removals from the LULUCF sector, as described in section 6.3.3 of its NIR (p.194). The ERT noted that CBM was used for the first time for the Party's 2019 submission and this is the first review of the Party's LULUCF inventory since starting to use the model. Many of the key elements of transparent reporting of a tier 3 model are evident in the current NIR.</p> <p>However, the ERT noted that some aspects are not yet in place; for example (1) detailed uncertainty analysis for CBM was not provided (as noted in the NIR (p.182)); (2) comparison of the CBM outputs with measured data (e.g. from the national forest inventory), with in-situ data or other models in the 2020 submission (information on comparisons with other models, such as CARBWARE, which was used for reporting up to 2017, was not included in the current submission, but rather noted in the 2019 NIR, whilst the evidence specific to the CARBWARE model validation is in the 2018 NIR); and (3) further evidence of the CBM output validation and sensitivity analysis.</p> <p>During the review, the Party provided detailed responses summarizing key elements to justify the selection and calibration of the model using national parameters and its appropriateness for modelling the LULUCF emissions and removals according to national circumstances. Furthermore, the Party clarified that research is ongoing to evaluate the model's performance against real-time eddy covariance data, in order to test the net ecosystem exchange model and verify that specific pool outputs such as biomass are being validated, where possible, using stock change values obtained from the national forest inventory. The Party indicated that this information will be presented in its next annual submission.</p>	Further description will be provided in the NIR	Section 6.10.1	-
L.12	4.A Forest land – CO2. Transparency	The ERT recommends that Ireland improve the methodological description of and approach to reporting forest land areas in order to clearly describe the reporting approach for young stands that were afforested just prior to 1990 and demonstrate that the reporting of land areas in category 4.A (forest land) is complete, in order to improve transparency. This will enable future ERTs to evaluate the accuracy and completeness of the country-specific method.	<p>Regarding the reporting of emissions and removals for category 4.A.2, the NIR does not clearly describe the reporting of the forest land area for stands that have been converted to forest land shortly prior to 1990. For example, it is unclear where and whether the land areas for young stands converted to forest land in 1989 (most probably covered by sapling size trees) were reported across categories 4.A.1 (forest land remaining forest land) and/or 4.A.2 (land converted to forest land). As a result of this lack of transparency, the ERT was unable to evaluate completeness and accuracy in relation to the spatial coverage and reporting of forest land areas.</p> <p>In response to the questions of the ERT during the review regarding potentially incomplete spatial coverage of areas under category 4.A.1, the Party indicated that these areas were reported under category 4.A.2, leading to complete spatial coverage of land areas for category 4.A (forest land). The Party noted that the use of a transition period different from default approaches led to this reporting approach and indicated that this was an issue of transparency rather than completeness.</p>	Further description will be provided in the NIR	Section 6.3.5	-

Sector/ID	Issue	Recommendation	ERT assessment and rationale	Party response	NIR Section	Status
L.13	4.A.2 Land converted to forest land – CO <sub>2</sub> . Completeness	The ERT recommends that Ireland provide in the NIR a justification for the exclusion of the emissions and removals from the areas of land converted to forest land prior to 1990, which are currently not reported. If the Party cannot demonstrate that emissions and removals from these areas are insignificant, consistent with the UNFCCC Annex I inventory reporting guidelines (para. 37(b)), the ERT recommends that Ireland review and update its modelling and reporting under the Convention to reflect the conversions to forest land prior to 1990 in order to report complete tracking of the national area per land-use category (complete geographical coverage); and ensure accurate modelling of emissions and removals from all land converted to forest land (also that converted prior to 1990) and forest land remaining forest land, thereby improving the completeness of the inventory.	<p>The Party documented in its NIR (p.209) the modelling approach for CSC in land converted to forest land. Ireland started to report its conversions from non-forest land to forest land (category 4.A.2) in 1990 and has aggregated the area since then (NIR, p.188). The cumulative areas since 1990 are documented in NIR table 6.13 (p.211). Ireland applied the same method for calculating CSC for all pools for category 4.A.2 in CRF table 4.A, and for afforestation in CRF table 4(KP-I)A.1.</p> <p>The ERT noted that, for reporting under the Convention, reporting of conversions in general, thus also those to forest land (category 4.A.2), should start from 1990. However, conversions before 1990 should also be taken into account in order to report a full geographical coverage of sources and sinks in 1990 (according to the UNFCCC Annex I inventory reporting guidelines, paragraph 4(d)). More specifically, the category land converted to forest land for 1990 should, in addition to afforestation in 1990, cover all land afforested since 1990 minus the transition period plus one. If the land converted to forest land category for 1990 includes only the area of afforestation in 1990 then the emission and removal estimates will be biased for 1990 to 1990 plus the transition period minus one because the estimates exclude the emissions and removals from the areas afforested before 1990.</p> <p>Thus, the ERT considers that the reported emissions and removals under land converted to forest land have been underestimated due to the omission of emissions and removals from land to forest land conversions before 1990. During the review, the Party clarified that CBM estimates CSC in soils as a function of the mean soil value for a soil stratum of the previous land use and that CSC in soils from land-use conversions is taken into account. The ERT agrees that the CSC in soils before 1990 is taken into account for those areas reported under category 4.A.2 starting in 1990, but not for those areas converted to forest land shortly before 1990, since they have not been reported under category 4.A.1 (forest land remaining forest land) or under category 4.A.2 (land converted to forest land), and thus not taken into account.</p> <p>During the review, the Party provided additional information indicating that it assessed emissions from mineral soils in conversions to forest land for 1970–1989 as not significant. The Party indicated that this was its justification for not estimating these emissions, but noted that this was not documented in the NIR.</p>	Further description will be provided in the NIR	Section 6.3.5	-

Sector/ID	Issue	Recommendation	ERT assessment and rationale	Party response	NIR Section	Status
L.14	4.D.1 Wetlands remaining wetlands – CO2. Completeness	The ERT recommends that Ireland report complete estimates of CSC in soil for off-site CO2 emissions from peat extraction for wetlands.	<p>The Party reported in its NIR (section 6.6.9, p.268) recalculations of emissions and removals from wetlands associated with revised data on market shares for the main companies involved in peat harvesting for the horticultural peat market.</p> <p>During the review, the Party provided the ERT with the model used to estimate emissions from on-site and off-site CO2 emissions from peat extraction, in order to clarify the reasons for the recalculations.</p> <p>The ERT noted that the model did not correctly aggregate the calculated CSC in soil for off-site CO2 emissions, omitting the component of emissions calculated to reflect the peat extraction activity from a subset of operators in Ireland, leading to an underestimation of emissions across the time series. For 2018, for example, the missing emissions are estimated to be about 817 kt CO2 eq.</p> <p>The ERT recommends that Ireland report complete estimates</p>	Further description will be provided in the NIR. The error identified will be corrected for the next submission	Section 6.6.9	-
L.15	4.D.1 Wetlands remaining wetlands – CO2. Transparency	The ERT recommends that Ireland provide in the NIR a full and transparent description of the recalculations, i.e. any changes to the AD, EFs and methods used to estimate emissions from wetlands.	<p>The Party reported in its NIR (section 6.6.9, p.268) recalculations of emissions and removals from wetlands (category 4.D.1) associated with revised data on market shares for the main companies involved in peat harvesting for the horticultural peat market. The recalculation under this category was the most significant single recalculation in the 2020 national inventory, increasing estimated emissions in the base year and reducing estimated emissions in 2017, and altering the 1990–2017 reported trend by around –800 kt CO2. The ERT noted that the explanation for the recalculation was limited to two sentences in the NIR referring to revised data on market shares for companies involved in peat harvesting, and a revision to the area of peat burned in 2017.</p> <p>During the review, the ERT reviewed the model used by Ireland to estimate emissions and removals from wetlands and identified an error in the calculations; this finding illustrated that the documentation of the recalculation in the NIR was incorrect. The ERT notes that the correction of the error (to address the completeness issue under ID# L.14 above) will lead to a further recalculation of the emissions from wetlands for the next submission.</p>	Further description will be provided in the NIR	Section 6.6.9	-

Sector/ID	Issue	Recommendation	ERT assessment and rationale	Party response	NIR Section	Status
W.1	5.B.2 Anaerobic digestion at biogas facilities – CH4 (W.6, 2018) Accuracy	Report CH4 emissions from unintentional leakage and other unexpected events at anaerobic digestion facilities outside of the wastewater treatment area digesting other forms of waste (including agricultural waste) and explain the estimations in the NIR.	Not resolved. Ireland reported in the NIR (p.290) that it has not yet sourced the necessary AD to estimate CH4 emissions from unintentional leakage and other unexpected events at anaerobic digestion facilities outside of the wastewater treatment area and is as yet unable to subtract the required amount of agricultural slurries that are digested in these plants. CH4 emissions from such facilities due to unintentional leakages during process disturbances or other unexpected events will be reported under the waste sector when suitable AD have been sourced for Ireland. During the review, the Party stated that until data become available this category is being reported as “NO”. The ERT concluded that the recommendation has not yet been implemented and that the use of the notation key “NO” until data is available may not be appropriate as emissions seem to occur.	Resolved. Estimates provided in Submission 2021 for the years 2014 to 2019. See section 7.4.2 of NIR 2021.	Chapter 7 section 7.4.2	Resolved
W.2	5.D Wastewater treatment and discharge – CH4 and N2O (W.5, 2018) (W.7, 2016) (W.7, 2015) (72, 2014) Completeness	Describe the source and derivation of the AD and the industrial sectors contributing to the biochemical oxygen demand load.	Resolved. The Party reported that information on individual industry sectors is not readily available. It reported in its NIR (pp.294–298) that the centralized wastewater treatment plants also treat commercial and industrial wastewater and that emissions from industrial wastewater (5.D.2) are included under domestic wastewater (5.D.1). Ireland further reported in its NIR (p.298) that on-site wastewater treatment provisions at industrial facilities, where they exist, are aerobic systems and no CH4 emissions from these sites occur. During the review, Ireland confirmed the approach to estimating emissions from industrial wastewater treatment. The ERT noted that, according to the 2006 IPCC Guidelines (vol. 5, chap. 6, equation 6.3), emissions from industrial wastewater treatment may be estimated together with emissions from domestic wastewater treatment. The ERT also considers that the Party’s reporting of emissions from industrial wastewater treatment is sufficient and in line with the 2006 IPCC Guidelines.	-	-	Resolved
W.3	5.D.1 Domestic wastewater – CH4 (W.7, 2018) Transparency	Provide a reference to justify the use of a methane correction factor of 0.083 or apply the default value from the 2006 IPCC Guidelines	Not resolved. The Party did not provide a reference to justify the use of a methane correction factor of 0.083. During the review the Party provided a link to Ireland’s national meteorological service ( <a href="https://www.met.ie/climate/available-data/monthly-data">https://www.met.ie/climate/available-data/monthly-data</a> ). The ERT considers that this new reference confirms that the soil temperature exceeds 15 °C for two months of the year and justifies the methane correction factor used by the Party. However, the reference was not provided in the NIR.	Reference provided in section 7.5.1.2 of NIR 2021. <a href="https://www.met.ie/climate/available-data/monthly-data">https://www.met.ie/climate/available-data/monthly-data</a>	Chapter 7 section 7.5.1.2	Resolved
W.4	5.D.1 Domestic wastewater – CH4 (W.8, 2018) Transparency	Amend the text in the NIR to reflect the number of wastewater treatment plants with biogas recovery in the country.	Resolved. The Party updated chapter 7.6.1.2 of its NIR. It reported that there are 16 urban wastewater treatment plants with biogas recovery for heat only or combined heat and power; and of these 16 plants, 12 were operational for part or all of 2018.	-	-	Resolved

Sector/ID	Issue	Recommendation	ERT assessment and rationale	Party response	NIR Section	Status
W.5	5.D.1 Domestic wastewater – CH4 and N2O (W.9, 2018) Transparency	Report wastewater flows including treated (aerobically and anaerobically) and untreated wastewater in the NIR.	<p>Not resolved. The Party reported in its NIR (p.294) that on the basis of the available data on wastewater treatment in Ireland the inventory agency considers that all wastewater is accounted for in its approach, with two thirds of the population of Ireland being served by centralized sewage treatment plants and one third of the population using septic tanks.</p> <p>During the review, the Party provided further information on the types of wastewater treatment plants in the country (urban wastewater treatment plants and domestic wastewater treatment systems (septic tank systems)), including a reference to a publication (EPA, 2019). The ERT noted the statement on page 3 of the publication that sewage from the equivalent of 77,000 people in 36 towns and villages is released into the environment every day without treatment. The ERT also noted that this information on untreated wastewater has not been included in the NIR and that the emissions from untreated wastewater were not included in the inventory (see ID# W.8 in table 5).</p> <p>The ERT considers that the recommendation has not been fully addressed because the Party has not reported wastewater flows including treated (aerobically and anaerobically) and untreated wastewater in the NIR. The ERT considers that such reporting could for example be provided as a diagram with the wastewater flows.</p>	Ireland will endeavour to include relevant information on waste flows in NIR 2021 Chapter 7 section 7.5.1.2	Chapter 7 section 7.5.1.2	-
W.6	5.B.1 Composting – CH4 and N2O. Transparency	The ERT recommends that Ireland change the reporting of AD and CH4 and N2O EFs to a dry weight basis in CRF table 5.B for the whole time series.	<p>The Party reported in NIR table 7.6 (p.289) the use of a CH4 EF of 4 g CH4/kg and an N2O EF of 0.24 kg N2O/kg from the 2006 IPCC Guidelines (vol. 5, table 4.1). In addition, these EFs are used for calculating emissions on a wet weight basis. However, in CRF table 5.B the AD is expressed as dry matter and thus the table indicates that the AD used by Ireland to estimate emissions from composting are 149.72 kt dry matter in 2018.</p> <p>During the review, Ireland explained that it reported the AD on a wet weight basis in CRF table 5.B. It stated that it will change the reporting of AD to a dry weight basis. The Party also explained that the EFs for dry waste are estimated from those for wet waste assuming a moisture content of 60 per cent wet waste. The ERT considers that the CH4 and N2O emissions have been correctly estimated.</p>	Activity data is provided based on dry matter in Ireland's CRF tables in Submission 2021. See Table 7.6 in section 7.3.1.2 of NIR 2021.	Chapter 7 section 7.3.1.2	-
W.7	5.C.2 Open burning of waste – CO2, CH4 and N2O. Transparency	The ERT recommends that Ireland report in the NIR the AD (e.g. the estimates of the amount of uncollected municipal solid waste) and assumptions used to estimate emissions from open burning of waste.	<p>According to the NIR (p.293), statistics on open burning of waste are not available in Ireland and estimates reported in CRF table 5.C are based on AD for uncollected household waste. However, no documentation or references were provided in the NIR.</p> <p>During the review, Ireland explained that data on uncollected household waste is sourced from the EPA national waste statistics publications and provided a link to the source (<a href="https://www.epa.ie/nationalwastestatistics/household/">https://www.epa.ie/nationalwastestatistics/household/</a>).</p>	Ireland will include a reference to AD in NIR 2021 Chapter 7 section 7.5.2.2	Chapter 7 Section 7.5.2.2	-

Sector/ID	Issue	Recommendation	ERT assessment and rationale	Party response	NIR Section	Status
W.8	5.D.1 Domestic wastewater – CH4 and N2O. Completeness	The ERT recommends that Ireland report CH4 and N2O emissions from uncollected and untreated wastewater for the whole time series and provide an explanation in the NIR of the methods, AD and EFs used.	The Party reported in its NIR (section 7.6.1.2, p.294) that two thirds of the population of Ireland is served by centralized sewage treatment plants and the remaining one third of the population uses septic tanks to treat wastewater, mainly for individual houses in non-urban areas. During the review, Ireland explained that the types of wastewater treatment plants in Ireland are urban wastewater treatment plants and domestic wastewater treatment systems (septic tank systems) and provided a reference to an EPA report (see ID# W.5 in table 3). Furthermore, during the review, Ireland stated that it will provide further information on untreated wastewater on the basis of available information in the above-mentioned EPA report in its next submission. Ireland acknowledged that the emissions from untreated wastewater were not included in the inventory and estimated that the missing emissions account for about 2.52 kt CO2 eq in 2018. The ERT acknowledges that this is below the level of significance for including this issue in the list of potential problems and further questions raised by the ERT in accordance with decision 22/CMP.1 in conjunction with decision 4/CMP.11, annex, paragraph 80(b) (30.47 kt CO2 eq, i.e. 0.05 per cent of total national emissions without LULUCF in 2018).	Ireland will provide an updated description of untreated wastewater on the basis of available information in the Urban wastewater treatment EPA report 2019 in its next submission. NIR Chapter 7 Section 7.5.1.2	Chapter 7 section 7.5.1.2	Unresolved.
KL.1	General (KP-LULUCF) (KL.7, 2018) Transparency	Complete the documentation box of CRF table 4(KP-I)B.1.1 to provide information on how HWP are included under the FMRL	Resolved. The Party provided information on how HWP are included in the FMRL in the documentation box of CRF table 4(KP-I)B.1.1. The Party also gave a cross reference in its NIR (section 11.5).	-	-	Resolved
KL.2	Deforestation – CO2 (KL.3, 2018) (KL.6, 2016) (KL.6, 2015) Transparency	Report the appropriate notation key with explanation or estimated values in CRF table 4(KP-I)A.2.	Resolved. The Party reported the net CSC for HWP in CRF table 4(KP-I)A.2 as “NO” and “IO” (instantaneous oxidation). The footnote to CRF table 4(KP-I)A.2 provides the definition of the notation key “IO”. The ERT considers the reporting to be transparent, and hence the issue is resolved.	-	-	Resolved
KL.3	CM – CO2 (KL.8, 2018) Transparency	Provide the numerical values for cropland area under CM in the relevant section of the NIR and verify the consistency of that information between CRF table NIR-2 and the NIR.	Addressing. During the review, the Party clarified that detailed data on cropland area have been provided in annex 3.4.D to the NIR (p.427) and that the data reported in the CRF tables and the NIR are consistent with each other. However, the ERT noted that the area under CM in CRF table NIR-2 is equal to that in CRF table 4(KP-I)B.2 (781.67 kha in 2018) but is not consistent with the area under CM reported in table 3.5 of annex 3.4.C to the NIR (780.40 kha in 2018) (p.431). The ERT considers that this recommendation has not yet been fully addressed because there are still some inconsistencies between the CRF tables and the NIR.	Will be addressed in next submission	Annex 3.4 D updated	-
KL.4	GM – CO2 (KL.9, 2018) Transparency	Provide the numerical values for grassland area and verify the consistency of the information between the CRF tables and the NIR.	Resolved. The Party provided consistent numerical values for GM in CRF tables NIR-2 and 4(KP-I)B.3 (4,161.90 kha in 2018). The GM area reported in table 3.6 of annex 3.4.D to the NIR was also consistent with that reported in the CRF tables.	-	-	Resolved

Sector/ID	Issue	Recommendation	ERT assessment and rationale	Party response	NIR	
					Section	Status
KL.5	HWP – CO2 (KL.10, 2018) Convention reporting adherence	Ensure that correct values and units are reported for harvesting activities (columns D and E) under Article 3, paragraphs 3–4, of the Kyoto Protocol in CRF table 4(KP-1)C.	<p>Not resolved. The Party populated the column assigned for the units in which harvest is reported with numerical values (instead of units), whilst the column in which the numerical values should have been reported was left blank.</p> <p>During the review, the Party clarified that the error is related to a CRF Reporter bug; the XML files have the harvest volume and units reported in the correct rows, but the data were not correctly imported into CRF Reporter.</p> <p>The ERT considers that the recommendation has not yet been fully addressed because the Party populated column “E” assigned for the units with numerical values (instead of units) for Article 3, paragraph 3–4, activities, while column “D”, in which the numerical values should have been reported, were left blank in CRF table 4(KP-1)C.</p>	Issue still unresolved in CRF	-	-

## Appendix 1

### Standard Independent Assessment Report (Electronic Appendix)

## AN GHNÍOMHAIREACHT UM CHAOMHNÚ COMHSHAOIL

Tá an Ghníomhaireacht um Chaomhnú Comhshaoil (GCC) freagrach as an gcomhshaoil a chaomhnú agus a fheabhsú mar shócmhainn luachmhar do mhuintir na hÉireann. Táimid tiomanta do dhaoine agus don chomhshaoil a chosaint ó éifeachtaí díobhálacha na radaíochta agus an truaillithe.

## Is féidir obair na Gníomhaireachta a roinnt ina trí phríomhréimse:

**Rialú:** Déanaimid córais éifeachtacha rialaithe agus comhlíonta comhshaoil a chur i bhfeidhm chun torthaí maíthe comhshaoil a sholáthar agus chun díriú orthu siúd nach gcloíonn leis na córais sin.

**Eolas:** Soláthraimid sonraí, faisnéis agus measúnú comhshaoil atá ar ardchaighdeán, spriocdhírithé agus tráthúil chun bonn eolais a chur faoin gcinnteoireacht ar gach leibhéal.

**Tacaíocht:** Bímid ag saothrú i gcomhar le grúpaí eile chun tacú le comhshaoil atá glan, táirgiúil agus cosanta go maíthe, agus le hiompar a chuirfidh le comhshaoil inbhuanaithe.

## Ár bhFreagrachtaí

### Ceadúnú

Déanaimid na gníomhaíochtaí seo a leanas a rialú ionas nach ndéanann siad dochar do shláinte an phobail ná don chomhshaoil:

- saoráidí dramhaíola (*m.sh. láithreáin líonta talún, loisceoirí, stáisiúin aistriúcháin dramhaíola*);
- gníomhaíochtaí tionsclaíoch ar scála mór (*m.sh. déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta*);
- an diantalmhaíocht (*m.sh. muca, éanlaith*);
- úsáid shrianta agus scaoileadh rialaithe Orgánach Géinmhodhnaíthe (OGM);
- foinsí radaíochta ianúcháin (*m.sh. trealamh x-gha agus radaiteiripe, foinsí tionsclaíochta*);
- áiseanna móra stórála peitрил;
- scardadh dramhuisce;
- gníomhaíochtaí dumpála ar farráige.

### Forfheidhmiú Náisiúnta i leith Cúrsaí Comhshaoil

- Clár náisiúnta iniúchtaí agus cigireachtaí a dhéanamh gach bliain ar shaoráidí a bhfuil ceadúnas ón nGníomhaireacht acu.
- Maoirseacht a dhéanamh ar fhreagrachtaí cosanta comhshaoil na n-údarás áitiúil.
- Caighdeán an uisce óil, arna sholáthar ag soláthraithe uisce phoiblí, a mhaoirsiú.
- Obair le húdaráis áitiúla agus le gníomhaireachtaí eile chun dul i ngleic le coireanna comhshaoil trí chomhordú a dhéanamh ar líonra forfheidhmiúcháin náisiúnta, trí dhírú ar chiontóirí, agus trí mhaoirsiú a dhéanamh ar leasúchán.
- Cur i bhfeidhm rialachán ar nós na Rialachán um Dhramhthrealamh Leictreach agus Leictreonach (DTLL), um Shrian ar Shubstaintí Guaiseacha agus na Rialachán um rialú ar shubstaintí a ídíonn an ciseal ózóin.
- An dlí a chur orthu siúd a bhriseann dlí an chomhshaoil agus a dhéanann dochar don chomhshaoil.

### Bainistíocht Uisce

- Monatóireacht agus tuairisciú a dhéanamh ar cháilíocht aibhneacha, lochanna, uisce idirchriosacha agus cósta na hÉireann, agus screamhuisc; leibhéal uisce agus sruthanna aibhneacha a thomhas.
- Comhordú náisiúnta agus maoirsiú a dhéanamh ar an gCreat-Treoir Uisce.
- Monatóireacht agus tuairisciú a dhéanamh ar Cháilíocht an Uisce Snámha.

## Monatóireacht, Anailís agus Tuairisciú ar an gComhshaoil

- Monatóireacht a dhéanamh ar cháilíocht an aeir agus Treoir an AE maidir le hAer Glan don Eoraip (CAFÉ) a chur chun feidhme.
- Tuairisciú neamhspleách le cabhrú le cinnteoireacht an rialtais náisiúnta agus na n-údarás áitiúil (*m.sh. tuairisciú tréimhsúil ar staid Chomhshaoil na hÉireann agus Tuarascálacha ar Tháscairí*).

## Rialú Astaíochtaí na nGás Ceaptha Teasa in Éirinn

- Fardail agus réamh-mheastacháin na hÉireann maidir le gáis ceaptha teasa a ullmhú.
- An Treoir maidir le Trádáil Astaíochtaí a chur chun feidhme i gcomhair breis agus 100 de na táirgeoirí dé-ocsaíde carbóin is mó in Éirinn.

## Taighde agus Forbairt Comhshaoil

- Taighde comhshaoil a chistiú chun brúnna a shainiú, bonn eolais a chur faoi bheartais, agus réitigh a sholáthar i réimsí na haeráide, an uisce agus na hinbhuanaitheachta.

## Measúnacht Straitéiseach Timpeallachta

- Measúnacht a dhéanamh ar thionchar pleananna agus clár beartaithe ar an gcomhshaoil in Éirinn (*m.sh. mórphleananna forbartha*).

## Cosaint Raideolaíoch

- Monatóireacht a dhéanamh ar leibhéal radaíochta, measúnacht a dhéanamh ar nochtadh mhuintir na hÉireann don radaíocht ianúcháin.
- Cabhrú le pleananna náisiúnta a fhorbairt le haghaidh éigeandálaí ag eascairt as taismí núicléacha.
- Monatóireacht a dhéanamh ar fhorbairtí thar lear a bhaineann le saoráidí núicléacha agus leis an tsábháilteacht raideolaíochta.
- Sainseirbhísí cosanta ar an radaíocht a sholáthar, nó maoirsiú a dhéanamh ar sholáthar na seirbhísí sin.

## Treoir, Faisnéis Inrochtana agus Oideachas

- Comhairle agus treoir a chur ar fáil d'earnáil na tionsclaíochta agus don phobal maidir le hábhair a bhaineann le caomhnú an chomhshaoil agus leis an gcosaint raideolaíoch.
- Faisnéis thráthúil ar an gcomhshaoil ar a bhfuil fáil éasca a chur ar fáil chun rannpháirtíocht an phobail a spreagadh sa chinnteoireacht i ndáil leis an gcomhshaoil (*m.sh. Timpeall an Tí, léarscáileanna radóin*).
- Comhairle a chur ar fáil don Rialtas maidir le hábhair a bhaineann leis an tsábháilteacht raideolaíoch agus le cúrsaí práinnfhreagartha.
- Plean Náisiúnta Bainistíochta Dramhaíola Guaisí a fhorbairt chun dramhaíl ghuaiseach a chosaint agus a bhainistiú.

## Múscailt Feasachta agus Athrú Iompraíochta

- Feasacht comhshaoil níos fearr a ghiniúint agus dul i bhfeidhm ar athrú iompraíochta dearfach trí thacú le gnóthais, le pobail agus le teaghlaigh a bheith níos éifeachtúla ar acmhainní.
- Tástáil le haghaidh radóin a chur chun cinn i dtithe agus in ionaid oibre, agus gníomhartha leasúcháin a spreagadh nuair is gá.

## Bainistíocht agus struchtúr na Gníomhaireachta um Chaomhnú Comhshaoil

Tá an ghníomhaíocht á bainistiú ag Bord Iánaimeartha, ar a bhfuil Ard-Stiúrthóir agus cúigear Stiúrthóirí. Déantar an obair ar fud cúig cinn d'Oifigí:

- An Oifig um Inmharthanacht Comhshaoil
- An Oifig Forfheidhmithe i leith cúrsaí Comhshaoil
- An Oifig um Fianaise is Measúnú
- Oifig um Chosaint Radaíochta agus Monatóireachta Comhshaoil
- An Oifig Cumarsáide agus Seirbhísí Corparáideacha

Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag comhaltaí air agus tagann siad le chéile go rialta le plé a dhéanamh ar ábhair inné agus le comhairle a chur ar an mBord.



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